El Tigre Engineering

Sustainable Design for a Hydropower System in the Comarca Ngöbe-Buglé

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International Senior Design

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Michigan Tech
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Sustainable Design for a Hydropower System in the Comarca Ngöbe-Buglé

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Disclaimer

This report represents the efforts of undergraduate students in the Department of Civil and Environmental Engineering, Department of Mechanical Engineering – Engineering Mechanics and Department of Electrical and Computer Engineering of Michigan Technological University. While students worked under the supervision and guidance of associated faculty members, the contents of this report should not be considered professional engineering and will require professional review.

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Mission Statement

The mission statement of El Tigre Engineering for the senior design project in the Comarca Ngöbe-Buglé, as a part of International Senior Design, has been defined as:

> *"To develop an economically and environmentally sustainable hydropower design to the communities of Mamey, Cerro Piedra, and Arena of the Comarca Ngöbe-Buglé, Panama to provide a better quality of life."*

Executive Summary

El Tigre Engineering has designed a hydropower system for the indigenous communities of Quebrada Mamey, Cerro Piedra, and Quebrada Arena of the Comarca Ngöbe-Buglé, Panama. The need for electricity was brought to attention by the current Peace Corps Master's International student (PCMI), Jacob Midkiff. The PCMI requested a proposal of a feasible hydropower system with associated requirements.

With the collaboration of the PCMI and faculty at Michigan Technological University, an interdisciplinary senior design team, El Tigre Engineering, traveled to the communities in August 2011 for field data collection and community assessment. These communities received their first PCMI less than a year before El Tigre Engineering had arrived. The communities are currently underdeveloped without electricity or running water. El Tigre's recommended system will be implemented once the communities have established leadership and organization with guidance from their PCMI.

Over the course of the fall 2011 semester, El Tigre Engineering developed a design package for the proposed project. The package includes necessary documentation for construction, installation and maintenance of a hydropower system utilizing a nearby 46 foot (14 meters) high waterfall. The system is designed for sustainability with the consideration of low maintenance requirements and low profile within the surrounding environment.

The total cost of the system is estimated to be $38,000 or $112,000, depending on the system selected, and construction is estimated to be completed over the course of 62 days. Funding for the hydropower system is planned to be achieved through grants and donations.

Introduction

El Tigre Engineering is a student design team with Michigan Technological University's International Senior Design, iDesign, program. The team comprises of Grace Neuburg, a Mechanical Engineering undergraduate; Jennifer Fuller, a Civil Engineering undergraduate; Tristram Hokenson, a Civil Engineering undergraduate; and Benjamin Coultes, an Electrical Engineering undergraduate who served as Project Manager. iDesign is offered through the Department of Civil and Environmental Engineering at Michigan Tech and provides opportunity to immerse in challenging engineering design and cultural diversity.

On a two week venture in August 2011 to Panama, El Tigre Engineering visited the communities of Cerro Piedra, Quebrada Arena and Quebrada Mamey with efforts for collecting data to design a hydropower system. El Tigre Engineering assessed the community and site to determine the most feasible, economical and sustainable options to deliver power with the guidance of Peace Corps Master's International student (PCMI), Jacob Midkiff.

Cerro Piedra, Quebrada Arena and Quebrada Mamey are three communities in one area of interest located in the Comarca Ngöbe-Buglé in Western Panama. Jacob Midkiff works with these communities to build organization. Before Jacob's arrival, approximately one year prior to El Tigre's arrival, the community was unorganized and challenged with health concerns. A hydropower system is currently only a proposed concept to the community.

Data collection for the proposed hydropower system design consisted of measuring, surveying, photographs, Global Positioning System waypoints and communication. Utilizing this compiled information, El Tigre was able to generate a proposed design. The assumptions associated with the design are stated throughout the analysis.

El Tigre Engineering has produced a design recommendation to best meet the expectations of the PCMI for a hydropower system. This recommendation includes design analysis, cost estimates and a construction and operation guide.

Background

The Republic of Panama is a coastal country located in Central America, bordered by Costa Rica and Colombia of South America. Currently, the population is estimated to be 3.5 million people, and the main language spoken is Spanish. However, many Panamanians speak English as well [11]. Panama consists of nine provinces and three provincial level comarcas, the Emberá-Wounaan, Kuna Yala, and Ngöbe-Buglé. After years of protesting, in 1997 the Ngöbe-Buglé people were granted their own comarca, also known as a reservation. It is said that the government has withheld many rights to their land because of the interest in the mineral resources [3].

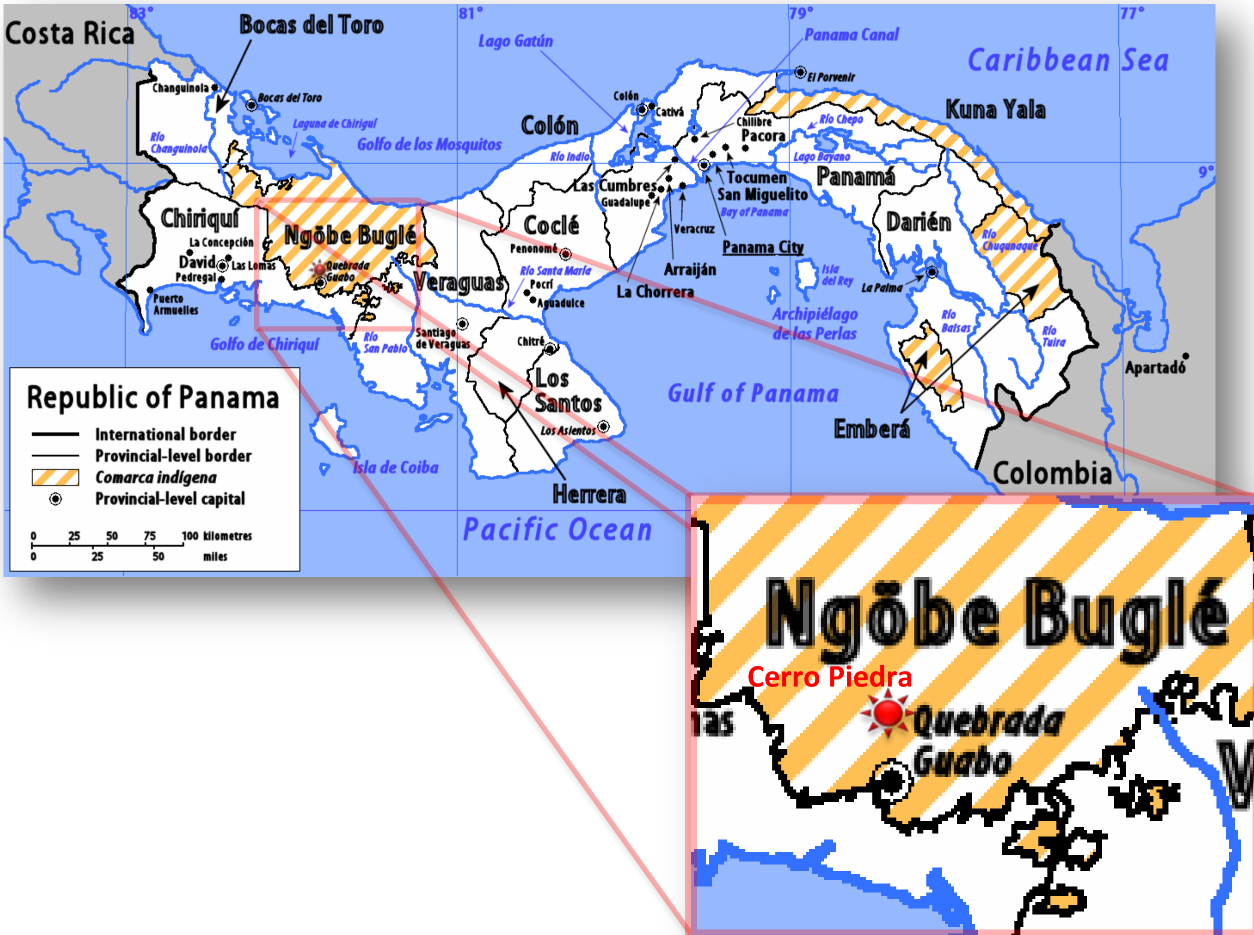

Figure 1: Republic of Panama Map and Location of Cerro Piedra[6]

Near the southern border of the Comarca Ngöbe-Buglé, El Tigre spent time collecting data and assessing the area and community. The residents of the communities consist of natives of the Ngöbe tribe. The sun, shown in **Figure 1**, represents the location of El Tigre Engineering during the August visit in the comarca. Cerro Piedra, Quebrada Arena and Quebrada Mamey are three separate communities situated within a close proximity and overseen by a single PCMI, Jacob Midkiff. The communities consist of 456 Ngöbe in approximately 70 homes [6]. These communities are located amongst treacherous hills and densely forested land. In order to access these communities, a half hour chiva, a small truck, ride followed by a one hour hike was necessary.

Recently, the implementation of latrines has helped improve community heath and suppress the spread of diseases. The communities are developing committees in order to oversee the prospective aqueduct systems being proposed by their PCMI. Once the communities have become proficient in the management of clean water distribution and payments, they will be assessed for their readiness to acquire power. Being an indigenous society, there is concern held by the PCMI that the communities will not be able to manage the power system. However, there are currently a few homes that do possess photovoltaic panels to produce enough electricity to charge a cell phone and offer a small amount of light. Photovoltaic panels were deemed too costly and not as reliable as a hydropower system during the assessment by the PCMI.

Methods and Objectives

The homes within the communities of Cerro Piedra, Quebrada Arena and Quebrada Mamey presently survive without clean running water and most without electricity. The PCMI, Jacob Midkiff, had conducted assessments to promote the welfare of the community. During this assessment, it was determined that water and electricity were needs that will benefit the community. Jacob is conducting assessments on the implementation of the aqueducts, where El Tigre has been given the objective to produce an analysis for hydropower. Data was collected and analyzed to design the prospective hydropower system.

Site Assessment

With assistance from the PCMI and local people, El Tigre was able to complete various methods of data collection

Surveying

El Tigre Engineering surveyed various locations and elevations along the river for the hydropower system components. Surveying was conducted to gather measurements and locations for possible inlets, penstock pipelines, and turbine/generator placements. A total station was used to measure the slope of potential penstock layouts and distances of inlet placements from the possible turbine – generator sites.

River Characteristics

A 100 foot (30.5 meters) tape measure was used to obtain measurements of the waterfall height, the hole characteristics, and various other profiles of Rio Juay. To determine the velocity and flow of the river, the float method was used upstream of the waterfall and a depth profile was created with a stick and measuring tape. For the float method, an orange peel was dropped at a specified point upstream and timed over a measured distance. The field results can be shown in **Table 1**. The first row has been highlighted red as it was neglected in the data calculations due to an irregular reading.

Table 1: Float Method Data Upstream of Waterfall

Trial	Distance (ft)	Time (sec)	Velocity (ft/sec)
1	34	11.1	3.06
2	34	7.7	4.42
3	34	8.6	3.95
4	34	8.42	4.04
		Average	**4.14**

The depth profile was created by measuring the distance across the stream and dividing it into 2 foot (0.6 meters) segments. At each segment, a depth measurement was taken. The profile is shown in **Figure 2**.

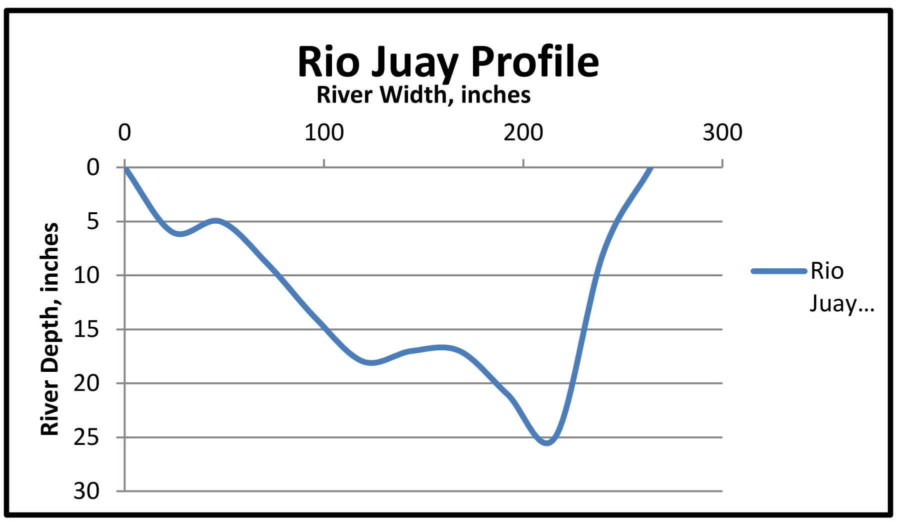

Figure 2: Depth Profile Upstream of the Waterfall

Figure 3: Depth Profile Measuring
Photo by Grace Neuburg

The method for measuring the depth profile is shown in **Figure 3**.

Global Positioning System

A hand-held Global Positioning System (GPS) was used to indicate waypoints along the footpaths in the communities for the potential transmission line layout. Areas of interest included the kindergarten, the stores, the community borders, the waterfall, the soccer field, and homes along the trials. Using the equator as a reference point, where an arc length of 1° Latitude equals 365,776 feet (111,488.5 meters), distances were calculated between waypoints to determine lengths of transmission lines. Google Earth was used to calculate more precise measurements between the waypoints. This data is shown in **Appendix J**.

Figure 4 below displays the data collected by GPS in the field.

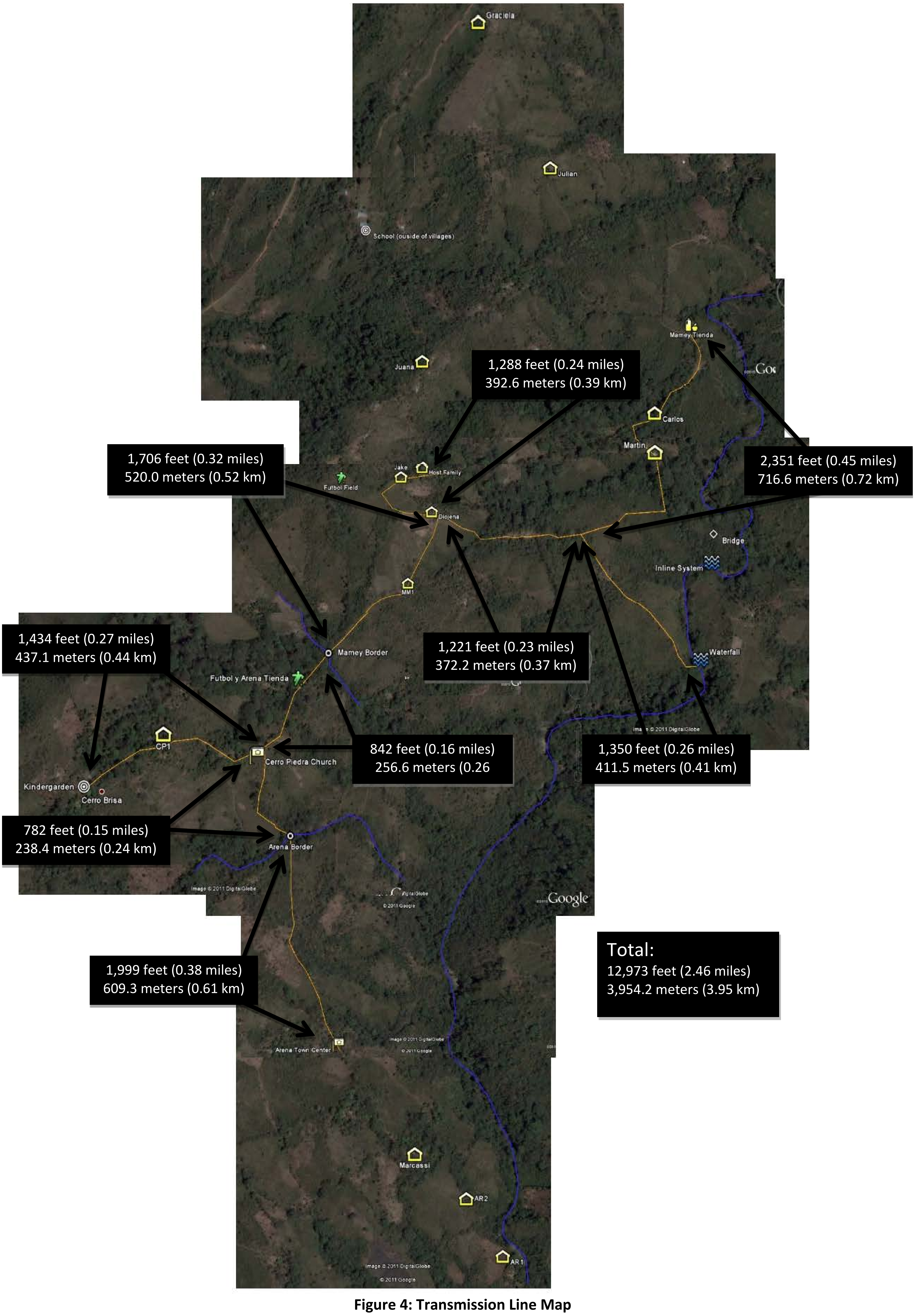

Figure 4: Transmission Line Map
Map from Google Earth by Tristram Hokenson

Design Objectives

The objectives of this project were developed mostly from the interviews with the PCMI, Jacob. Instead of setting a goal for an amount of power to be achieved, or a cost limit, the project objectives aim for dependability and simplicity with cost and power in consideration. El Tigre Engineering left Panama with the expectation to complete preliminary designs on a few different systems utilizing the data collected. Upon submittal of alternatives to Jacob, a final recommendation was made, and the final hydropower system was analyzed more thoroughly.

Table 2 lists design objectives.

Table 2: Design Objectives

Produce Power	No minimum power requirement was determined. A system would be designed around feasibility to determine how much power could be generated.
Include Transmission / Distribution System	The design must include methods for delivering power to as many homes in the communities as is financially feasible.
Structural Durability	The design needs to be durable and offer an extended lifetime if it is going to be utilized. If a major component fails, it is unlikely that it will be repaired or replaced.
Minimal Maintenance	The design must be reliable and operational without requiring major technical troubleshooting or a complex maintenance schedule.
Low Profile	The size of the design should be minimized to offer a low environmental impact as well as to preserve the traditional uses of the river for the Ngöbe natives.

Design Constraints

Designing a system in an isolated area presents certain limitations not typically encountered in the United States. **Table 3** defines the project constraints and challenges that needed to be accounted for.

Table 3: Design Constraints

Flashfloods	It is common for large trees and debris to wash down the river in heavy storms. The generator and turbine building needs to be located above the flood plain to avoid system washout.
Dry Season	The hydropower system needs to be designed to be operational when the river level is down. Rain ceases for about four months every year.
Remote Location	Every component in the system will be carried to the site through steep, narrow, muddy trails and across rivers.
Constructability	The design should be assembled with hand tools and small power tools through the use of a generator or portable diesel engine. No heavy duty machinery or lifting equipment is feasible.
Material Choice	The only materials considered are available locally or able to be delivered from outside the country.
Cost	A major restriction to the design will be cost since most of the people do not have large steady income. Grants and donations will be possible but may be difficult to acquire.
Community Preparedness	With no systems in place, there is concern that the community will not be organized and prepared enough to handle an electrification system.

Analysis of Hydropower Design

Upon departure from Central America, El Tigre conducted three preliminary analyses back at Michigan Tech. These three options were then presented to the PCMI, Jacob Midkiff, for his final recommendation. With the approval of Jacob, El Tigre pursued the design consisting of an inlet drilled into the face of the waterfall. Through the face of the waterfall, a hole is positioned. This hole will be utilized as the part of the inlet. Following the inlet, 111 feet (33.8 meters) of PVC penstock will carry the water to the turbine. The power producing system is an option of a turbine – generator combination or a constructible turbine that will be connected to a transmission and distribution system to carry the power to the native's homes. This design fit most the requested design parameters. It is predicted to be low maintenance and low profile.

Intake Design

Behind the face of the waterfall, a hole evolved over time creating an ideal location for the intake to be drilled through the face of the waterfall. **Figure 5** shows a profile view of the inlet design.

Figure 5: Waterfall Profile
Model by Grace Neuburg

In order to anchor the inlet into the rock face, El Tigre Engineering designed a mechanism for mounting the inlet assembly. This assembly consists of two solid flanges sandwiching an 1/8 inch aluminum plate. This system will be used on both faces of the rock; in the hole and on the face.

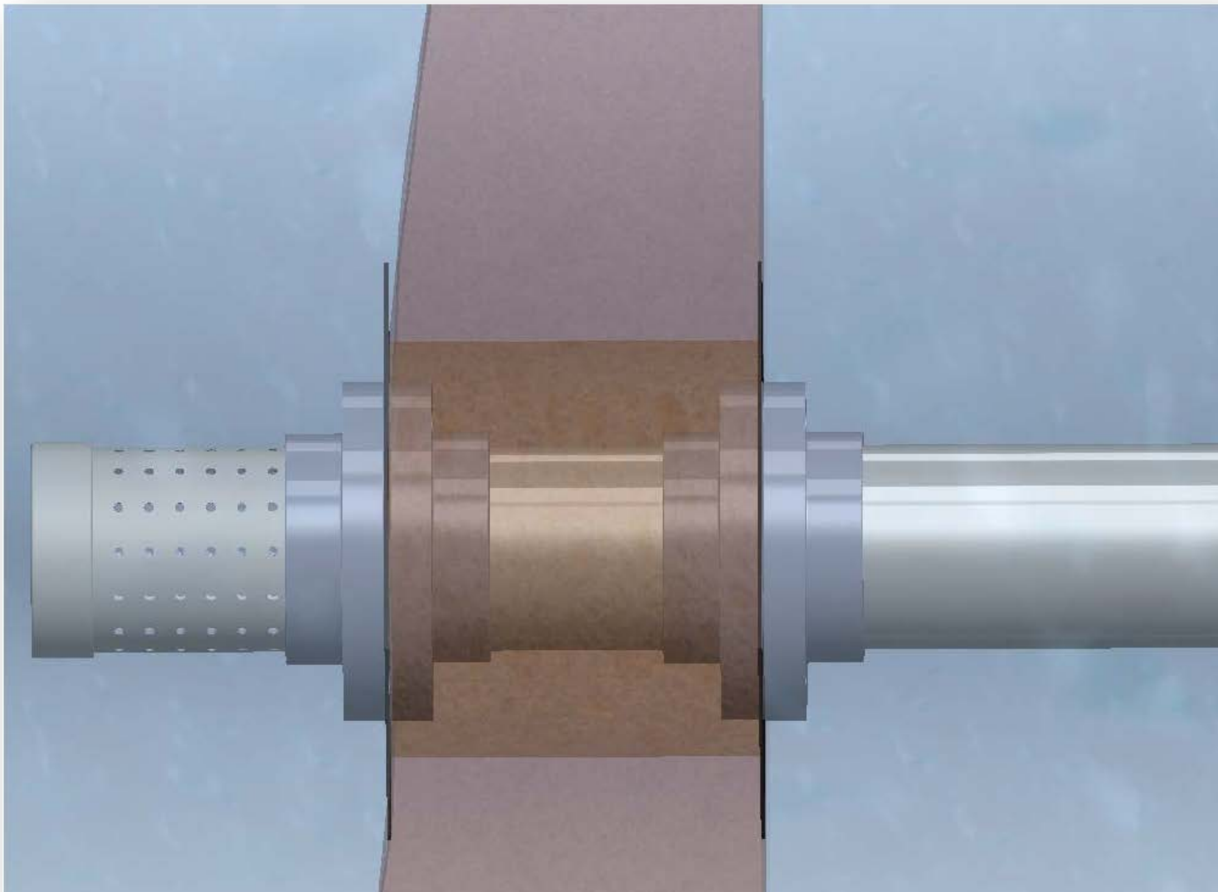

Figure 6: Profile View of Inlet Assembly
Model by Grace Neuburg

Figure 6 shows a model on the anchoring system. The PVC pipe will protrude into the hole behind the rock face. Holes will be drilled into the pipe at a diameter of 1/8 inch to prevent debris from entering the penstock and damaging the mechanical equipment.

Penstock Design

The penstock is designed with 12 inch diameter schedule 40 PVC pipe. This pipe is recommended to be coated with water based latex paint as a UV proofing agent before installation. The head losses in the penstock are shown in the power generation calculations in **Appendix I**. The calculation package provides options for both the placement of a turbine on the halfway rock, as shown in **Figure 7**, and also near the bottom of the waterfall. To maximize power generation, utilizing all of the head available, the turbine placement near the bottom of the waterfall is recommended.

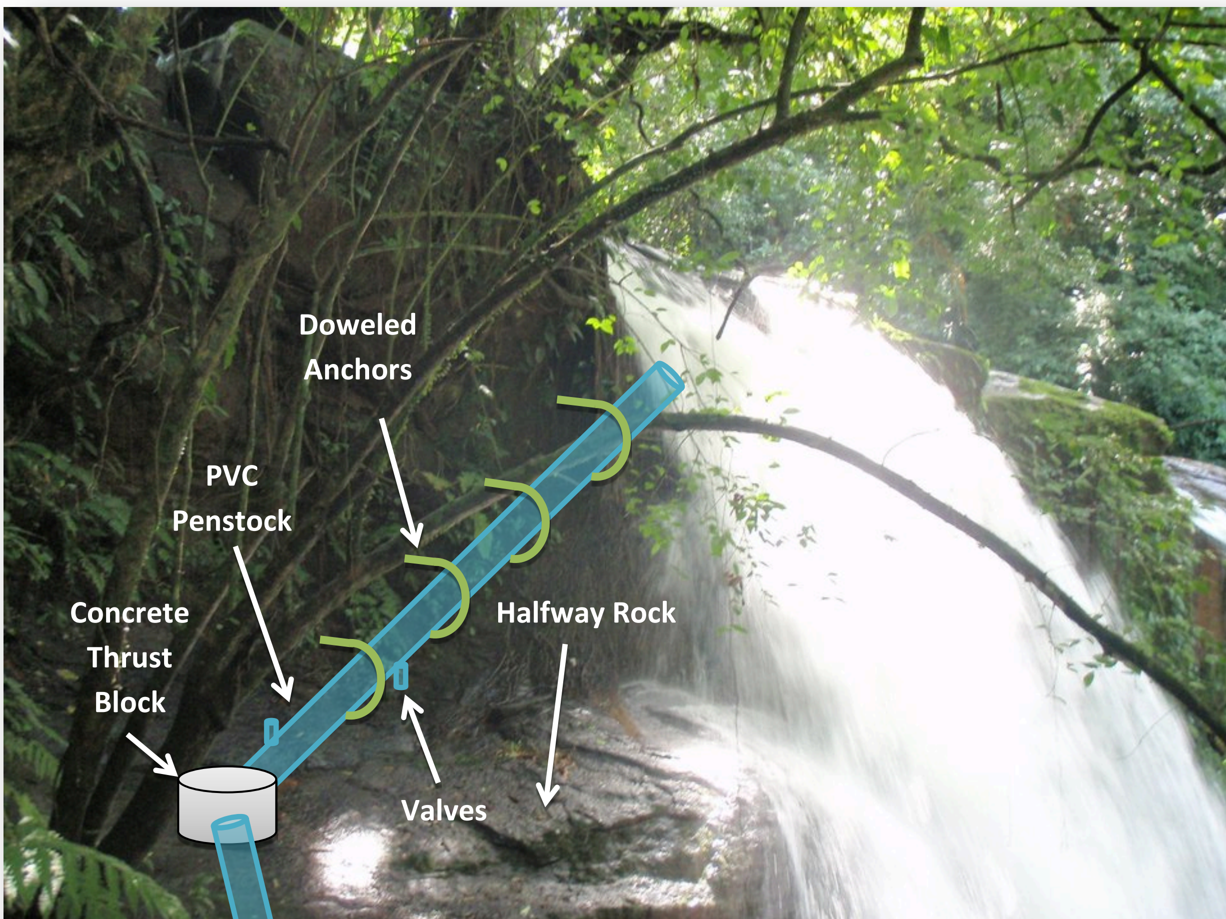

Figure 7: PVC Pipe Layout
Photo by Jennifer Fuller

Figure 7 displays the projected path for the penstock that will carry the 10 cubic feet per second (0.28 cubic meters per second) flowrate. From the inlet, the pipe will bend 90˚ extending approximately 41.3 feet (12.6 meters), at an angle of 23˚ from horizontal, to a thrust block located on halfway rock. The PVC pipe will bear against the thrust block to stabilize the pipe. The penstock pipeline will bend 135˚ at the thrust block and travel approximately 30 feet (9.1 meters) to another 135˚ bend to enter the turbine with a 40 foot (12.2 meters) long pipe.

El Tigre recommends having two valves located before the thrust block as shown in **Figure 7**. From the inlet, the first valve will be used as a pressure release valve. This valve will be opened to allow water and pressure to exit the pipe in order to reduce the risk of a burst in the pipe. The valve located closest to the turbine will be a shut off valve. This can be closed to stop flow to the turbine. This may be necessary for maintenance. The thrust block is recommended to have a bearing area of 6 inches by 6 inches, and be 15 inches thick (15.2 centimeters by 15.2 centimeters wide, and 38.1 centimeters thick) concrete block.

Following the turbine, the tailrace will extend 20 feet (6.1 meters). The estimated 20 foot long pipe will then bend 135˚, angled downward from horizontal, to be submerged a few feet below the dry season water level. The lengths and bends of the penstock pipeline were estimated from field measurements and photos taken of the area.

A surge tank, upstream to turbine, needs to be considered for pressure changes from the turbine and the possibility of water hammer. For this project, a surge tank was not considered and determined out of the scope for the design. Further consideration is recommended.

Turbine Shelter Design

In order to protect the turbine – generator system from the heavy rainfall in the rainy season of the comarca, a lean-to styled shelter unit was designed. This shelter unit consists of a one walled lean-to with a corrugated roof on an 8 foot long by 6 foot wide (2.4 meters by 1.8 meters) concrete slab. The slab is designed to be 5 inch thick with #3 reinforcing steel at 8 inch center to center distances, placed in the length and width directions. The location of the slab is shown in **Figure 8**.

Figure 8: Location of Slab
Photo taken by Tristram Hokenson

The turbine shelter is built from the local trees. The posts, wall and roof structure are easily constructed by the local people. Corrugated plastic panels were chosen over the traditional thatch leaves many of the homes are sheltered with. This decision was made to increase the life of the roof. A thatch roof would also be adequate protection for the unit from rain. The turbine shelter can be found below in **Figure 9**.

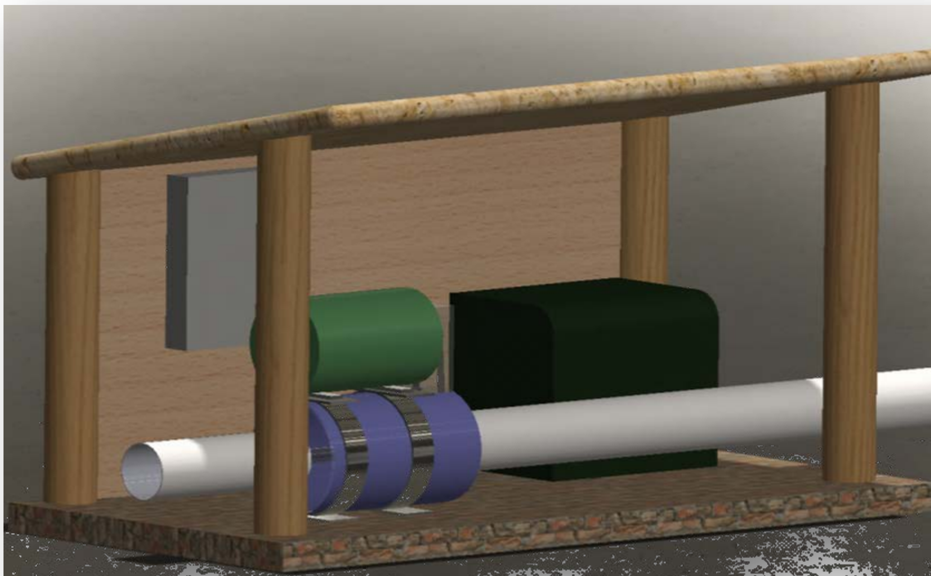

Figure 9: Turbine Shelter
Model by Grace Neuburg

Turbine - Generator Selection

Two options for the turbine are being recommended. The first is the Toshiba eKIDS Type S turbine - generator unit. This turbine is an impeller turbine that has the potential to produce 15 kilowatts (kW) of power based on El Tigre's Design. This option will be most feasible but less economical. The second option is a constructible crossflow turbine. This turbine is an impulse turbine also projected to produce 15kW of power. This option is dependable and low cost.

Toshiba eKIDS Turbine

In order to select a turbine from Toshiba, El Tigre's design criteria paired with **Figure 10** determined the appropriate turbine size. **Figure 10** displays the graph that assisted the in the selection process of the Type S turbine with El Tigre Engineer's design criteria.

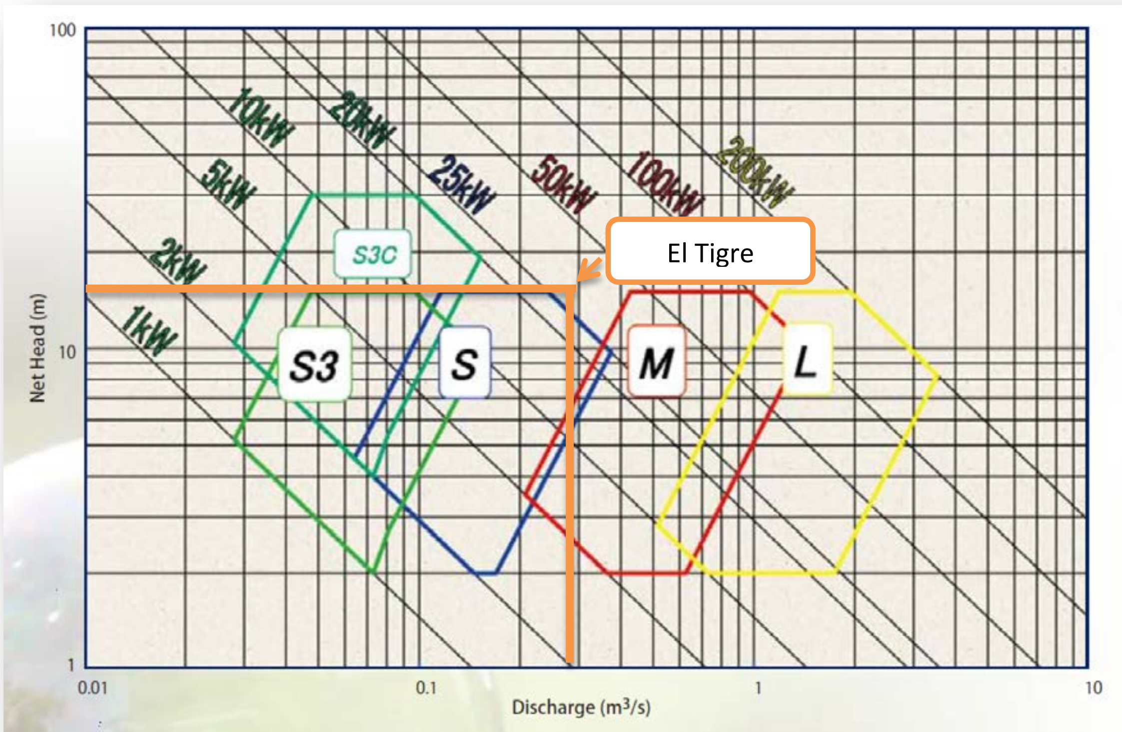

Figure 10: Toshiba Criteria for Turbine Selection [4]

Figure 11: Toshiba Turbine - Generator [4]

An installed Toshiba eKIDS turbine – generator unit is shown in **Figure 11**.

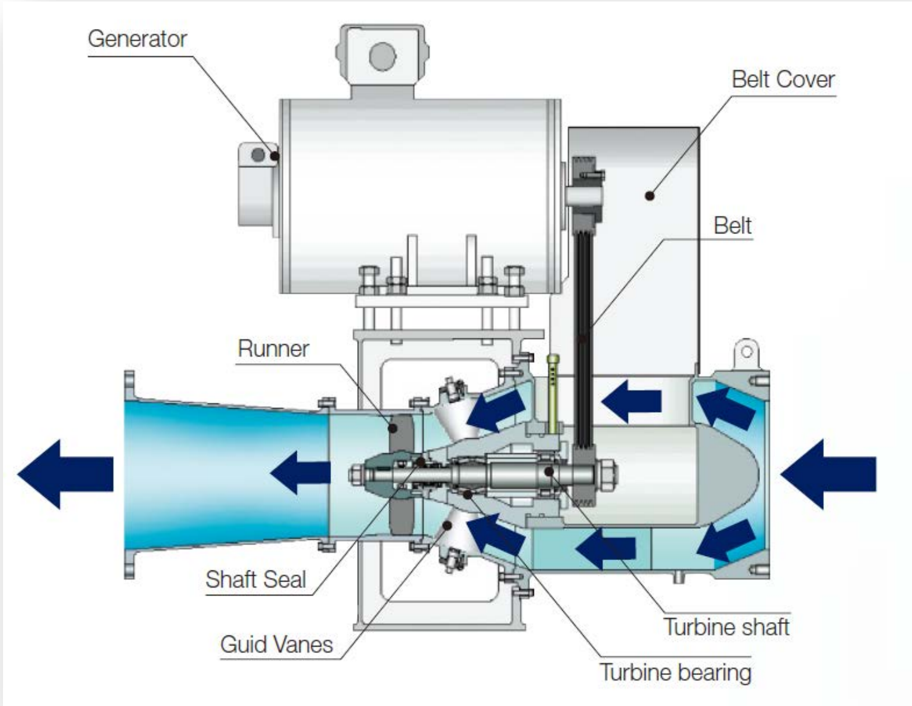

Figure 12: Toshiba Types S Turbine - Generator [4]

This turbine was also selected due to its ability to be moved without heavy equipment. The generator mounts on top of the turbine to conserve space. The induction generator couples directly to the turbine shaft with a drive belt. This is an added benefit because it significantly decreases the possibility of damaging parts, losses and a non-optimal gear ratio because of misalignment. It also simplifies the installation process and prevents the community from needing to keep spare couplers on hand [4]. The Hydro-eKIDS Toshiba Type S turbine - generator unit, shown previously in **Figures 11** and **Figure 12**, is uniquely designed to function well in various site conditions. With the potential to produce between 5 and 25kW of power from 6 to 50 feet (2 to 15 meters) of head, this design can be adjusted to accommodate flow changes if necessary for the rainy and dry seasons by moving the runner vanes. The site selected, the waterfall, offers 46 feet of head thus meeting the needs of the unit.

This system can be purchased from Toshiba International Corporation Hydro Electric Power Group located in Easthampton, Massachusetts. The tailrace will lead the water back to the river as mentioned previously in the penstock design.

Crossflow Turbine

A crossflow turbine, also known as the Mitchell, Banki, or Ossberger turbine, has been recommended and designed as an alternative turbine selection. The challenges include manufacturing this turbine with precision and structural reliability, as well as adapting it to unforeseen conditions on site. These may include the need to measure shaft rotational velocity in the field to determine gear ratio. It has been determined that this turbine may better be suited to handle the non-quantified seasonal flow changes with minimum adverse effects in efficiency, shown in **Figure 13**. Since it performs well even when the load decreases, this turbine is able to be left relatively unattended [9].

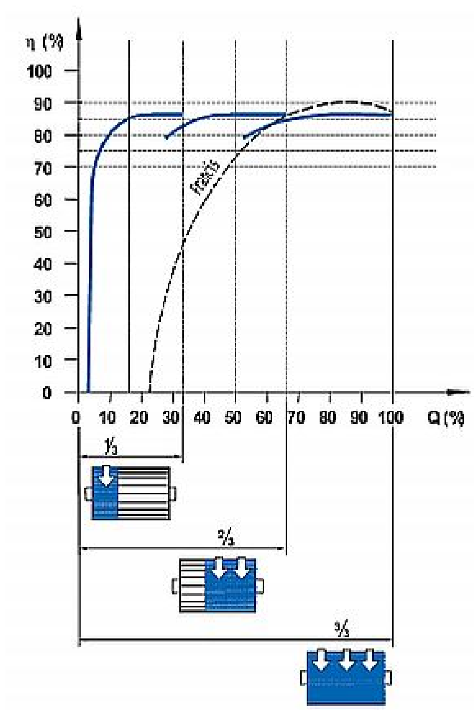

Figure 13: Turbine Efficiency, η, Under Various Flow Conditions, Q [13]

The crossflow turbine is a simple mechanism that can be repaired without calling an experienced technician, which should give the community a sense of ownership. It also lets debris escape better than a standard propeller blade. Crossflow turbines operate under the principal that the force of water flowing into the turbine hits both a near and far paddle blade to increase rotational velocity of the turbine shaft, as illustrated in **Figure 14**.

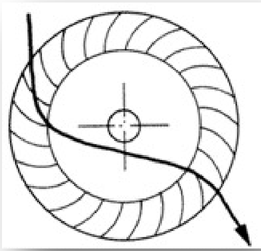

Figure 14: Water Path Through Crossflow Turbine [5]

Dimensions for the turbine were calculated based off Crossflow Turbine - A DIY Design Manual. If this turbine option is utilized, a review of this guide is recommended. The guide can be found in **Appendix E**.

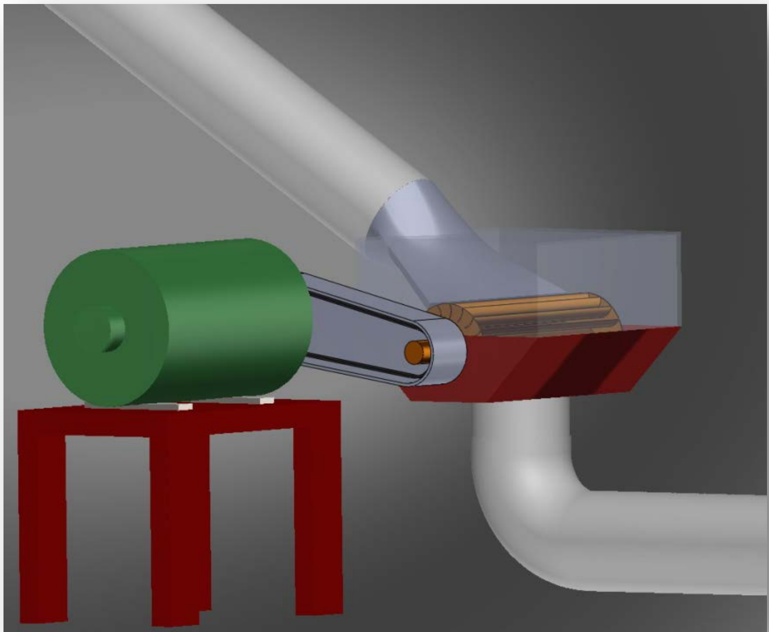

Figure 15: Crossflow Turbine
Model by Grace Neuburg

An assembled example of the cross flow turbine is shown in **Figure 15**.

Generator Control Components

A generator controller will be mounted on the generator to monitor the voltage and frequency produced by the generator and demand from the grid. The grid is a network of transmission lines and wires transporting and delivering power through the village. If the grid is demanding less power than the generator is supplying, then the controller will send the excess power to a dump load. This allows the generator to always see full load conditions to achieve low voltage and frequency regulation.

Following the controller, the next regulating component is the main system breaker. This allows the transmission system to be disconnected from the generator for maintenance and emergencies. Connected to the main breaker is the transformer which steps voltage up to a transmitting level of 600 volts (V) from the 200V it is generated at. The voltage needs to be stepped to a higher level in order to minimize losses in the transmission lines.

Connected to the main transformer and the transmission lines is the ground fault circuit interrupter, GFCI. This device will stop the flow of electricity when it detects a difference in the amperes in the positive line and the negative line. If the amperage reading is different, the GFCI trips and shuts down the system. The GFCI has its own breaker built in, therefore has the ability to disconnect the generator from the system if it detects a ground fault. One reason that these two currents would not be the same could be that a person completed the circuit between the positive transmission line and the ground by touching an exposed transmission line with bare hands or any material that conducts electricity. In this instance, the GFCI would cut the power to the system because the amperes in each line, positive and negative, are not the same. The GFCI is designed to eliminate power instantaneously; therefore the person completing the circuit should not receive a fatal shock.

The GFCI must be after the transformer in order to detect the ground fault. With this set up, a more expensive and heavy duty GFCI will have to be purchased. This is a drawback to having individual transformers at each house, because the house circuits are not protected by the system GFCI and could deliver a fatal shock to anyone that completes the circuit in a manner mentioned previously. The generator connections are shown in **Figure 16**.

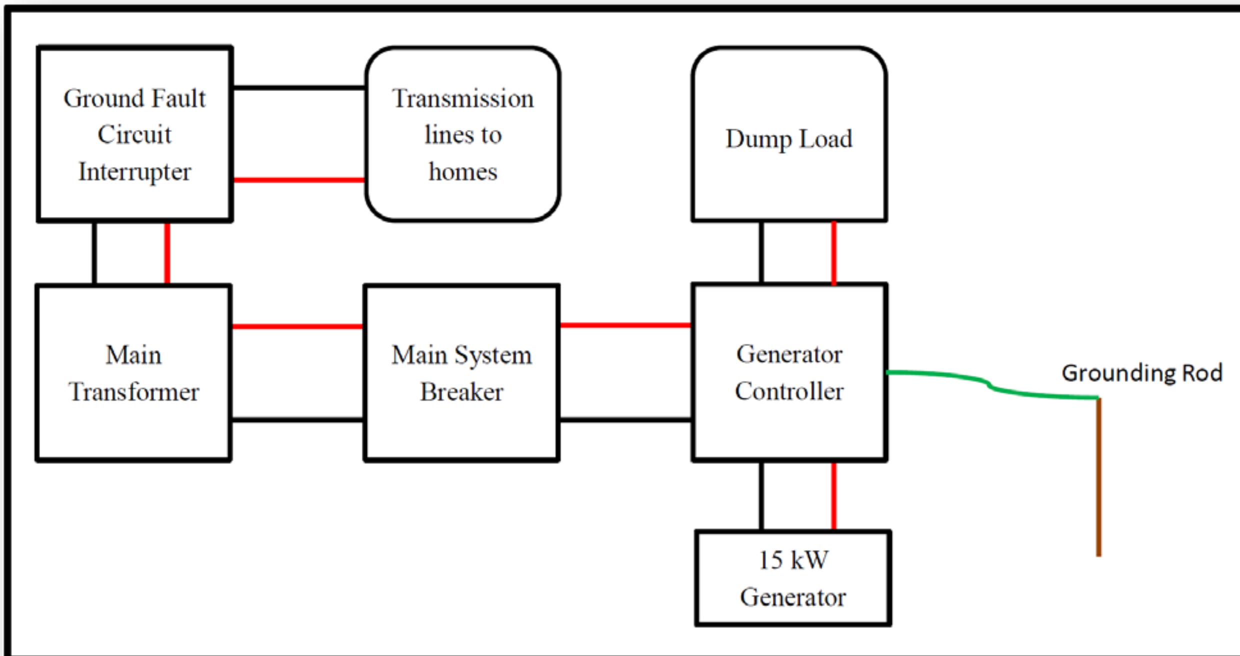

Figure 16: Generator Connection Diagram
Diagram by Benjamin Coultes

Power Distribution & Transmission

The transmission and distribution system will be single phase, 600V AC system, 60Hz, can carry a max of 247A and transmit a maximum power of 148kW. This system does not have distinct transmission and distribution systems. They are, in part, the same. This is due to the spatially distributed nature of the three communities. Normally the transmission portion would have higher voltage than the distribution system to lower the losses over great distances. Because there are houses along every path that the lines will travel, this is not feasible. Therefore, the transmission lines have to be at distribution voltage everywhere. This problem is solved by making the distribution and transmission systems the same and using step down transformers at each house. This is to keep the losses as low as possible by using the highest voltage that the transmission lines are rated for, and also to eliminate the need for a secondary line to carry distribution voltage. The need to minimize the amount of conductors comes down to cost. This is one reason why the system is single phase, so that there are only two conductors and a grounding rod at all houses and the generator.

The system was designed as a single phase system for cost purposes and component availability in Panama. Three phase transmission and distribution systems would have been more efficient and resulted in fewer losses in the transmission lines. If there were more conductors to carry the same amount of amperes, then each conductor would carry less than when the system was only single phase. The amount of losses in a wire depends directly on the amount of current flowing through it. The higher the current in the wire means that the losses are also higher in the wire. Three phase was not feasible because the generator controller is only available in single phase in country. An external, American, distributer would have to be utilized to acquire the necessary components for a three phase system.

The recommended transmission line is 00 gauge stranded insulated aluminum. It will be cheaper than copper, even with the increased gauge size to achieve the same characteristics as copper. The aluminum wire will also be lighter than the copper wire. This will help when hanging the transmission lines. The lines will require a weak connection so that if an object, such as a tree, would fall on to the transmission lines, the connection to the tree will break first preventing the transmission lines from breaking. This is safer than directly attaching the transmission line to the trees because a break in the transmission line would be dangerous and costly to replace.

In order to compile an accurate map of the transmission line layout, the Global Positioning System (GPS) coordinates were uploaded into Google Earth. Google Earth assisted in the measurement and layout of the transmission lines following the topography of Ngöbe- Buglé land. From the create Google Earth map, 2.5 miles of transmission lines were calculated. A map is shown previously in **Figure 4**.

Home Connections

Each home will have its own transformer to step the voltage down from 600V to 120V. There will be a switch between the main line and the transformer to be able to turn off the power to each house individually.

It was stated before that each individual house will not have protection from ground faults. This could be solved by purchasing outlets that have GFCIs built into them. The transformers will be 0.5 kilovolt-ampere (KVA), and able to deliver a maximum of 4.1 amperes (A) per house. This provides a maximum amount of power for each house of about 500 watts (W), or five 100W light bulbs. The houses will be limited by a fuse between 0.5A and 4A which would allow for either 60W or 480W of power, respectfully. The home connection diagram is shown in **Figure 17**.

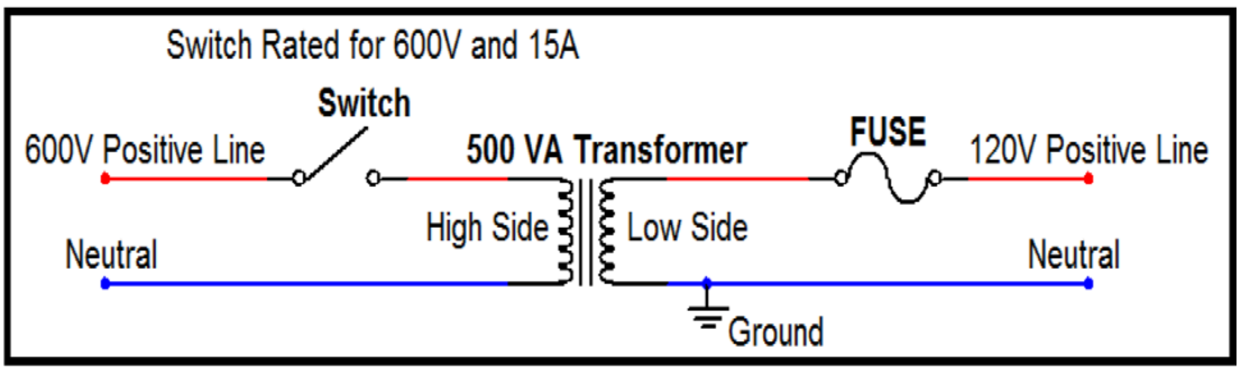

Figure 17: Household Connection Diagram
Diagram by Benjamin Coultes

Using fuses with ratings between 0.5A to 4A in 0.5A steps would allow for different power ratings in increments of 60W of power. With a power generation of 15 kW and 40 houses connected, the average amount of power supplied to each house is 360W, or six 60W light bulbs that can run continuously. The size of the transformer was chosen because this size will be a little overrated for each house in current, and power rating. The transformer is rated for about 500W, and over 4A on the low side at 120V. Each house will be able to use between 0.5A and 4A for power between 60W and 480W. Some homes would be allowed to use almost 500W as long as there are minimal amounts of homes using 4A fuses. This would be controlled by the committee that oversees the project.

Wiring from the transformer to the rest of the house will be up to each individual household. All connections in the houses must be wired in parallel. Wiring in parallel is when the house is wired so that all of the positive connections connect to each other and to the positive conductor. The same goes for the negative conductor, all of the negative terminals are connected together and to the neutral conductor. This can be shown in **Figure 15** below.

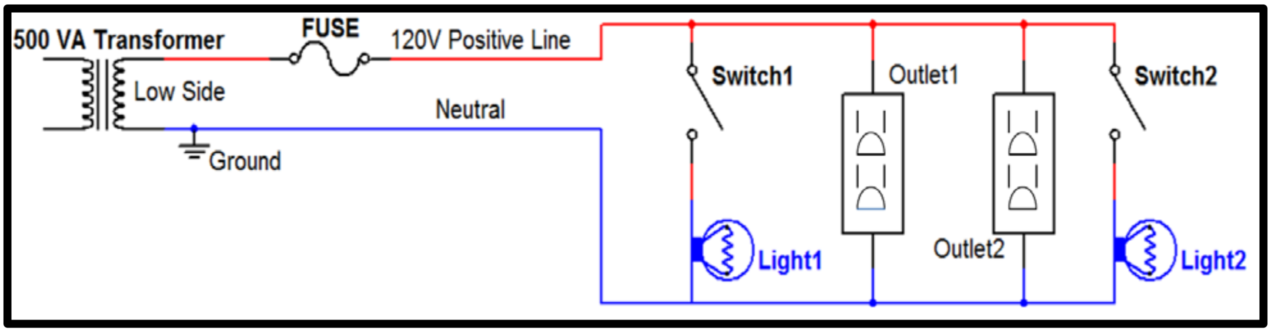

Figure 18: Internal Home Connection Diagram
Diagram by Benjamin Coultes

Cost Estimate

Prices were gathered from American suppliers, Panamanian suppliers, and Peace Corps Volunteers. Standard construction tools were all priced from Lowe's and assumed to be a similar price in Panama. Many tool rental prices came from the surrounding area of the Comarca Ngöbe-Buglé. Stores available to provide rental information included Cochez y Cia and Medina Tools. Another reliable source that El Tigre used frequently was Tim Burke. Tim Burke is a former Peace Corps Volunteer who previously completed a hydropower system in Panama.

Mobilization includes transportation for various types of equipment from different suppliers. It was estimated that transportation of basic construction materials would be provided by Cochez y Cia at a rate of $90 per trip from Chiriqui to San Felix. From another Peace Corps Volunteer's, Jessica Rudder, estimation of the price from Chichica to Tole, it was determined that a chiva could be utilized for mobilization from San Padro to San Felix at a rate of $45 per day. Medina Tools, supplying a jackhammer and air compressor, water pump, and electric drill with drill bits, offered transportation services from David to Tole for $100 per trip. Finally it was estimated that a chiva would be utilized to transport all material to Cerro Piedra to start construction. This was approximated at $40 per day for 5 days.

The inlet will require a pneumatic jackhammer or handheld chipper. This was priced at $125 per day of renting from Medina Tools. A water pump will be used to keep the hole behind the face of the waterfall dry. This was estimated to cost $150 per rental week. In order to drill holes for the screen of the inlet, an electric drill with drill bits will be provided from Medina Tools at a rate of $65 per week. Along with various other items necessary to construct the inlet, it is estimated that the inlet and anchoring system will cost $8,000.

The penstock and tailrace is estimated to cost $11,000. This price includes various rentals and construction materials. The 12 inch schedule 40 PVC pipe and fittings are estimated to cost $9,000. Medina Tools provided an estimate of rental cost for a generator. A 7kW gas generator would cost $225 per week.

Toshiba eKIDS Type S turbine – generator was estimated to cost $70,000. Assuming no labor costs in the manufacturing of the crossflow turbine and attachment components, this option would cost an estimated $2,000.

To distribute the power to approximately half of the homes, $13,000 would be necessary. The major costs associated include the insulated #00 gauge aluminum wires at $752.50 per kilometer. At each of the 40 homes, a step down transformer will need to be installed at a rate of $146 per unit.

A 7% tax was added to the overall price to account for variation in tax prices across Panama and the United States. This tax also was determined to include inflation. Also the cost estimate does include some duplicated items as some rental items may be necessary for different tasks. This was also used to account for inflation and an over estimate of the total net cost. This estimate includes the assumption that all items to be rented will be on site from mobilization till the day after the task is completed. Labor is not included in the estimate as it has been assumed to be donated.

An overview of the total cost is shown in **Table 4** and **Table 5**. The detailed cost estimate can be found in **Appendix A.**

Table 4: Cost Estimate with Toshiba Turbine

Category	Total Cost
Mobilization	500
Inlet	8,000
Penstock	11,000
Mechanical Equipment / Housing	71,500
Power Distribution	15,000
Total Cost	*$105,000*
including 7% tax	**$112,350**

Table 5: Cost Estimate with Crossflow Turbine

Category	Total Cost
Mobilization	500
Inlet	8,000
Penstock	11,000
Mechanical Equipment / Housing	2,000
Power Distribution	15,000
Total Cost	*$36,500*
including 7% tax	**$39,055**

Construction Schedule

Since El Tigre is offering two options for the turbine, two slightly different construction schedules have been included. Both construction schedules can be found in **Appendix B**.

The power distribution has been estimated to the critical task. This is due to the long duration estimated to complete preparing the trees and erect the lines to the trees.

Regardless of the turbine selection chosen, construction is estimated to last for 62 days. Construction was selected to start in 2013 in order to allow time for the PCMI to prepare the communities. This requires organizing committees and providing training on how to manage systems such as the hydropower system.

Final Recommendations

From the analysis and data collection conducted by El Tigre Engineering, it has been decided that a hydropower system in Cerro Piedra, Quebrada Arena and Quebrada Mamey is a feasible project to pursue. It is recommended that further design and research be completed before the design is implemented. The recommendation of pursuing donations and grants will need to be pursued since the prices of the proposed systems exceed a reasonable cost for the community.

There are various uncertainties with in the cost estimate as it was difficult to find distributers that spoke English and could offer prices.

El Tigre's design of a hydropower system has been deigned to achieve 15kW of power from a 10 cubic feet per second (0.28 cubic meters per second) flowrate. The water will enter an inlet anchored through the face of the waterfall and travel through a 12 inch penstock to either an impeller or impulse turbine. A turbine shelter has been designed to protect the mechanical and electrical equipment. A tailrace will follow the turbine and release the water back into the river. The transmission and distribution system will extend to half the homes, the school and two stores in the community; each will be offered an average of 340W of power.

With the two options provided between the Toshiba turbine and crossflow turbine, it has been determined that the Toshiba turbine be recommended if it can be donated. The crossflow is the second recommended option. This option is reliable, simple to build and economically feasible. Due to the high cost of transmission lines to reach each home and step down transformers required at each home, it is recommended to only provide power to half of the homes in the community. This includes providing power to the school and two stores.

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Appendix A – Cost Estimate

Toshiba Turbine

Item No.	Description	Unit	Quantity	MATERIALS		EQUIPMENT		Total $
				$/Unit	Cost	$/Unit	Cost	
Mobilization								
	Cochez Transport from Chiriqui to San Felix	TRIP	2		0.00	90.00	180.00	180.00
	Transport from San Padro to San Felix	DAY	1		0.00	45.00	45.00	45.00
	Medina Tool Transport from David to Tole	TRIP	1		0.00	100.00	100.00	100.00
	Chiva Services to Cerro Piedra	DAY	5		0.00	40.00	200.00	200.00
	TOTALS	LS	1		$0.00		$525.00	$525.00
Inlet								
	Jackhammer / Chipper, 90 lb, with an Air Compressor	DAY	33		0.00	125.00	4,125.00	4,125.00
	Wood, Trees	EA	6	0.00	0.00		0.00	0.00
	Electric Drill, with Drill Bits	WEEK	5		0.00	65.00	325.00	325.00
	HIT HY 10 Plus Adhesive Anchor	EA	1	160.66	160.66		0.00	160.66
	Aluminum Sheet, 1/8", 24" x 24"	EA	2	62.04	124.08		0.00	124.08
	447-120F 12 inch cap sch 40	EA	1	319.00	319.00		0.00	319.00
	851-120 12inch socket solid flange	EA	4	545.30	2,181.20		0.00	2,181.20
	Blue Hawk 90-Count #6 x 1-1/4" Black Phosphate Drywall Screws	EA	1	2.97	2.97		0.00	2.97
	Water Pump, 150 GPM, 2 in, Gas Powered	WEEK	6		0.00	150.00	900.00	900.00
	TOTALS	LS	1		$2,787.91		$5,350.00	$8,137.91
Penstock								
	PVC Pipe, Sched 40, 12 in x 10 ft	FT	200	22.05	4,410.00		0.00	4,410.00
	Oatey 8 Oz. PVC and CPVC Purple Primer	EA	4	5.38	21.52		0.00	21.52
	Oatey 32 Oz. PVC Cement	EA	3	10.98	32.94		0.00	32.94
	Valves, 12"	EA	2	150.00	300.00		0.00	300.00
	12" Elbow 90 Degree PVC Fitting Slip x Slip Schedule 40	EA	2	1,084.69	2,169.38		0.00	2,169.38
	12" 45° Elbow Slip x Slip PVC Fitting Schedule 40	EA	3	782.96	2,348.88		0.00	2,348.88
	Rebar, #3, 40 ft	EA	1	5.00	5.00		0.00	5.00
	Electric Drill, with Drill Bits	WEEK	6		0.00	65.00	390.00	390.00
	7kw Gas Powered Generator	WEEK	6		0.00	225.00	1,350.00	1,350.00
	Cement, 1 bag, 42.5 kg	EA	1	8.90	8.90		0.00	8.90
	Gravel, 20 cubic ft	EA	0.20	15.95	3.19		0.00	3.19
	Sand, 1 cubic m	EA	0.10	13.90	1.39		0.00	1.39
	Stanley 15" Hand Saw	EA	1		0.00	13.98	13.98	13.98
	TOTALS	LS	1		$9,301.20		$1,753.98	$11,055.18
Mechanical Equipment / Housing								
	Toshiba Turbine / Generator Combination	EA	1		0.00	70000.00	70,000.00	70,000.00
	Cement, 1 bag, 42.5 kg	EA	16	8.90	142.40		0.00	142.40
	Gravel, 20 cubic ft	EA	2.50	15.95	39.88		0.00	39.88
	Sand, 1 cubic m	EA	0.30	13.90	4.17		0.00	4.17
	Task Force 16 Oz. Smooth Hammer	EA	4	3.98	15.92		0.00	15.92

	Wood, Trees	EA	8	0.00	0.00		0.00	0.00
	Grip-Rite 5 Lbs. #16 x 3-1/2 Common Nails	EA	1	6.99	6.99		0.00	6.99
	Kobalt 12" Finishing Trowel	EA	1		0.00	15.98	15.98	15.98
	Truper 47" Fiberglass Long Handle Round-Point Shovel	EA	1		0.00	9.98	9.98	9.98
	Blue Hawk Welded Steel Garden Rake	EA	1		0.00	9.98	9.98	9.98
	4'x8' Corrugated Plastic Sheets	EA	4	6.20	24.80		0.00	24.80
	Poulan 14" 33cc Gas Chain Saw	EA	2		0.00	109.00	218.00	218.00
	Oregon 2-Pack 14" Replacement Saw Chain	EA	2		0.00	19.96	39.92	39.92
	Poulan Pro Quick Start Oil Kit	EA	2		0.00	5.68	11.36	11.36
	Machete	EA	2		0.00	3.00	6.00	6.00
	Rebar, #3, 40 ft	EA	4	5.00	20.00		0.00	20.00
	Tie Wire	LB	5.00	0.30	1.50		0.00	1.50
	TOTALS	LS	1		$255.66		$70,311.22	$70,566.88
Power Distribution								
	Copper Wire #12 500 ft Roll	EA	20	52.77	1,055.40		0.00	1,055.40
	Fi-Shock High-Tensile Wire Cutters	EA	2		0.00	24.12	48.24	48.24
	Aluminum Exterior Cable #00	KM	4	752.50	3,010.00		0.00	3,010.00
	Special Primary Single-Phase Transformers Primary 600V, Secondary 120 / 240V, 85-5025SH	EA	40		0.00	146.00	5,840.00	5,840.00
	Special Primary Single-Phase Transformers Primary 600V, Secondary 120 / 240V, 85-5035SH	EA	3		0.00	248.00	744.00	744.00
	1000 W Dump Load Resistor, Adj .75 Ohm	EA	15		0.00	150.00	2,250.00	2,250.00
	IGC Type Generator Controllers	EA	1		0.00	660.00	660.00	660.00
	Amp Switch	EA	40		0.00	2.00	80.00	80.00
	Motor Capacitor	EA	1		0.00	300.00	300.00	300.00
	Connection Box	EA	40		0.00	10.00	400.00	400.00
	Machete	EA	4	3.00	12.00		0.00	12.00
	Poulan 14" 33cc Gas Chain Saw	EA	2		0.00	109.00	218.00	218.00
	Oregon 2-Pack 14" Replacement Saw Chain	EA	2		0.00	19.96	39.92	39.92
	Poulan Pro Quick Start Oil Kit	EA	2		0.00	5.68	11.36	11.36
	Task Force 16 Oz. Smooth Hammer	EA	4	3.98	15.92		0.00	15.92
	Fi-Shock 1-3/4in Barbed Staples 5-lb Box	EA	20	25.36	507.20		0.00	507.20
	IDEAL 4-Oz. Tube Noalox Anti-Oxidant	EA	12	6.79	81.48		0.00	81.48
	IDEAL 225-Pack Plastic Wing Wire Connector	EA	1	16.99	16.99		0.00	16.99
	TOTALS	LS	1		$4,698.99		$10,591.52	$15,290.51
	TOTAL ESTIMATE				$17,043.76		$88,006.72	$105,050.48
	TOTAL ESTIMATE (including 7% tax)				$18,236.82		$94,167.19	$112,404.01

Crossflow Turbine

Item No.	Description	Unit	Quantity	MATERIALS		EQUIPMENT		Total $
				$/Unit	Cost	$/Unit	Cost	
Mobilization								
	Cochez y Cia Transport from Chiriqui to San Felix	TRIP	2		0.00	90.00	180.00	180.00
	Chiva Services from San Padro to San Felix	DAY	1		0.00	45.00	45.00	45.00
	Medina Tool Transport from David to Tole	TRIP	1		0.00	100.00	100.00	100.00
	Chiva Services to Cerro Piedra	DAY	5		0.00	40.00	200.00	200.00
	TOTALS	LS	1		$0.00		$525.00	$525.00
Inlet								
	Jackhammer / Chipper, 90 lb, with an Air Compressor	DAY	33		0.00	125.00	4,125.00	4,125.00
	Wood, Trees	EA	6	0.00	0.00		0.00	0.00
	Electric Drill, with Drill Bits	WEEK	5		0.00	65.00	325.00	325.00
	HIT HY 10 Plus Adhesive Anchor	EA	1	160.66	160.66		0.00	160.66
	Aluminum Sheet, 1/8", 24" x 24"	EA	2	62.04	124.08		0.00	124.08
	447-120F 12 inch cap sch 40	EA	1	319.00	319.00		0.00	319.00
	851-120 12inch socket solid flange	EA	4	545.30	2,181.20		0.00	2,181.20
	Blue Hawk 90-Count #6 x 1-1/4" Black Phosphate Drywall Screws	EA	1	2.97	2.97		0.00	2.97
	Water Pump, 150 GPM, 2 in, Gas Powered	WEEK	6		0.00	150.00	900.00	900.00
	TOTALS	LS	1		$2,787.91		$5,350.00	$8,137.91
Penstock								
	PVC Pipe, Sched 40, 12 in x 10 ft	FT	200	22.05	4,410.00		0.00	4,410.00
	Oatey 8 Oz. PVC and CPVC Purple Primer	EA	4	5.38	21.52		0.00	21.52
	Oatey 32 Oz. PVC Cement	EA	3	10.98	32.94		0.00	32.94
	Valves, 12"	EA	2	150.00	300.00		0.00	300.00
	12" Elbow 90 Degree PVC Fitting Slip x Slip Schedule 40	EA	2	1,084.69	2,169.38		0.00	2,169.38
	12" 45° Elbow Slip x Slip PVC Fitting Schedule 40	EA	3	782.96	2,348.88		0.00	2,348.88
	Rebar, #3, 40 ft	EA	1	5.00	5.00		0.00	5.00
	Electric Drill, with Drill Bits	WEEK	6		0.00	65.00	390.00	390.00
	7kw Gas Powered Generator	WEEK	6		0.00	225.00	1,350.00	1,350.00
	Cement, 1 bag, 42.5 kg	EA	1	8.90	8.90		0.00	8.90
	Gravel, 20 cubic ft	EA	0.20	15.95	3.19		0.00	3.19
	Sand, 1 cubic m	EA	0.10	13.90	1.39		0.00	1.39
	Stanley 15" Hand Saw	EA	1		0.00	13.98	13.98	13.98
	TOTALS	LS	1		$9,301.20		$1,753.98	$11,055.18
Mechanical Equipment / Housing								
	Generator (20 hP motor)	EA	1		0.00	155.00	155.00	155.00
	3.75" Diameter steel tubing, 3' lengths, 0.25" wall thickness	EA	5	120.00	600.00	155.00	775.00	600.00
	Wedge V-belt	EA	2	30.00	60.00		0.00	60.00
	Penstock to nozzle adapter (0.13" galvinized 2'x4'steel sheet metal)	EA	3	100.00	300.00		0.00	300.00
	Paint, 1 gallon, fast drying, corrosion resistant	EA	1	62.00	62.00		0.00	62.00
	Galvinized Fasteners and Miscillaneous		1	100.00	100.00		0.00	100.00
	Electrical Controls	EA			0.00		0.00	0.00
	Tachometer/ Stroboscope	EA	1	360.00	360.00		0.00	360.00

	Cement, 1 bag, 42.5 kg	EA	16	8.90	142.40		0.00	142.40
	Gravel, 20 cubic ft	EA	2.5	15.95	39.88		0.00	39.88
	Sand, 1 cubic m	EA	0.30	13.90	4.17		0.00	4.17
	Task Force 16 Oz. Smooth Hammer	EA	4	3.98	15.92		0.00	15.92
	Wood, Trees	EA	8	0.00	0.00		0.00	0.00
	Grip-Rite 5 Lbs. #16 x 3-1/2 Common Nails	EA	1	6.99	6.99		0.00	6.99
	Kobalt 12" Finishing Trowel	EA	1		0.00	15.98	15.98	15.98
	Truper 47" Fiberglass Long Handle Round-Point Shovel	EA	1		0.00	9.98	9.98	9.98
	Blue Hawk Welded Steel Garden Rake	EA	1		0.00	9.98	9.98	9.98
	4'x8' Corrugated Plastic Sheets	EA	4	6.20	24.80		0.00	24.80
	Poulan 14" 33cc Gas Chain Saw	EA	2		0.00	109.00	218.00	218.00
	Oregon 2-Pack 14" Replacement Saw Chain	EA	2		0.00	19.96	39.92	39.92
	Poulan Pro Quick Start Oil Kit	EA	2		0.00	5.68	11.36	11.36
	Machete	EA	2		0.00	3.00	6.00	6.00
	Rebar, #3, 40 ft	EA	4	5.00	20.00		0.00	20.00
	Tie Wire	LB	5	0.30	1.50		0.00	1.50
	TOTALS	LS	1		$1,737.66		$1,241.22	$2,203.88
Power Distribution								
	Copper Wire #12 500 ft Roll	EA	20	52.77	1,055.40		0.00	1,055.40
	Fi-Shock High-Tensile Wire Cutters	EA	2		0.00	24.12	48.24	48.24
	Aluminum Exterior Cable #00	KM	4	752.50	3,010.00		0.00	3,010.00
	Special Primary Single-Phase Transformers Primary 600V, Secondary 120 / 240V, 85-5025SH	EA	40		0.00	146.00	5,840.00	5,840.00
	Special Primary Single-Phase Transformers Primary 600V, Secondary 120 / 240V, 85-5035SH	EA	3		0.00	248.00	744.00	744.00
	1000 W Dump Load Resistor, Adj .75 Ohm	EA	15		0.00	150.00	2,250.00	2,250.00
	IGC Type Generator Controllers	EA	1		0.00	660.00	660.00	660.00
	Amp Switch	EA	40		0.00	2.00	80.00	80.00
	Motor Capacitor	EA	1		0.00	300.00	300.00	300.00
	Connection Box	EA	40		0.00	10.00	400.00	400.00
	Machete	EA	4	3.00	12.00		0.00	12.00
	Poulan 14" 33cc Gas Chain Saw	EA	2		0.00	109.00	218.00	218.00
	Oregon 2-Pack 14" Replacement Saw Chain	EA	2		0.00	19.96	39.92	39.92
	Poulan Pro Quick Start Oil Kit	EA	2		0.00	5.68	11.36	11.36
	Task Force 16 Oz. Smooth Hammer	EA	4	3.98	15.92		0.00	15.92
	Fi-Shock 1-3/4in Barbed Staples 5-lb Box	EA	20	25.36	507.20		0.00	507.20
	IDEAL 4-Oz. Tube Noalox Anti-Oxidant	EA	12	6.79	81.48		0.00	81.48
	IDEAL 225-Pack Plastic Wing Wire Connector	EA	1	16.99	16.99		0.00	16.99
	TOTALS	LS	1		$4,698.99		$10,591.52	$15,290.51
	TOTAL ESTIMATE				$18,525.76		$18,936.72	$36,687.48
	TOTAL ESTIMATE (including 7% tax)				$19,822.56		$20,262.29	$39,255.60

Appendix B – Construction Manual & Schedule

Construction Manual and Schedule

While various amounts of detail are provided throughout this analysis, these are only recommendations. Possible changes are permitted to increase efficiency, reduce time or cost, offer a safer product or safer working conditions. The construction for the hydropower design has an estimated duration of 62 days. The schedule can be found in the attached Microsoft® Project Gantt chart located at the end of **Appendix B**.

It will be assumed, unless otherwise noted, that construction will be completed by the Ngöbe-Buglé people. A vacation period is granted from December 23, 2013 to December 27, 2013. It is also recommended that technical supervision be provided for the connections of the electrical components to the generator and for the connection of the homes to the transmission lines. Operations and maintenance procedures can be found in **Appendix F**.

Mobilization

Mobilization

Mobilization includes retrieving the necessary equipment for construction and for the system in Panama from David, San Felix, Chiriquí, and San Pedro. The Toshiba turbine – generator will be acquired from Massachusetts, USA. Some items what will need to be rented during portions of construction include: a rental air compressor, pneumatic jackhammer, electric drill, and a water pump. Examples of materials that are to be purchased: power distribution supplies, turbine, cement, concrete reinforcement, and PVC pipe. For the purpose of this design, it is also assumed that mobilization of all materials will be completed before the project starts and that the equipment is returned after the task is completed.

Turbine Shelter

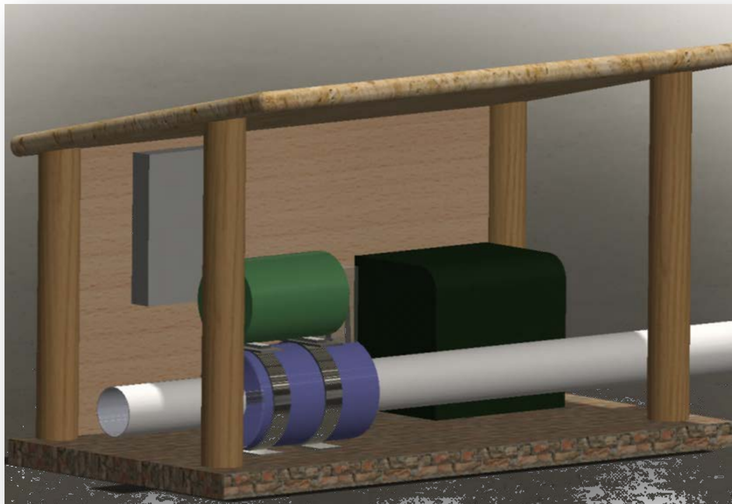


Figure C1: Turbine Shelter
Model by Grace Neuburg

The construction of the turbine shelter, shown in **Figure C1**, is estimated to take 16 days.

Build Falsework

Trees will be needed for the construction of the slab falsework. The timbers will be used for boards as forms to pour the concrete slab. The formwork will be sized for a 6 feet wide by 8 feet long by 5 inches thick (1.8 meters wide by 2.4 meters long by 12.7 centimeters thick) slab.

Set Grade and Level Slab

First the grade will have to be set for the slab. This will be completed by digging out an area of 6.5 feet wide by 8.5 feet long by 1 inch deep (2 meters wide by 2.6 meters long by 2.5 centimeters) in order to remove organic matter and debris from the slab footprint. The length of the slab will run parallel to the river. The 6 feet wide by 8 feet long by 5 inches thick (1.8 meters wide by 2.4 meters long by 12.7 centimeters thick) slab will be placed on the banks of the river near a large tree. Unlike most of the area surrounding the base of the waterfall, this tree offers a relatively large flat area to construct a concrete slab on.

The location of the tree and slab are shown in **Figure C2**. Digging into the side of the hill may be necessary in order to accommodate the size of the slab. The slab will then be leveled in order to shelter the turbine and generator on a flat surface.

Figure C2: Location of Slab
Photo taken by Tristram Hokenson

Slab Falsework
The falsework for the concrete slab pour will be constructed from the timber boards. The falsework will be used to make a square slab with a level surface. This formwork will be the dimensions of the slab, 6 foot by 8 foot by 5 inches (1.8 meters by 2.4 meters by 12.7 centimeters) and will be nailed together.

Concrete Reinforcement

The reinforcement for the concrete will be placed inside the slab falsework. The reinforcement, rebar, will be laid in a grid pattern and tied at 8 inch center-to-center in both longitudinal and transverse directions. Reinforcement steel, size #3 consisting of 0.375 in (9.53 millimeters) diameter, will be used. Four bars purchased at 40 foot (12.2 meters) lengths will be needed to construct the grid pattern. The rebar will be in lengths of 5.75 feet (1.8 meters) and 7.75 feet(2.4 meters) with a center-to-center spacing of 8 inches (20.3 centimeters) and a 1.5 inch (3.8 centimeters) clearance from the face of the concrete. This can be elevated 2.5 inches (6.4 centimeters) off the ground with rocks.

Concrete Pour

The concrete will be mixed according to **Appendix C**. The concrete will consist of 18.5 gallons on water (0.07 cubic meters), 1 sack of cement and 37.0 gallons (0.14 cubic meters) of coarse aggregate. This is based off a cement:sand:coarse aggregate ratio of 1:2:4.

Concrete Cure

The concrete must be given 7 days to cure before placing any loads on it to ensure adequate strength. Large leaves from trees can be dipped into the water and set over concrete slab. This can be done a few hours after the pour once the concrete surface has hardened. The leaves are recommended to cover the entire slab. The leaves must be dipped into the water every morning to maintain a proper cure for the concrete.

Remove Slab Falsework

After the concrete cures for a few days, the slab falsework can be removed by hand tools such as hammers. This is recommended to be completed 4 days after the pour, at a minimum.

Cut Down Trees

Four posts from the trees will be needed for the construction of the turbine shelter. These are recommended to be a minimum of 4 inches (101.6 millimeters) in diameter.

Prune Trees

Branches must be removed of the trees. Shelter posts will be cut to 10 foot and 11 foot (3 meters and 3.4 meters) lengths, two of each. This length includes 4 foot (1.2 meters) deep burial and 6 to 7 foot (1.8 to 2.1 meters) tall lean-to structure, as shown previously in **Figure C1**. The post diameter will be a minimum of 4 inch (101.6 millimeters) diameter.

Construct Boards for Wall

Additional boards will also need to be made to make a wall within the turbine shelter.

Dig Post Holes

Post holes will need to be dug 4 feet (1.2 meters) deep. It is recommended that a hole be dug a few inches wider than the post diameter to allow for concrete to fill in around the post.

Erect Post/Concrete Pour

The concrete can be mixed the same as previously stated, following **Appendix C**.

Concrete Cure

The concrete in the post holes must be given 7 days to cure.

Roof Structure

The structure will be made from the trees previously cut down. They can be made into boards to be used as the structure of the roof. The boards will be a maximum of 2 feet (0.6 meter) spacing, in both directions. This will be the support for the corrugated roof.

Set Roofing

Two 4 feet by 8 foot (1.2 meter by 2.4 meter) corrugated plastic or metal sheets will be used as the roof material. This will protect the turbine – generator and control systems from rainfall. The corrugated roof is recommended to ensure longevity of the structure. Thatch roof may also be used.

Mechanical Equipment

The mechanical equipment is estimated to take 5 days, regardless of the option chosen. For the crossflow turbine, this will not include any outsource work that must be completed.

Install Toshiba Turbine - Generator Unit

For the Toshiba turbine option, installing the turbine involves mounting it to the slab and connecting to the penstock and tail race. The generator mounts directly above the turbine with a vendor supplied attachment piece, as shown previously in **Figure C2**. The belt needs to be installed connecting the turbine shaft to the generator shaft. According to the manufacturer, Toshiba, no alignment work is necessary [4].

Adjust Runner Vanes

After the system is set up and the penstock installed, explained later, the runner vanes will need to be adjusted to maximize performance. Adjusting the angle increases or decreases the cross sectional area of water being aimed at the propellers. This is done by first opening the valve closest to the inlet to release pressure in the pipe. Close the shut off valve closest to the turbine to stop the flow of water. Suggested locations of the valves are shown in **Figure C4**. Then flow is turned on and the process repeated until the highest speed of the turbine has been found.

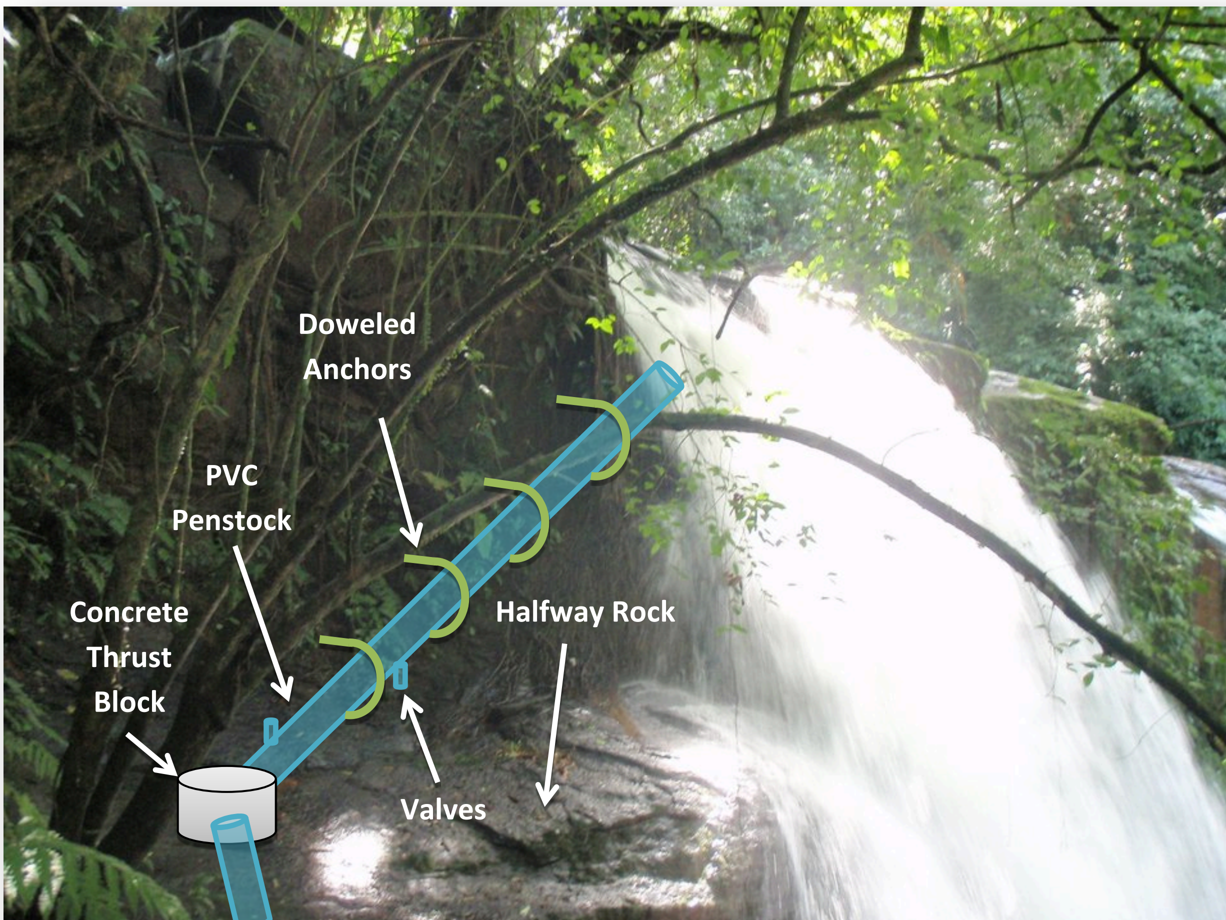


Figure C4: Valve and PVC Pipe Layout
Photo by Jennifer Fuller

Sufficient time is allotted to assess this adjustment over the course of a few days if necessary. Adjusting the runner vanes should be done again when the wet season begins to let more water into the turbine.

Build Crossflow Turbine

For the crossflow turbine option, the community will need to find a machine shop with capabilities including tungsten inert gas (TIG) welding, bending, milling, and precision cutting. The turbine can be manufactured by various methods depending on the capabilities of the shop. Design components, pictured in **Figure C3**, are depicted in a general configuration; however, the layout will need to be tailored according to the particular motor purchased and machining capabilities.

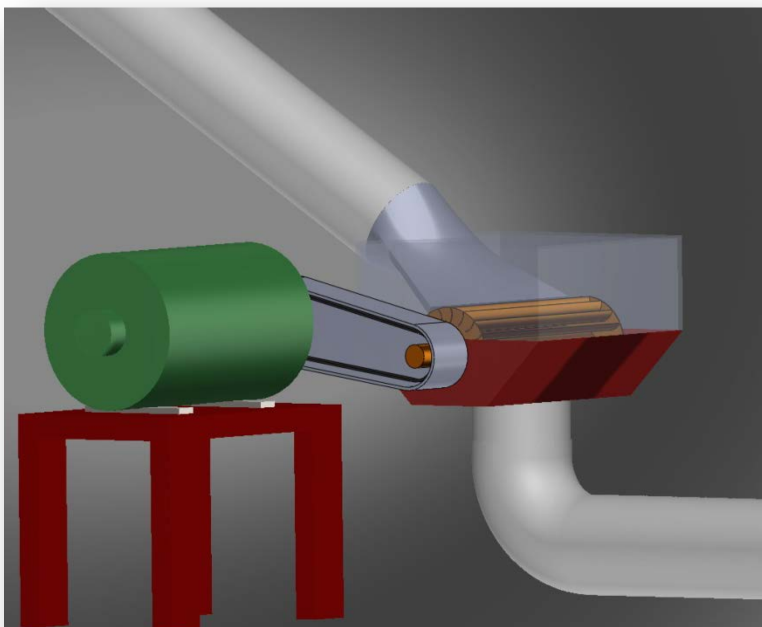


Figure C3: Crossflow Turbine
Model by Grace Neuburg

The drawings in **Appendix D** show the recommended dimensions for the turbine and nozzle. Other components of the mechanical system such as the tray, to lead water to the tail race, turbine guard, and belt guard have no critical dimensions, and can be built from the extra steel after the turbine and generator are oriented in the turbine shelter. Since the tail race extends vertically below the turbine, the generator will need to be raised. These decisions will depend on the motor orientation and dimensions. **Figure C3** shows the assembly of necessary components.

This option would also require a person with mechanical system and manufacturing experience to assist. The adapter piece tapers from the penstock to the outlet onto the turbine blades, which can be made of 1/8 inch galvanized steel and reinforced with painted steel braces.

The water hits the turbine blades twice thus the torque loading of the generator is unknown, a belt length and ratio will be determined on site. The ratio is based on the speed of turbine in operation compared to the speed of the generator. Since the priority in this option is low budget, a 20 horsepower induction motor to serve for a generator is recommended. Once a generator is found the belt ratio connecting the generator shaft to the turbine can be calculated as the proportion of the product of the turbine speed and pulley diameter to the product of the generator speed and pulley diameter. This is shown in **Equation B1** below

Equation B1

$$\frac{Turbine\ Speed\ in\ RPM}{Generator\ Operating\ Speed\ in\ RPM} = \frac{Generator\ pulley\ diameter}{Turbine\ pulley\ diameter}$$

The operating speed of the turbine will change when the generator is connected. The generator speed will change when the system is turned on. The operating speed of the turbine should be measured and the belt ratio calculated assuming the nominal motor speed. Enough belts and pulleys are accounted for in the budget to allow for trying out other gear ratios if the initial ratio yields an unsatisfactory result. The higher the ratio between turbine shaft diameter and generator shaft diameter, the more electric power will be produced.

The constant efficiency of the turbine over a large flow gradient depends on the installation of runner vanes in the nozzle. These allow the flow area to be reduced by 1/3 or 2/3 in lower flow conditions by sliding the vanes shut partially, as **Figure 13** in the report, described. If the yearly changes in flow are minor, these vanes will not need to be designed; however, this step could be taken to optimize the design if the flow fluctuations prove to be high.

The rotational speed of the shaft can be calculated with a strobe light. This is done by marking a dash at the outer edge of the shaft while stationary and shining the strobe light when the shaft is spinning. The strobe light rate is then slowly increased until the dash on the shaft appears to hold still. Great care should be taken to ensure no one comes in contact with the shaft during this measurement, since the shaft will appear to be stationary. The rate read off the strobe light setting is the rotational speed of the shaft. This can be completed with a stroboscope.

Inlet/Penstock

The construction of the inlet and penstock is estimated at 21 days.

Diversion Falsework

The diversion falsework will be made of rocks and wooden boards produced from local materials by skilled members of the community. It is estimated that it will take 3 days to cut the trees and gather the rocks for the diversion.

Divert Flow

It is estimated that it will take the local people 2 days to divert the flow from Channel A during the dry season. Channel A is shown below in **Image C5**.

Figure C5: Dry Season Flow
Photo taken by Jacob Midkiff

The flow diversion is illustrated in **Image C6**.

Figure C6: Flow Diversion
Photo taken by Jennifer Fuller

Remove Water

The remaining water in the hole after diversion will be removed by hand with buckets. The pool will then need to be cleaned of debris. A pump will rented to be set in the pool and keep the area dry for construction.

Chip Hole in Rock Face

Once the air compressor and pneumatic jackhammer are moved to the large rock next to Channel A, a minimum of a 13 inch (33 centimeters) diameter hole will be chipped from the inside of the pool for the intake design. It is estimated that the rock will be less than 2 feet (0.6 meters) in length. The chipped hole will be located approximately 5.5 feet (1.7 meters) below the lip of the face. This is shown in **Figure C7**.

Figure C7: Estimation of Waterfall Face Thickness
Photo taken by Jennifer Fuller

Intake Assembly
Figures C8 shows the inlet assembly in the face of the rock extending into the pool.

Figure C8: Waterfall Profile
Model by Grace Neuburg

After the completion of chipping, a 2.5 foot (0.8 meter) section of PVC pipe will be inserted into the chipped out hole. Then the two part epoxy will need to fill the entire cavity to prevent washout and seepage. A solid 12 inch (30.5 centimeter) diameter flange will be slipped on to both ends of the PVC pipe that fits through the length of the chipped hole in the waterfall rock face, with the smaller diameter base facing outward. This will need to be embedded in the epoxy to create a bond and flush surface for the plate. The epoxy will need to dry according to the manufacture's recommendations. Once the epoxy is dry, the aluminum plate will be placed followed by the second solid flange. The outside flange will face the opposite direction from the inside flange. Screws then will be inserted into the flange and epoxy to securely hold the system in place. The plate will be used to cover the chipped hole and offer additional strength to hold the inlet in the rock face, this will prevent the force of water from pushing the inlet out of the rock. To get the 12 inch (30.5 centimeter) hole and screw holes in the plate, a machinist may be need to be contracted.

Figure C9 shows the inlet.

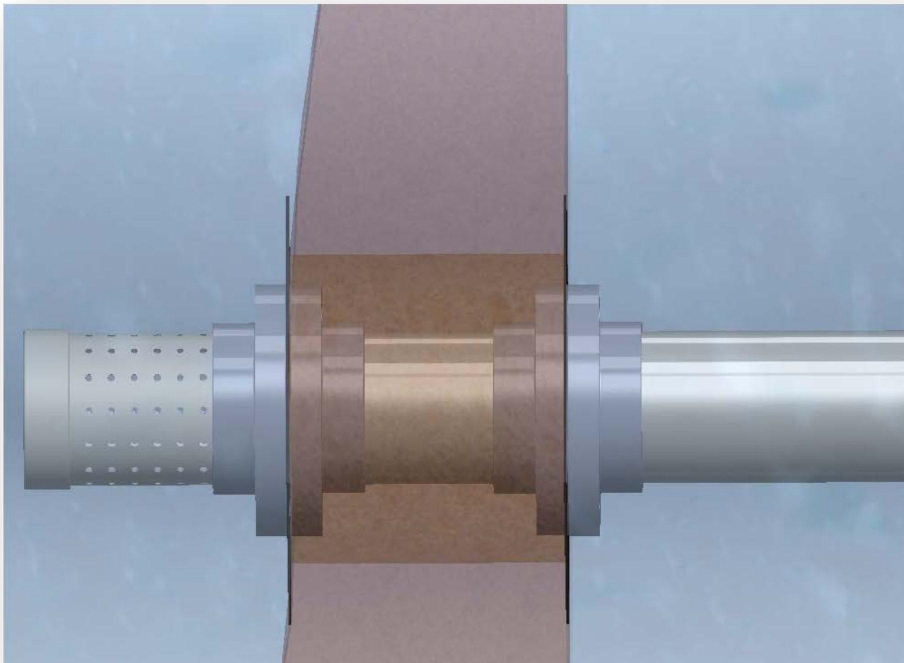


Figure C9: Profile View of Inlet Assembly
Model by Grace Neuburg

Construction on the face of the waterfall can be completed by propelling from the tree located next to the waterfall.

Connect PVC Pipe

The PVC pipe will be connected using PVC Primer and PVC Cement. Two valves will be placed in line with the 12 inch (30.5 centimeter) diameter pipes. One will be located near the turbine and the other will be further up the penstock near the inlet. The valve closest to the turbine will be a shut off valve needed for turbine maintenance, while the other will act as a pressure release valve. When the flow needs to be stopped, open the second valve to allow water to free flow out of the penstock to avoid pressure build up; followed by the shut off valve being closed.

Erect/Anchor PVC Pipe

The PVC pipe will be erected by repelling off the large tree next to Channel A, shown in **Figure C5**, of the waterfall. The penstock will be anchored to the rock with #3 rebar and a two part epoxy. A drill will be necessary to drill holes into the rock in order to dowel in rebar to hold the PVC pipe. This will be used as light support. The approximate recommended alignment is shown previously in **Image C3**.

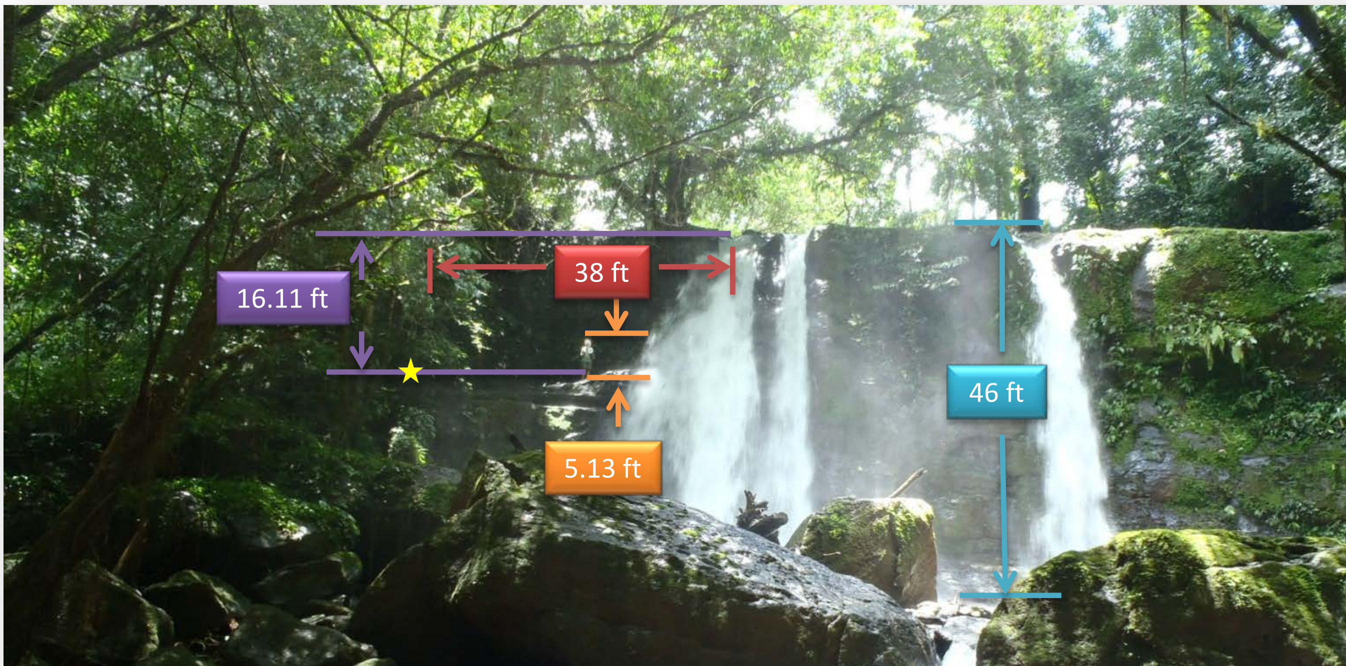


Image C10: Scale Diagram of Waterfall
Photo taken by Tristram Hokenson

The dimensions to the penstock were calculated using a scale diagram, shown in **Image C10**.

Remove Diversion Falsework

The diversion falsework may be removed once the system is securely in place. The shut off valve will need to be closed and the pressure release valve open.

Power Distribution

The transmission and distribution system are estimated to take 56 days to complete. The power distribution system has been determined the critical task.

Scout Trees for Post Use

Local people will scout and mark trees along the route, shown in the Transmission Line Map, located in **Figure 4** of the report, is an estimation of where the transmission lines can be located.

Prune Trees

The marked trees needed to be pruned up to an estimated height of 30 feet (9.1 meters) for the placement of the power lines.

Hang Lines

Lines will be hung by solid copper wire. The copper wire will be connected to the poles with fencing staples. These can be erected using hammers. This will offer a weak connection in the scenario that an object, a tree, would fall on to the transmission lines. This design allows the connection to break and to prevent the transmission lines themselves from breaking. This is shown in **Figure C11**.

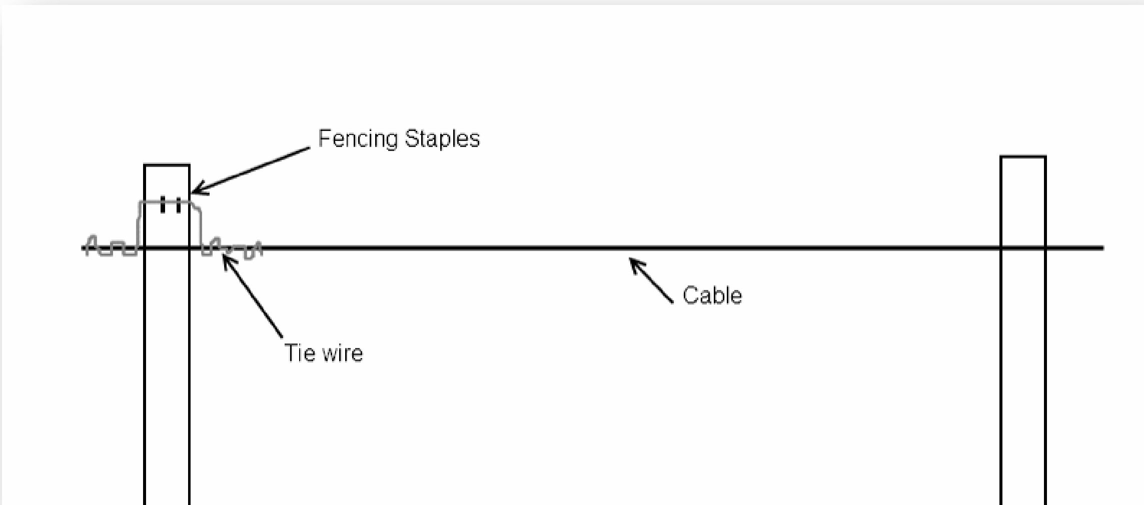


Figure C11: Transmission Line Connection [1]

Connect Generator Controller

This controller will determine where the power is sent. It will feed the grid to meet demand and the excess power will be sent to the dump load to be expelled as heat. The dump load will be directly connected to the dump load terminals on the controller. The grid side terminal will be connected to the main breaker. The input terminals will be connected to the generator. Make sure both connections are positive to positive and negative to negative. **Figure C12** shows how to add the capacitance in parallel with the windings of the three phase motor. This capacitance is required to keep the magnetic field in the generator and to keep the generator producing electricity. **Figure C12** assumes that the motor is three phase, with 12 leads.

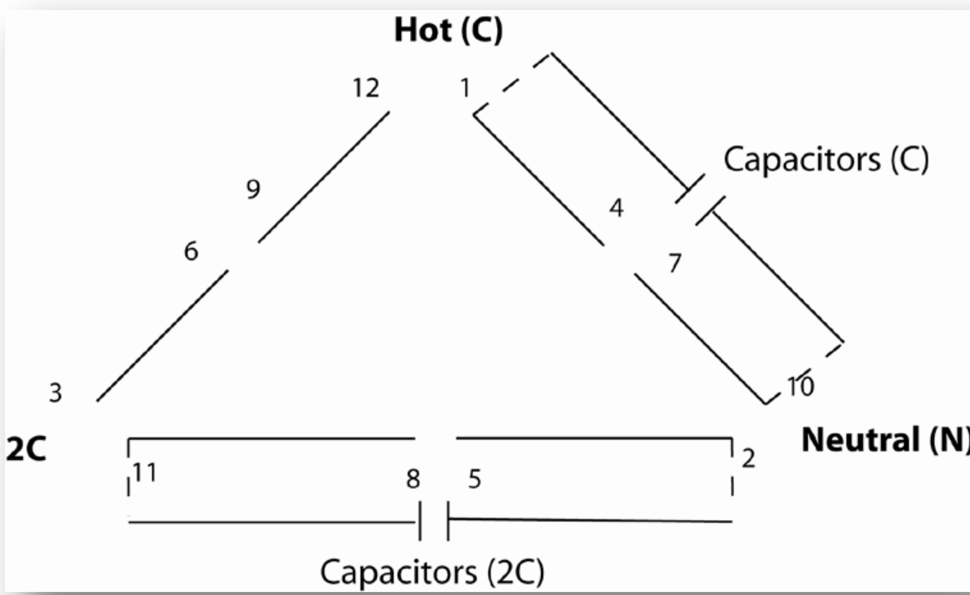


Figure C12: Capacitors [1]

Connect Dump Load

The dump load is connected to the generator controller and is used burn off excess power produced by the generator. In this case the dump load will be five dual burner electric stove tops that will be connected to the controller, bypassing built in controls. The current cost estimate also recommends the use of a dump load resistor. The generator controller will control how much power is sent to the dump load and should not be restricted by the controls that came with the stove top. Technical supervision is recommended for this task.

Connect Ground Fault Circuit Interrupter (GFCI)

The GFCI is designed to detect very small changes in the difference in the current that is flowing out to the grid and returning from the grid. This will be connected to the main transformer and the transmission lines. The connection is recommended to be completed by a technical expert. It must be placed after the transformer in order to detect ground faults. Make sure both connections are positive to positive and negative to negative.

Connect Main Transformer

The transmission and distribution voltage of the system will be 600 volts (V). The main transformer will be used to step up the voltage from the 200V that the generator outputs to 600V. It will be connected to the GFCI and to the main breaker of the system. The high side will be for the GFCI and the low side will be connected to the main breaker. Connections are positive to positive and negative to negative.

Household Connections & Transformer

Connect positive terminal of the high side of the household transformer to one pole of the switch and the other pole of the switch to the positive transmission line. Connect the negative terminal of the high side of the transformer directly to the negative transmission line. The low side of the transformer will be connected to the houses. The positive terminal on the low side will go to the fuse holder. As per El Tigre Engineering's design, the wiring, as specified in **Figure C13**, from the fuse to the house will be completed by individual households.

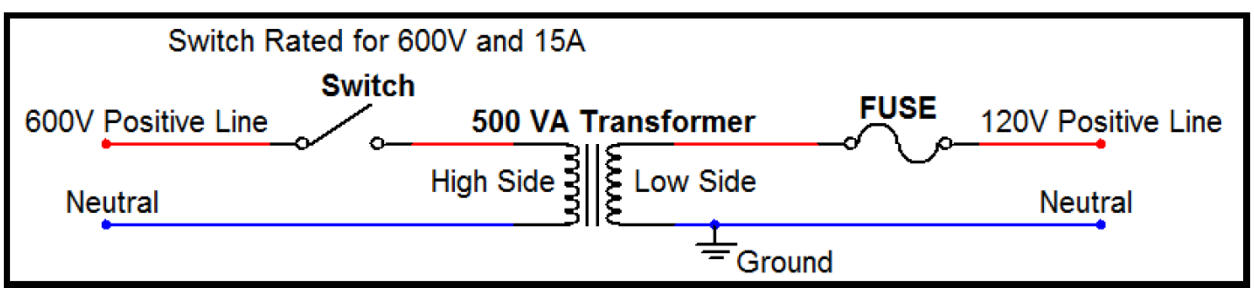


Figure C13: Household Connection Diagram
Diagram by Benjamin Coultes

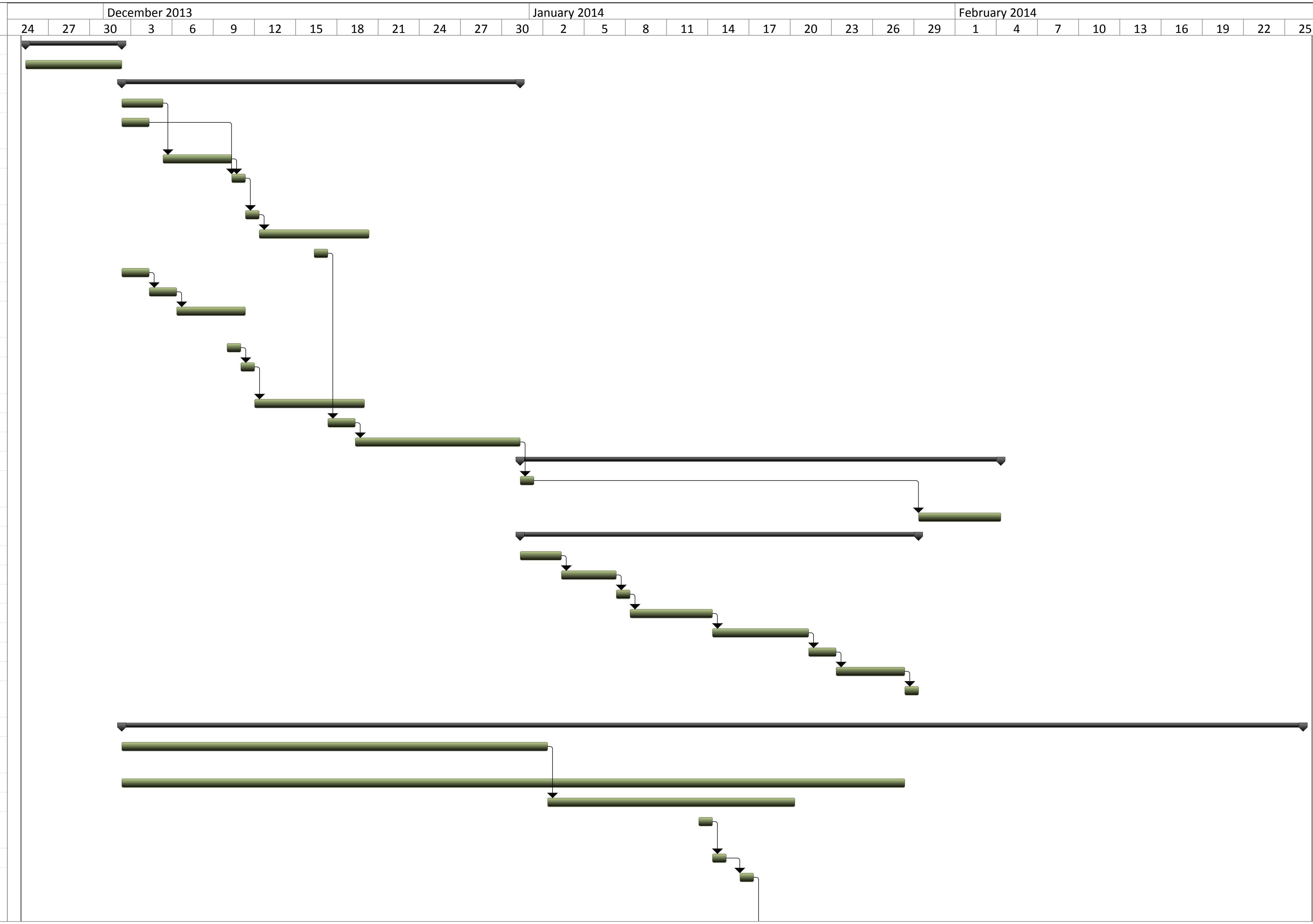
Connect Lines to GFCI, Transformer & Main Breaker

This connection will be between the GFCI, the main breaker for the system, and the main transformer. Connect the breaker to the positive line between the generator controller and the positive terminal on the low side of the main transformer. Connections are positive to positive and negative to negative.

Grounding Rod

The grounding method for this system is a grounding rod installed at the generator and at the electrical equipment box of each home. Connect the boxes to the grounding wire using copper wire. The grounding rod will be installed underground and flush with the earth's surface.

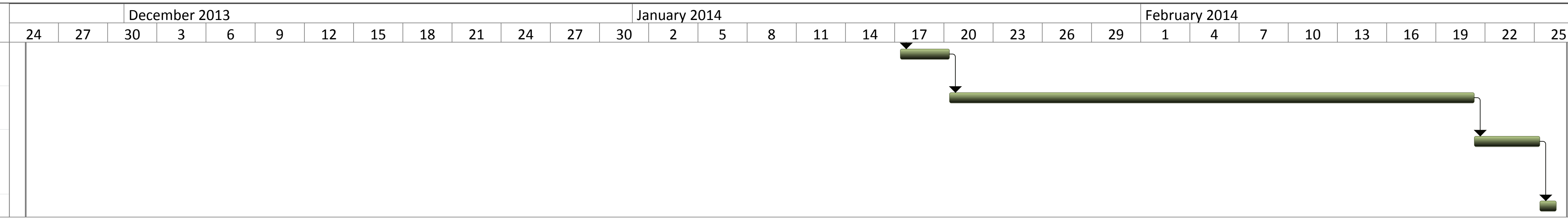
ID	Task Name	Duration
1	**Mobilization**	**5 days**
2	Mobilization	5 days
3	**Turbine Shelter**	**16 days**
4	Build Falsework	3 days
5	Set Grade and Level Slab	2 days
6	Slab Falsework	3 days
7	Concrete Reinforcement	1 day
8	Concrete Pour	1 day
9	Concrete Cure	6 days
10	Remove Slab Falsework	1 day
11	Cut Down Trees	2 days
12	Prune Trees	2 days
13	Construct Boards for Wall	3 days
14	Dig Post Holes	1 day
15	Erect Posts/Concrete Pour	1 day
16	Concrete Cure	6 days
17	Roof Structure	2 days
18	Set Roofing	3 days
19	**Mechanical Equipment**	**25 days**
20	Install Toshiba Turbine - Generator Unit	1 day
21	Adjust Runner Vanes	4 days
22	**Inlet/Penstock**	**21 days**
23	Diversion Falsework	3 days
24	Divert Flow	2 days
25	Remove Water	1 day
26	Chip Hole in Rock Face	4 days
27	Intake Assembly	5 days
28	Connect PVC Pipe	2 days
29	Erect/Anchor PVC Pipe	3 days
30	Remove Diversion False Work	1 day
31	**Power Distribution**	**57 days**
32	Scout Trees for Post Use	18 days
33	Prune Trees	36 days
34	Hang Lines	12 days
35	Connect Generator Controller	1 day
36	Connect Dump Load	1 day
37	Connect Ground Fault Circuit Interrupter (GFCI)	1 day



Project: Construction_Schedule_T
Date: Fri 12/9/11

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

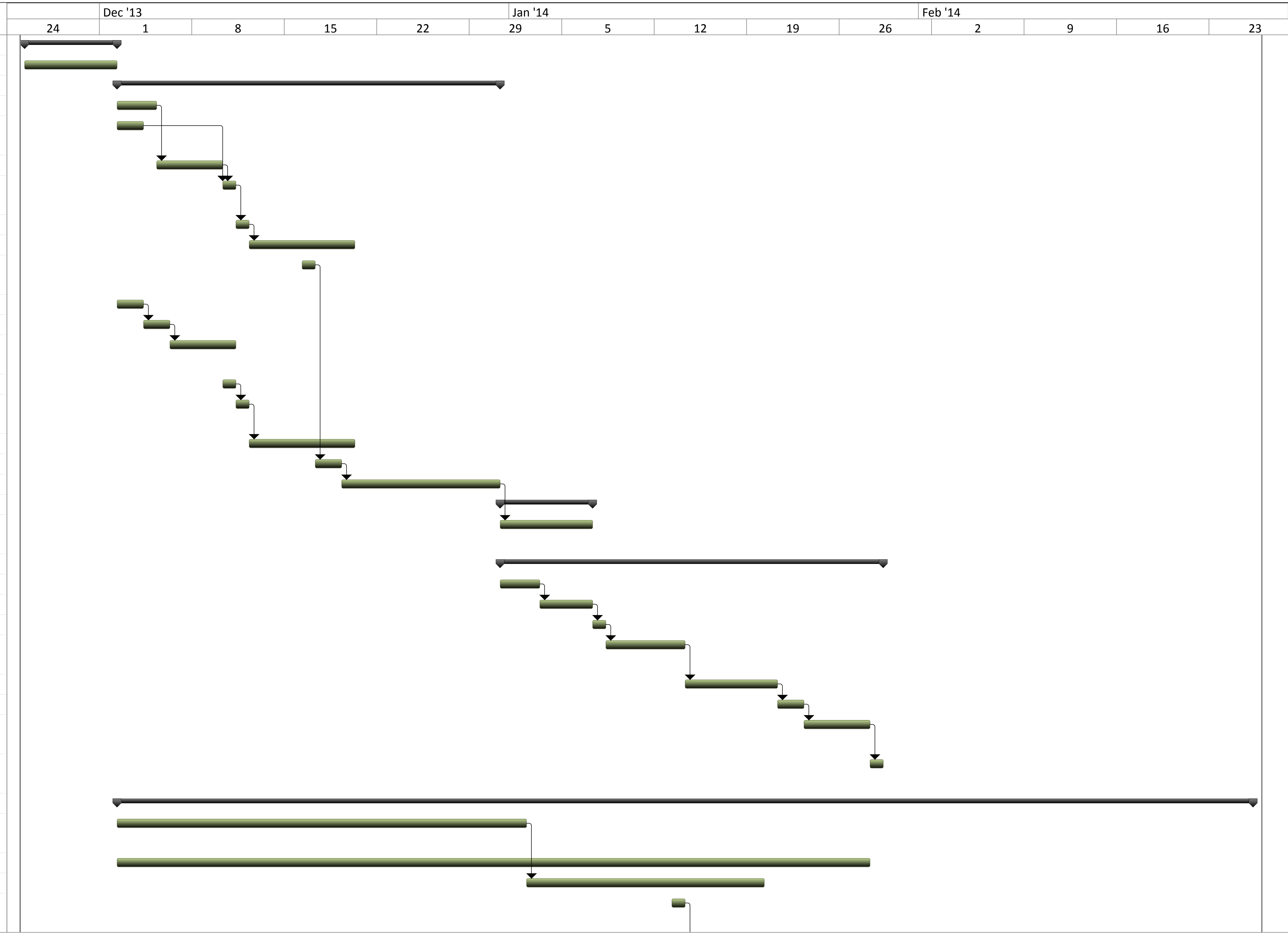
ID		Task Mode	Task Name	Duration
38			Connect Main Transformer	1 day
39			Household Connections and	24 days
40			Connect Lines to GFCI, Transformer & Main Breaker	2 days
41			Grounding Rod	1 day



Project: Construction_Schedule_T
Date: Fri 12/9/11

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

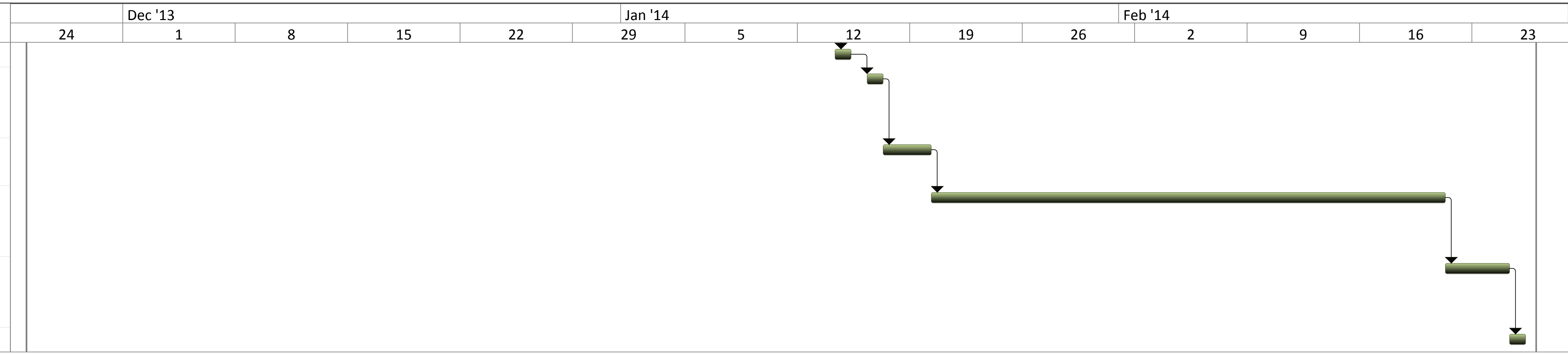
ID	Task Mode	Task Name	Duration
1		**Mobilization**	**5 days**
2		Mobilization	5 days
3		**Turbine Shelter**	**16 days**
4		Build Falsework	3 days
5		Set Grade and Level Slab	2 days
6		Slab Falsework	3 days
7		Concrete Reinforcement	1 day
8		Concrete Pour	1 day
9		Concrete Cure	6 days
10		Remove Slab Falsework	1 day
11		Cut Down Trees	2 days
12		Prune Trees	2 days
13		Construct Boards for Wall	3 days
14		Dig Post Holes	1 day
15		Erect Posts/Concrete Pour	1 day
16		Concrete Cure	6 days
17		Roof Structure	2 days
18		Set Roofing	3 days
19		**Mechanical Equipment**	**5 days**
20		Build Crossflow Turbine	5 days
21		**Inlet/Penstock**	**21 days**
22		Diversion Falsework	3 days
23		Divert Flow	2 days
24		Remove Water	1 day
25		Chip Hole in Rock Face	4 days
26		Intake Assembly	5 days
27		Connect PVC Pipe	2 days
28		Erect/Anchor PVC Pipe	3 days
29		Remove Diversion False Work	1 day
30		**Power Distribution**	**57 days**
31		Scout Trees for Post Use	18 days
32		Prune Trees	36 days
33		Hang Lines	12 days
34		Connect Generator Controller	1 day



Project: Construction_Schedule_C
Date: Thu 12/8/11

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

ID		Task Mode	Task Name	Duration
35			Connect Dump Load	1 day
36			Connect Ground Fault Circuit Interrupter (GFCI)	1 day
37			Connect Main Transformer	1 day
38			Household Connections and Transformer	24 days
39			Connect Lines to GFCI, Transformer, and Main Breaker	2 days
40			Grounding Rod	1 day



Project: Construction_Schedule_C
Date: Thu 12/8/11

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

Appendix C - Field Mixing Concrete

The concrete will consist of four materials: air, cement, aggregate, and water. Field mixing of concrete for this project will refer to the *Basics of Construction* section in the "Field Guide to Environmental Engineering for Development Workers" [7].

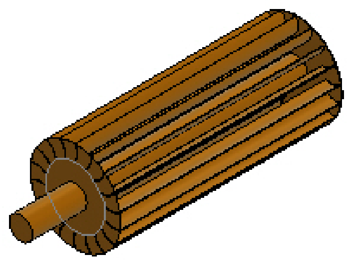
- Cement can be purchased locally, in San Felix, Panama, in 49.5 kilogram sacks.
  - The cement must be kept dry.
- Majority of the larger sized aggregates will be gathered from the river banks. Aggregates must be cleaned of organic matter and other materials by rinsing in water.
  - Coarse aggregates are particles larger than 0.187 inch (4.75 millimeter) and can be obtained from the river.
  - Fine aggregates are sand sized particles and can also be obtained by local collection. However, sands containing clay, silt, salt and organic matter should be avoided as these characteristics decrease concrete strength. These characteristics are evident in the locally collected sand. It is advised that sand is obtained by purchasing from a near-by source.
  - Aggregate diameters must be smaller than 1/3 the thickness of the slab.
    - This project allows for a maximum size of 1.67 inch diameter for aggregates, 1/3 of the 5 inch slab design.
- The water used for the concrete should be potable water. This community currently does not have an adequate source of potable water so in the instance that this has not improved before construction of this project, water from the river may be used but a decreased of concrete strength in expected.
  - A common water-to-cement (w/c) ratio is achieved by simply using the ball test as an indicator for the mix. Water should begin to be added to the mix until workability is achieved. Once water is added to the overall mix, a handful of concrete is formed into a ball and squeezed. If the ball does not stay intact then the mix has too high of a w/c ratio and more cement and aggregates must be added to compensate.
- Air is a naturally evident material in the mix and is variable with water content. Air contents are not practically calculated in field locations.

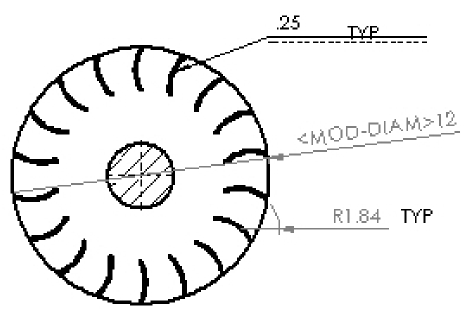
- The concrete mix design for this project is shown below [7].

Mix Ratio, by volume	Cement, 49.5 kg sack	Sand, gallon (m^3)	Coarse Aggregate, gallon (m^3)
1:2:4	1	18.5 (0.07)	37.0 (0.14)

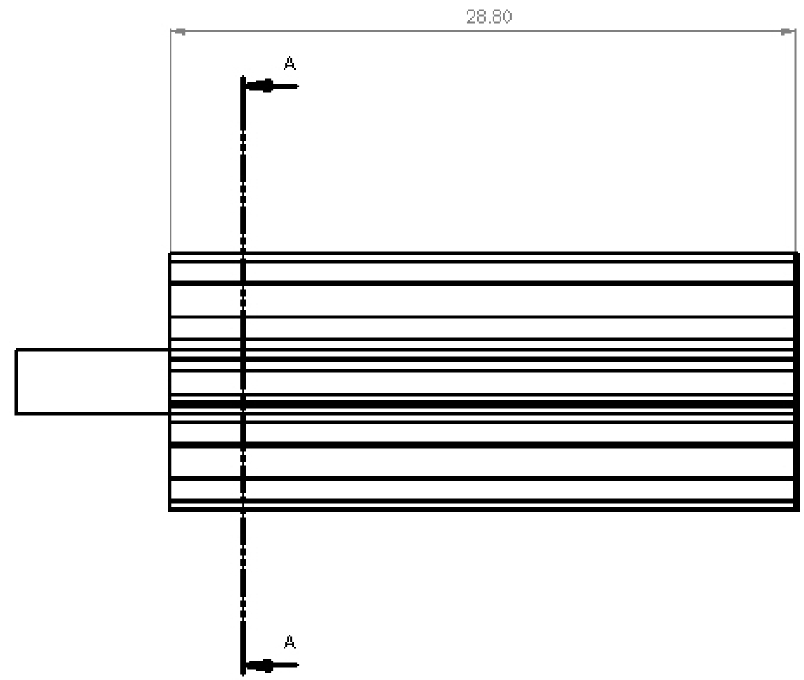
- The materials can be mixed in large buckets, barrels, or on the ground. Once the materials are mixed, the concrete can only be worked within 2 to 4 hours of adding water.
- The concrete can be cured with wet cement bags or wet leaves to secure moisture during the process.

Appendix D – Crossflow Turbine Details





SECTION A-A
SCALE 1 : 5



NOTES

1.) MATERIAL: CUT BLADES FROM 3.75"DIAMETER CARBON STEEL TUBING OR METRIC EQUIVALENT. SAME CAN BE USED FOR INNER SHAFT.

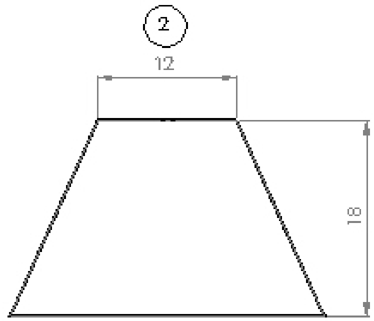
2.) BOTH SIDE PLATES .25" CARBON STEEL

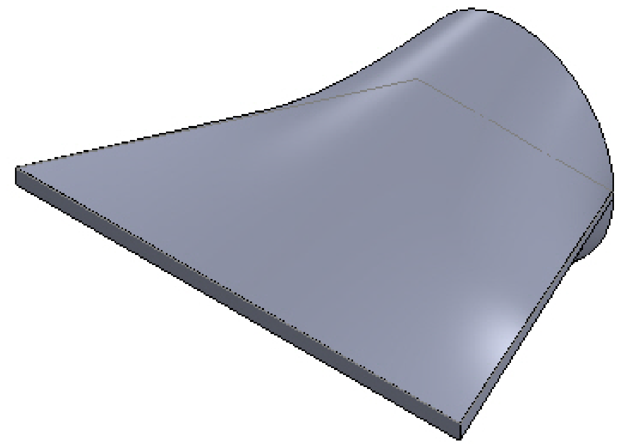
3.) PAINT ALL SURFACES AFTER WELDING

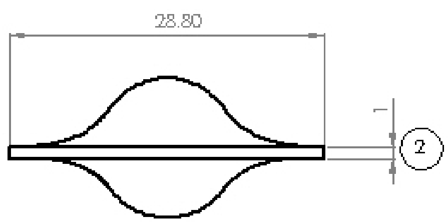
EL TIGRE ENGINEERING

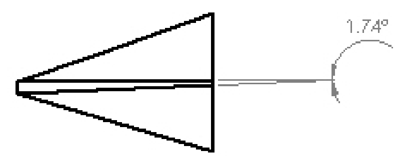
TURBINE ASSEMBLY

A3









NOTES

1.) MATERIAL: 1/8" GALVANIZED STEEL SHEETS

2.) CRITICAL DIMENSIONS. ALL OTHERS INCLUDING CURVATURE OF SHEET METAL CAN BE APPROXIMATE ACCORDING TO BENDING AND FORMING CAPABILITIES AVAILABLE

EL TIGRE ENGINEERING	
TURBINE ASSEMBLY	
NOZZLE	A3

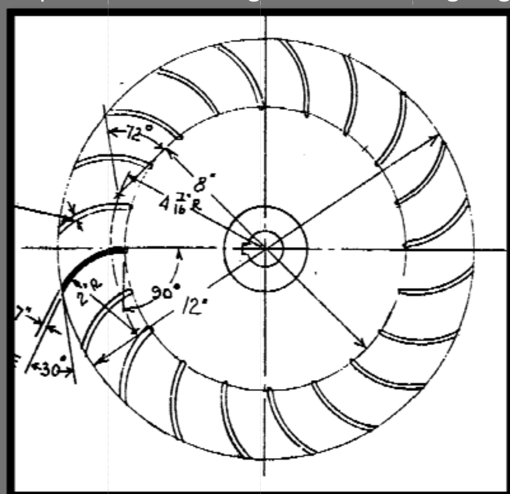
Appendix E - Crossflow Turbine Design Guide

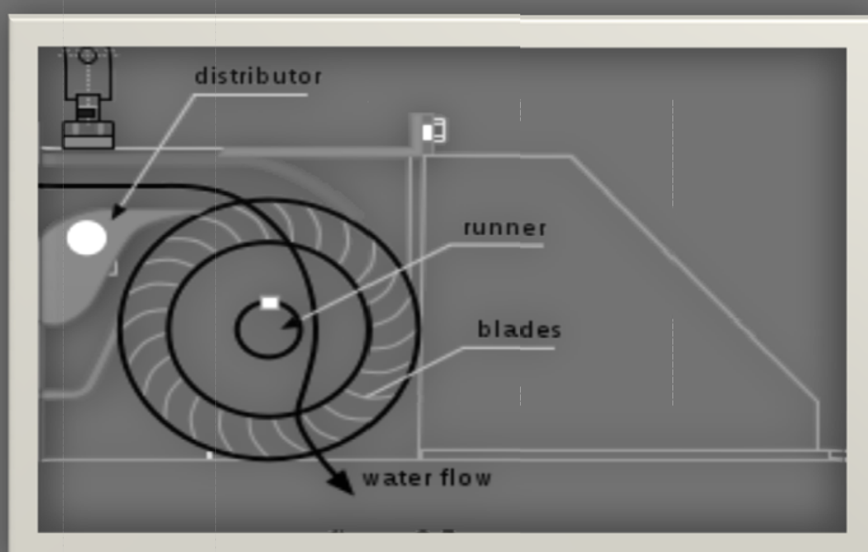
2010

Cross-Flow Water Turbine

A Design Manual

A quick and reliable guide to the designing of a cross-flow water turbine





Abhiroop Chattopadhyay

4/25/2010

THE CROSS-FLOW WATER TURBINE

-Also called the Banki-Mitchell-Ossberger Turbine

A Design Manual (Metric System)

The cross-flow water turbine is widely considered by many to be the most efficient and apt type of turbine for applications in micro-hydro and pico-hydro projects.

However, it should also be noted that designing this kind of a turbine is no child's play.

Nevertheless, in this article, I will show you exactly how the designing of the turbine is to take place. With a very basic knowledge of mathematics, it is possible to design and construct an efficient working water turbine.

Before, designing, just get an idea about how must hydraulic power is theoretically available at a particular site.

Use this equation to find power:

$$\boldsymbol{P = \rho g H \times Q}$$

Input g in m/s^2 (it is generally considered to be $9.8 m/s^2$), ρ is density of water in kg/m^3 (standard accepted value is $1000 kg/m^3$), H is the head in meters and Q is the volume flow rate in m^3/s. the power obtained will be in watts.

A. ASSESS THE SITE AND SITUATION:

The most essential thing to get right is the site. Visit the site and assess it for the head of water that is available. The head is the vertical distance the water will fall before impacting the turbine. Feel free to use any units of your choice, but before putting them in the formula, convert them to meters.

Calculate the flow of the river or stream. It is very essential that you get this very accurately. There are various ways of measuring the flow. Use any method that you find convenient and is compatible with your site. Again, use any units of your choice but ultimately convert them to cubic meter per second.

B. DETERMINIG THE LENGTH AND DIAMETER OF TURBINE:

Now the real designing part begins. After you obtain the values of head and flow, use this formula:

$$\boldsymbol{LD = 2.627 \frac{Q}{\sqrt{H}}}$$

You will now obtain the product of L and Das a constant value. Now, give some values to D and find the corresponding values of L. Tabulate these values in a table. Choose any value of L that you feel is convenient to use and does not make the construction too hard or cumbersome. All parameters like blade spacing, jet thickness, maximum efficiency speed and diameter will change as accordingly as you change your choice of L. Remember, input values in meters only, or else you will not get correct results. You might be thinking that this is too vague to be accurate or efficient, but don't worry. The result you see above is an outcome of very tedious and accurate calculations. You can check out the demonstration which I have provided at the end of this manual.

C. N-THE MAXIMUM EFFICIENCY SPEED:

Calculate the value of N using this formula:

$$\boldsymbol{N = \frac{39.81\sqrt{H}}{D}}$$

N obtained here will be in RPM (Revolutions per Minute).Remember, the turbine will be most efficient when running at this speed. However, The Cross-Flow turbine can work very efficiently even under a good deal of variation in head and flow.

D. DETERMING THE BLADE SPACING:

Blade spacing is the distance between the tips of two adjacent blades on the outer periphery. This quantity is usually denoted by t. Evaluate t by

$$\boldsymbol{t = \frac{kD}{\sin\beta}}$$

Here k is a constant whose value is 0.087 and β is 30°, so $\sin\beta$ will be 0.5. Thus simplifying, we obtain,

$$\boldsymbol{t = 0.174D}$$

When you get down to sketching this after all these calculations, you will find that the number of blades invariably is 18. This is actually the optimum number of blades although higher as well as lower numbers of blades have been used. However, my advice to you would be to just follow these steps and everything will take care of itself. The calculations would otherwise become quite tedious.

E. AREA AND THICKNESS OF JET:

The area of jet can easily be determined. This also enables us to calculate the optimum thickness of the jet, which is the same as nozzle width s. Use this formula,

$$\boldsymbol{s = 0.22\frac{Q}{L\sqrt{H}}}$$

F. RADIAL RIM WIDTH:

The radial rim width is the difference between the outer radius and inner radius. This zone starts from the outer radius and ends at the inner one. This space contains the blades. This is denoted by a.

$$\boldsymbol{a = 0.17D}$$

The outer radius is denoted by r_1, which is equal to D/2. Also, the inner radius r_2 is given by

$$\boldsymbol{r_2 = 0.66r_1 = 0.33D}$$

G. RADIUS OF BLADE CURVATURES:

All the blades are actually arcs of a circle. You need not worry yourself with how the radius is obtained and the theory behind it; I have done that for you. To determine the radius of curvature of the blades ρ,

$$\boldsymbol{\rho = 0.163D}$$

H. CONSTRUCT:

Now is the part that requires some concentration- how to construct, on paper, the structure of the water turbine. Take a graph paper. Using a graph paper for construction has many advantages. It is much easier to understand the scale of the project on graph paper and much less chances of making any error.

I. Select a point O as the center of the circle. Using a compass, draw a circle about this point with a diameter D. Choose any point on the circumference and name it A.

II. Draw an inner circle within the outer circle about the same point O with a radius r_2.

III. Draw a radius extending from O to A. From A, draw a tangent AB to the circle. Using a compass would be better than using a set square or protractor.

IV. At A, construct a 30° angle BAE.

V. Now construct a perpendicular AD on the line AE at A.

VI. Calculate the value of the radius of curvature ρ from the formula in section G. After you have obtained this value, measure out this distance on the line AD and cut an arc at C. AC so formed is the radius of curvature and C is the center of the circle of which the blade is an arc.

VII. Now, with the center at C and radius ρ , draw an arc starting from A and meeting the inner circle at S. That's it! The arc AS so formed is your first blade.

VIII. Now with your center at O and radius OC, draw another circle. You will notice that this circle is slightly greater than the inner circle.

IX. Calculate the value of t, the blade spacing, from the formula in section D. Measure out this value on the compass. Taking this value, start from A and cut an arc on the outer circumference (marked as 1). Proceeding in the same manner, cut out arcs along the whole length of the circumference- 2, 3, 4, 5…..

X. Taking ρ as radius, Position the compass on these arcs and intersect the intermediate circle at points a, b, c, d, e….. . All these intersection points will be the centers of the circles whose arcs will give us the blades.

XI. Now position your compass on these intersections and taking the radiusρ, draw arcs from the outer circle to the inner circle (the inner-most circle; the circle whose radius is r_2). The arcs so formed are thickened in the illustration.

XII. Your turbine design is now complete.

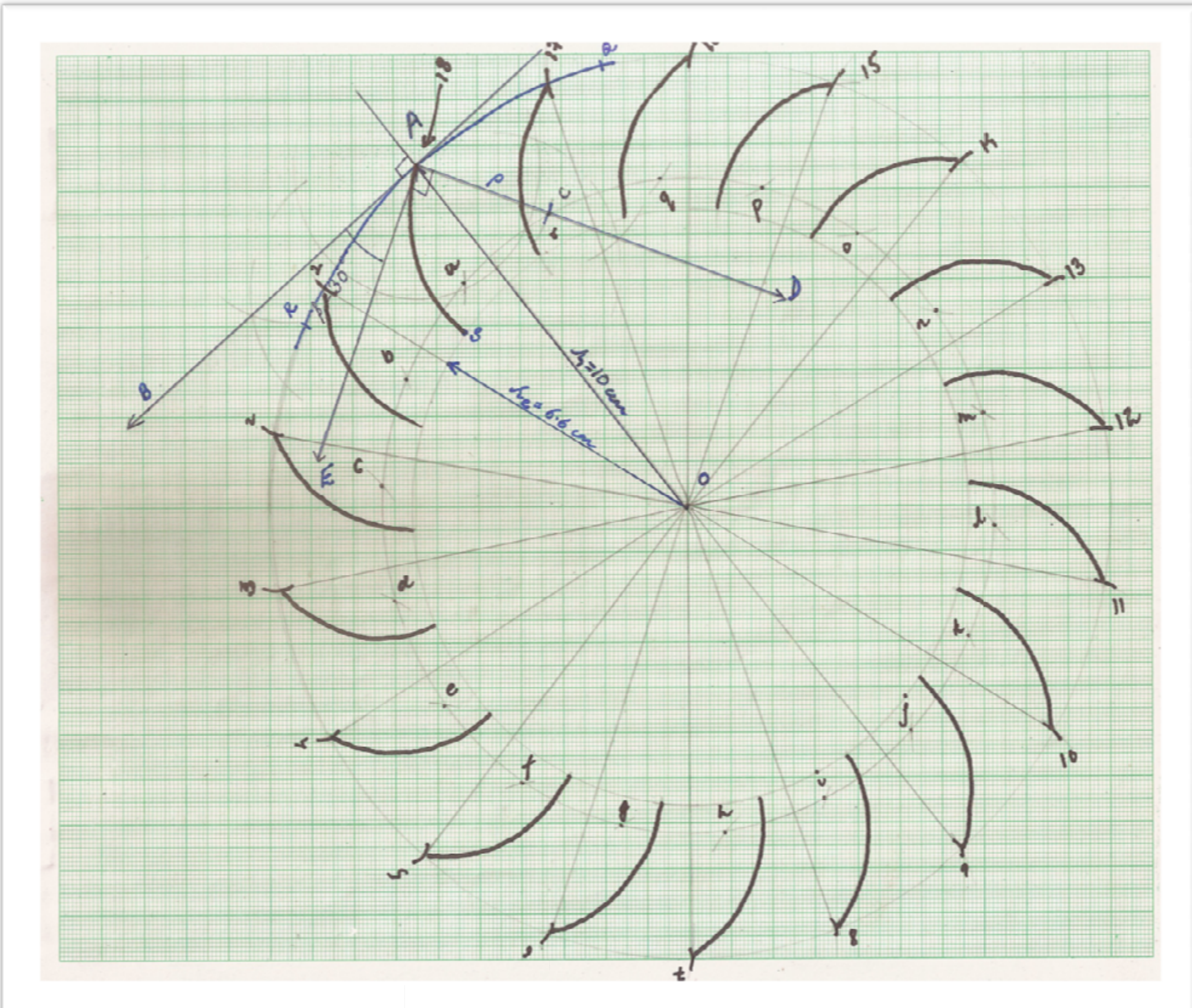
SOME OTHER DESIGN PARAMETERS:

Some design parameters have been derived after intense theoretical study and are now the standard accepted values. The most notable among these is the angle of attack of the nozzleα. First of all, a point on the turbine is selected where the jet is to be admitted. A tangent to this point is drawn and the jet is angled at an angle of 16°. α is universally accepted as 16 degrees.

$$\boldsymbol{\alpha = 16°}$$

On the next page you will find a sample design. This will give you an idea on how to proceed with the drawing.

The diameter is taken to be 20cm. The corresponding parameters are all calculated and tabulated for your convenience.



PARAMETER	VALUE (in meters)*	VALUE (In centimeters)*
Diameter - D	0.20	20
Blade Spacing - t	0.052	5.2
Rim Width – a	0.034	3.4
Inner Radius r_2	0.066	6.6
Radius of Curvature -	0.033	3.3

ILLUSTRATIVE EXAMPLE:

Let us now use all these equations and derive all the dimensions using the given data. This will help us better understand the parameters required and how they are to be found out.

Take this case: - we are given a site with these values-

$$Q = 0.1 m^3/s$$
$$H = 3.5\ m$$

First of all, we calculate the theoretical hydraulic power available:

$$P = 1000 \times 9.8 \times 3.5 \times 0.1$$
$$= 3430\ W$$
$$= 3.43 kW$$

Using the formula in section B, we find the product of D and L.

$$LD = 2.627 \times \frac{0.1}{\sqrt{3.5}}$$
$$LD = 0.14$$

We give D some values and tabulate the corresponding values of L. Input values in meters.

D (meters)	L (meters)
0.50	0.28
0.45	0.31
0.40	0.35
0.35	0.40
0.30	0.47
0.25	0.56

We select D=0.30 meters and L=0.47 meters.

$$D = 0.30\ m$$
$$L = 0.47\ m$$

Now we find the maximum efficiency RPM.

$$N = \frac{39.81\sqrt{3.5}}{0.30}$$
$$N = 248.25\ RPM$$
$$\therefore N \approx 249\ RPM$$

The blade spacing t is

$$t = 0.174 \times 0.30$$
$$t = 0.052\ m$$
$$\therefore t = 5.2\ cm$$

The nozzle width s is

$$s = 0.22 \frac{0.1}{0.47\sqrt{3.5}}$$
$$s = 00.025\ m$$
$$\therefore s = 2.5\ cm$$

The radial rim width is

$$a = 0.17 \times 0.30$$
$$a = 0.051\ m$$
$$\therefore a = 5.1\ cm$$

The inner radius is therefore

$$r_2 = 0.33 \times 0.30$$
$$r_2 = 0.099 m$$
$$\therefore r_2 = 9.9\ cm$$
$$r_1 = 0.15\ m = 15\ cm$$

The radius of curvature ρ is

$$\rho = 0.163 \times 0.30$$
$$\rho = 0.049\ m$$
$$\therefore \rho = 4.9\ cm$$

Before beginning your drawings, just tabulate these values and keep them at hand to avoid any sort of confusion.

PARAMETER	VALUE (in meters)*	VALUE (In centimeters)*
Length - L	0.47	47
Diameter - D	0.30	30
RPM - N	249 RPM	249 RPM
Blade Spacing - t	0.052	5.2
Nozzle Width – s	0.025	2.5
Rim Width – a	0.051	5.1
Inner Radius r_2	0.099	9.9
Radius of Curvature - ρ	0.049	4.9

*All units as shown in the leading column header unless clearly stated otherwise.

Feel free to contact me if you have any doubts. I would be happy to clear them.
Abhiroop_chat@yahoo.co.

Appendix F – Operations and Maintenance Manual

Operations and Maintenance Manual

Various parts of the design are explained for operations and maintenance purposes.

Inlet

The inlet will need to be visually checked monthly to verify that the inlet is not covered with debris. It is also recommended to be cleaned once yearly by diverting the flow in accordance to the diversion procedure during construction. This can be found in **Appendix B**. At this time, the pool will be cleaned of debris and sediment build - up by removing the debris. Any debris on the inlet will need to be carefully removed by hand. Remove the cap to check the inside of the PVC pipe and confirm that no debris appears in the pipe. All flange screws need to be checked for tightness and that none are missing. The plate on both sides of the rock face will need to be visually inspected. Replace cap and screws as necessary. In the event that the inlet breaks, it will be necessary to replace it. This will be completed by diverting the water in the dry season, as mentioned in **Appendix B**.

Penstock

The penstock PVC pipeline will need to be inspected twice monthly and after flash floods. The upstream river area, and near the penstock, should be cleaned of any large obstructions or potential hazardous objects to guarantee the life of the pipe. The pipeline should be inspected visually at the bends, thrust block, and turbine connections for secure connections and leaks. If the pipe bursts, breaks or any damage occurs to the PVC, it is recommended that the pressure release valve be opened and the shut off valve be closed to prevent water from entering the turbine system. Then the section of pipe needs to be replaced. If the section of broken pipe is before the valves closest to the inlet, it is recommended that the PVC penstock will need to be removed and replaced during the dry season to divert the flow from Channel A to Channel C, as mentioned in **Appendix B**. This will stop the flow in the penstock and allow for replacement.

Once yearly the PVC should be painted with the water - latex based paint to protect the PVC pipe from degradation of UV rays. If the PVC pipe is shaded by the surrounding trees, the UV protection paint will not be required.

Turbine Shelter

The turbine shelter must be visually inspected twice monthly. It should be checked for leaks and degradation. Verify that no water is leaking on to the control unit and turbine. Trees in the area will need to be monitored to ensure that none will fall on top of the shelter.

The life of the turbine is shortened by exposure to outdoor elements such as rain and sun. To maximize the lifespan, the turbine shelter roof needs to be kept intact. Sunlight can weaken the drive belt, so the system should always be in the shade. If the roof becomes damaged, it should be repaired immediately. The roof may be repaired with wood or thatching.

Turbine - Generator

Once a year the belt needs to be inspected, oiled, and replaced if worn. This will require the electrical system to be shut off, the penstock valve to be closed, and the pressure release valve to be open. Once all systems are completely shut down and the turbine and generator shafts have completely stopped moving, the belt guard should be removed for belt inspection. If the belt is cracked or worn, it must be replaced with a belt of the same size. If it appears to be in good working order it must be oiled with an available belt oil and then system put back together. It is important that the turbine is not put back into operation until the guard has been replaced since an exposed belt is a major safety hazard.

Generator bearings should be checked every year. Since they are self-lubricating bearings, the most important check is to listen for noise in the spinning of the generator shaft that could be caused by debris and contaminants in the inner race. The noise emerging from debris will sound like scrapping or clanging. If feasible, the community should replace the bearings every three years, although if there is no shaft noise it is acceptable to leave the bearing as it is for an additional year. The turbine bearings and seals can be inspected at the same time, but they have a five year life expectancy.

Since the system is a curious and new technology for the Ngöbe it needs to be clearly communicated that moving parts are dangerous and not meant to be tampered with.

Electrical Scheduled Maintenance and Safety Considerations

First, shut down the system. All generator and control connections should be checked for connectivity and corrosion each month. If electrical maintenance is required, shut down the system and reconnect it. If corrosion is present, disconnect the corroded connection and thoroughly clean all wires and terminals. Spray all wires and terminals with anticorrosive spray. Reconnect all wires and terminals, followed by turning the system back on.

An inspection of all of the connections along the transmission and distribution system should be performed once a year. Check that no bare cable is exposed. The cable connection, clearance above the ground, along with the particular tree's stability should be checked at the same time. If bare cable is exposed at a connection, turn off the system, remove all of the old electrical tape and re-tape the entire connection. Once finished, the system can be turned back on.

If an individual house has no electricity, first check the switch and the fuse. If those are not the problem, then refer to **Appendix G**. If the generator or transmission system becomes nonfunctional, review the preventative maintenance document attached in **Appendix G**.

Appendix G - Power Distribution Preventative Maintenance

SECTION 7

PREVENTATIVE MAINTENANCE

OVERVIEW:

A well installed electrical system is relatively trouble free. But troubles do arise. A sound preventative maintenance program will reduce the amount of failure. This section covers the basic elements of a preventative maintenance program. It also covers the elements of trouble shooting the problems that do occur.

As the PCVs will stay only two years, the local workers must be trained to perform the maintenance and trouble shooting operations. This section of instruction also describes the preparation of operation manuals to aid the PCVs in this instruction.

The activities of this section stress the learning of trouble shooting techniques. The PCVs cannot effectively teach the local workers if they do not have the skills themselves.

SECTION 7 PROJECT MAINTENANCE

OBJECTIVE: Train local workers to recognize, locate and correct faults, and perform necessary preventative maintenance.

TASKS:

1. Establish rules/procedures for locating and correcting faults in the distribution system.

2. Prepare an operation manual for instructing workers in these procedures.

3. Prepare a schedule of preventative maintenance procedures necessary to insure an efficient system. In the schedule, identify: procedure, frequency, tools and/or materials required, steps to follow, precautions to be taken.

4. Identify workers to be responsible for various maintenance functions.

5 Train workers to carry out their assigned tasks properly.

6. Establish a facility to house maintenance tools and replacement parts.

FUNCTIONAL SKILLS:

1. Recognize when trouble exists.

2. Identify the usual trouble areas for particular faults.

3. Operate a test lamp.

4. Interpret system and house diagrams.

5. Demonstrate proper techniques for installation of house wiring and service entrances, grounding, repairing poles, stringing, splicing, securing and sagging lines, and replacing fuses.

6. Recognize safety hazards and possible fault causes.

7. Simplify procedures to a level compatible with local language and worker education levels.

8. Design and construct work benches, tool boards, and stock bins out of cheap, local materials.

9. Demonstrate the proper uses, handling, and care of tools needed to effectively maintain the distribution system.

PROJECT MAINTENANCE (cont.)

TERMINAL PERFORMANCE TESTS:

1. Given an electrical system with a fault, locate and correct the fault. Repeat for various faults.

2. Given an existing electrical system, and manuals for the equipment being used, perform routine maintenance. Identify and correct any hazards that exist.

3. Prepare an electrical system trouble-shooting and maintenance manual for use by locally trained people.

PLANNING REQUIREMENTS

PROJECT MAINTENANCE

TROUBLE SHOOTING

Things can go wrong with an electrical system just as they can with an automobile. Therefore, to keep the electrical system operating after the installation is completed, you must be able to trouble shoot. Trouble shooting has three basic parts. These are:

1. Recognize the existance of trouble.
2. Determine the type and location of the trouble.
3. Correct the trouble.

PRECAUTIONS

Always observe the safety rules. Study and memorize the nine safety rules in Section 2 before you start to trouble shoot any electrical difficulty. Also carry with you a sketch of the system with the voltages and currents in each line clearly indicated. You should always know, not guess, how much voltage and curre t is flowing, or should be flowing in a wire before you approach it. Get nto the habit of saying to yourself, "This wire should have ____ volts running in it."

SYMPTOMS OF ELECTRICAL TROUBLE

To recognize the existance of trouble in an electrical system, you must be able to recognize the symptoms of trouble. The following are the most common types of trouble in an electrical system.

NO VOLTAGE

If the circuit is dead and no current flows there is no voltage. This is usually caused by a blown fuse, loose connection or broken wire. It might also be a failure of the generator.

FUSES KEEP BLOWING

This may be caused by an overload, that is, too many appliances are connected to the circuit, thus drawing too much current. It may be caused by a short circuit, which is a power wire touching a ground or two power wires in contact.

LIGHTS GROW DIM

When the lights grow dim and motors will not start, it usually means that the voltage is lower than it should be. A variety of troubles can cause this problem. There may be a loose connection or an arcing switch. The wiring may be undersized or too long, causing too much voltage drop.

LIGHTS BURN BRIGHTLY, BUT BURN OUT

This usually means that the voltage is too high. Either a generator is not regulated properly or a transformer is improperly connected.

LIGHTS FLICKER, MOTORS RUN UNEVENLY

This may happen when a motor is started. If so it is because the motor draws five times the current while starting than it does while running. While it is starting the voltage drop is five times as great, thus causing the flicker. If the flickering continues after the motor has started it may be that the motor is improperly grounded. Other causes might be loose connections or too small a transformer.

CONNECTIONS GET HOT

This usually means that the connection is loose and thus creating a high resistance. All electrical connections must be very tight and solid.

SHOCKS WHEN TOUCHING EQUIPMENT

This symptom indicates that the appliance or motor has not been properly grounded.

MOTORS RUN IN REVERSE OR WILL NOT START

This occurs in three phase circuits and means that one or more phases are not connected (blown fuse, loose connection, broken wire, etc.) and the motor is said to be "single phasing." Or, this symptom can mean that the connections to the motor have been reversed.

LOCATION AND TYPE OF FAULT

After realizing that the system is not operating properly you still need to determine the type of fault and where this fault is located. These two tasks are accomplished at the same time. The symptom observed gives clues to the type of trouble, but in most cases different faults could produce the same symptom. For example: what is the cause of no voltage? Is a fuse blown, is there a broken wire, is there an open connection, is there a bad switch, transformer, or other piece of equipment, or is there a generator failure? All of these faults could produce the symptom of no voltage. As you locate the fault you are simultaneously finding out what type of fault is present.

A systematic procedure must be used to find the location of the trouble. The design of an electrical system makes this fairly easy. An electrical system is like a tree. From any leaf there is only one stem, one branch, one limb, and one trunk that lead from that leaf to the roots where the energy is received from the soil. Similarly, in an electrical system there is only one branch circuit, one service entrance, one set of secondary lines, one set of distribution lines, and one set of transmission lines that lead from the load to the generator. To locate the fault start from the load that has the symptom and proceed toward the power source. At each convenient point along the system you will need to test to see if the fault exists at that point as well as at the points already checked behind it. When you find a point where the fault does not exist then work back towards the load testing each point until you find the location of the fault.

TEST EQUIPMENT

To locate the fault in a system you must test the system for the fault at the points successively closer to the power source. There are three pieces of equipment for this testing. They are:

1. Test lamp
2. Continuity tester
3. Meters

TEST LAMPS

There are several types of test lamps that can be used for testing the condition of various electrical circuits. Neon lamps are used in some test lamps and these will glow at any voltage from about 50 volts and up. Test lamps can be homemade by wiring in series 2 or more lamp sockets and inserting in each a 110 volt lamp. If 5 or 6 lamps are used, the tester can be used on circuits containing as high as 600 V.

Voltage Test

A test lamp can be used to determine if there is a voltage between two wires. If there is the lamps will light. The lower the voltage, the dimmer the lamps will be. If two lamps (in series) are placed across 110 volt lines the lamps will each be at half brightness. The same lamps placed across 220 volt lines will each be at full brightness. Similarly test lamps with 4 lamps or 5 lamps in series can be used to determine when higher voltages are present.

Determine Grounded Or Ungrounded Lines

After determining that voltage is present, it is useful to know if one of the lines is grounded. Place the test lamp(s) across one of the lines and a known ground. In a properly installed system the boxes or the fuse panel is grounded, or the lamp can be placed across the line and a radiator or other ground. If the test lamp lights the line is ungrounded. If the lamp does not light, the line is either a grounded line or the ground being used to test is not really grounded.

Determine A Blown Fuse

Fig. 7.1 shows a part of a distribution system, including the layout of a house wiring system. Suppose an appliance connected to outlet 5-A would not operate. With the test lamp touch the ends of the test lamp to the plug contacts. If it lights there is power at the outlet and the fault must be in the appliance. If it does not light then there is no power at the outlet and perhaps the fuse is blown. Go to the fuse box and make the following check. With two lamps in series test across the top of fuses A and B. (Fig. 7.2)

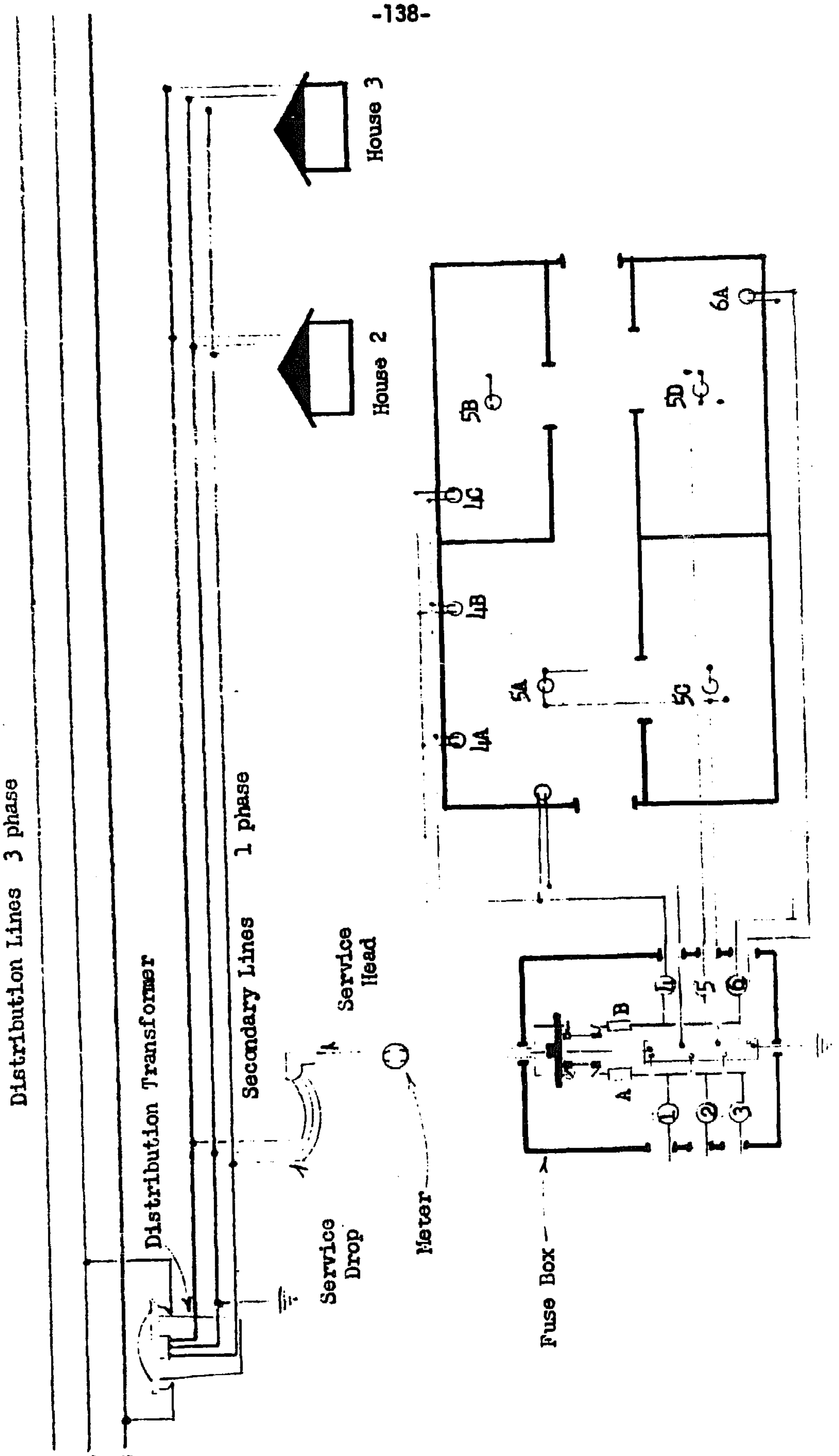

Distribution Lines 3 phase
A
B
C
Distribution Transformer
Secondary Lines
1 phase
Service Head
Service Drop
Meter
Fuse Box
House 2
House 3
House 1
4A
4B
4C
5A
5B
5C
5D
6A

Fig. 7.1

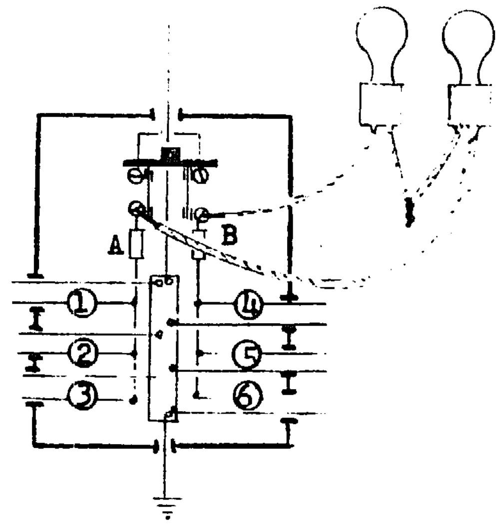


Fig. 7.2

If the lamps do not light then there is no power coming into the house. If they do light test to see if fuse A or fuse B is blown. This is done by placing the lamps across the top of one fuse and the bottom of the fuse to be tested. Fig. 7.3 shows the test for fuse B.

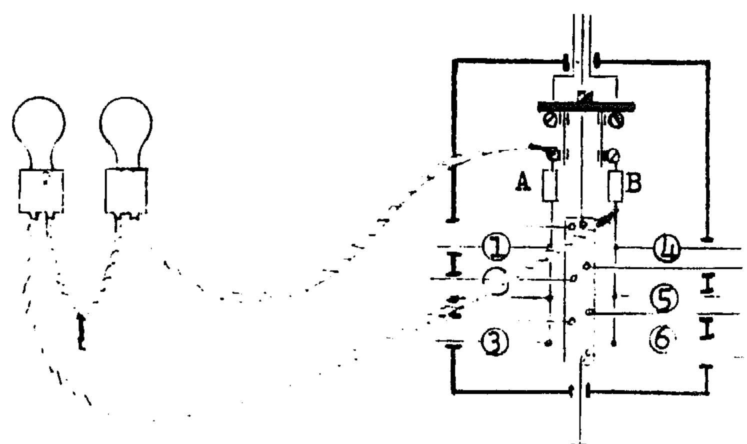


Fig. 7.3

If the lamps light, then the fuse is good. If the lamps do not light, then the fuse is bad and should be replaced. (See below the procedures to follow when changing a fuse).

If the main fuses are good, but there is no voltage at the outlet, test the circuit fuses. Fig. 7.4 shows the test for the fuse protecting circuit #5.

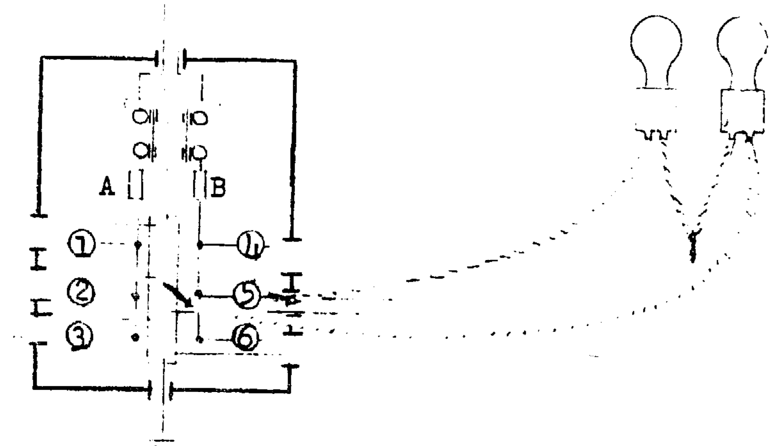


Fig. 7.4

If the lamps do not light then the fuse is blown. If they do light, they will only be at half brightness, since they are not across the full voltage (220V.) but only across one hot wire and the ground (110 V.). If they do light this indicates that the fuse is good and that there is a loose connection, a broken wire, and open switch or some other fault between the fuse panel and the outlet.

To check a fuse in a three phase circuit, shut down the motors and other loads in the circuit and then test to see that power is present at the fuses. If there is power on all three lines, then check the fuses as described for the main fuses of a house system. Place the test lamp across the top of one fuse and the bottom of another. If the lamp lights the fuse is good. Fig. 7.5 shows the test for fuse B.

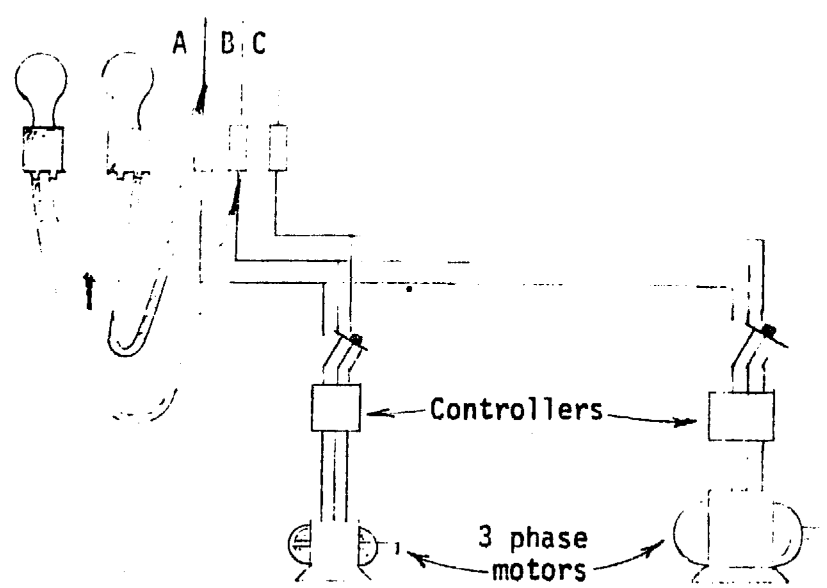


Fig. 7.5

CONTINUITY TESTER

Fig. 7.6 shows the construction of a continuity tester. It is made of a bell and batteries. When the test leads are touched together or when connected to a closed circuit the bell will ring. The continuity tester can be used for the following tests.

1. Short Circuits
2. Grounded Lines
3. Open Lines

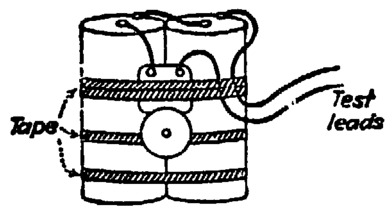


Fig. 7.6

Short Circuits

Before making any tests disconnect the power from the lines. A continuity tester must only be used on dead lines. If there is a length of cable that you suspect to be shorted between two of the conductors, followthe following steps. First, at the junction box at one end of the section of cable disconnect all the connections. Second, do the same at the other end of the section of cable. Third, connect the test leads of the tester across two wires at a time. It will ring when connected to the two shorted wires. Fig. 7.7 shows the connection of a continuity tester to find a shorted line.

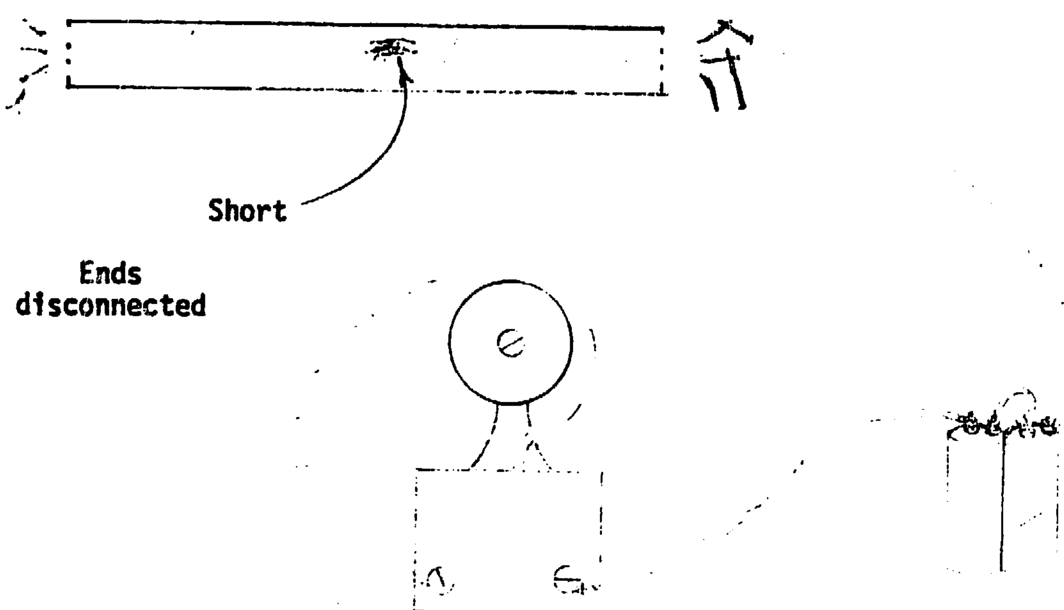


Fig. 7.7

Grounded Lines

The test for a grounded line is similar to the test for shorted lines. The only difference is the test is made between one of the open lines and a ground.

Open Lines

To test to see if a line is open, first disconnect all power from the part of the system that is being tested. Second, at one end of the cable being tested, connect all of the wires together in a firm (but temporary) splice. Third, at the other end of the section of cable connect the continuity tester across two lines at a time. It should ring each time as the circuit is closed at the other end. If it does not ring then one of the two lines is open.

METERS

A voltmeter is even better to use than a test lamp for it is able to indicate how much voltage is present rather than just that there is voltage. An ohmmeter can be used in place of a continuity tester but most ohmmeters use only a very small current and on longer lengths of line or when testing a poor ground they may not be reliable.

Whenever it is desired to know the amount of current or voltage present at a particular point in the system a meter should be used. It is always safest to disconnect the power when making the connections and then to reconnect the power to take the reading.

TROUBLE CORRECTION

When trouble shooting you are only half done when you have located the trouble. You now know why there is trouble and where this is. But you must ask, "Why?" If a fuse has blown, this is the reason that there is no power. But, you must ask, "Why did the fuse blow?" If a wire is broken you must ask, "What caused this wire to break?" Before correcting the obvious fault,these other faults must be corrected so that the same fuse won't blow again, or the wire break again because the cause was not corrected.

The specific corrections for various troubles are readily identifiable. If there is a bad connection, the connection should be opened and remade as if it were the first time it was being made. If there is a bad piece of equipment such as a switch or outlet plug, then this should be replaced. If there is a shorted cable this will need to be replaced or the circuit disconnected and not used. In most cases the skills needed to correct a trouble are the same skills needed for installation of that part of the system.

BEFORE ATTEMPTING TO WORK ON ANY PART OF THE SYSTEM, DISCONNECT THAT PART OF THE SYSTEM FROM THE POWER SOURCE.

FUSE REPLACEMENT

Suppose a fuse has blown. Before replacing it check all the outlets on that circuit to see what loads are connected. Total these loads and determine if the circuit is overloaded. If it is overloaded, disconnect some of the loads until the circuit is no longer overloaded. Now open the main switch and replace the fuse that blew with a fuse of the same rating. Close the main switch. If the problem was an overload, it has been corrected. If the fuse blows immediately,and the circuit is not overloaded there must be a short circuit either in one of the appliances or else in the wiring of the circuit. Before replacing the fuse again, disconnect all the appliances on the circuit and turn off all the lights. Now replace the fuse by again turning off the main switch, replacing the fuse and turning the main switch on. If the fuse again blows with all the loads disconnected, there is a short circuit in the wiring. Disconnect the main switch, and using the continuity tester, test to find where the short circuit is. If the fuse does not blow the short circutit is in one of the appliances. Connect the appliances one at a time. If the fuse does not blow when the appliance has been connected, that appliance is good. Disconnect it and try another appliance. Continue this process until the appliance that has the short circuit is connected and again blows the fuse. Disconnect this appliance and see that it is discarded or repaired. Now the other appliances may be reconnected and the fuse again replaced, always with a fuse of the same rating as the fuse that blew.

This is an example of how the cause was found for the blown fuse, and this cause corrected.

PREVENTATIVE MAINTENANCE

There is actually very little maintenance required by an electrical system. There are only two requirements of a maintenance program.

1. Periodically inspecting the system visually.
2. Performing the required preventative maintenance on all equipment and appliances as specified by the manufacturers.

PERIODIC VISUAL INSPECTION

It is wise to have the entire system inspected twice a year. Once in the fall and once in the spring.

Poles

Washout at ground line.

Rotting at ground line: Scrape away the earth from around the pole at the ground line to a depth of 2 or 3 inches. Use a short crowbar or hand spike to determine depth to which rot has penetrated.

Hollow rot: sound body of pole for hollow rot.

Splitting.

Effects of lightning.

Splitting or pulling of guys.

Twisting or raking.

Ground wire: See that this wire is rigidly supported and that it has not been cut or the cross section reduced to any considerable extent by linemen's spurs.

See that the connection between ground wire and ground rod has not been weakened by corrosion or mechanical injury.

Grass around base of pole: All grass, weeds, and any inflammable material should be kept cleared away from the base of the pole for a distance of 2 feet to reduce the fire hazard.

Crossarms

Rotting

Splitting and twisting (especially on double arms).

Loose, broken, or missing pins.

Loose or missing braces.

Insulators

Cracked: make close inspection for cracks.

Chipped or broken.

Unscrewed.

Wire

Broken wires.

Short circuits.

Twisted spans.

Loose connections.

See that the wire is clear of tree twigs, limbs, kite strings, hay wire, etc.

Delay necessary brush cutting until the autumn, except where there is danger of the brush fouling the lines in the interval.

Lightning Arresters (general)

Inspect pipe framework supports of arresters and paint with graphite if necessary.

Check gaps.

Check horns for loose bolts and position.

Inspect for loose ground connection.

Transformers

Inspect for Oil Leaks.

Ground

Make a mechanical inspection of all ground connections to transformer cases, transformer secondary wiring, and lightning arresters.

MAINTENANCE OF EQUIPMENT

All transformers, generators, motors, appliances, and any other equipment should be maintained according to the directions in the operation manuals provided by the manufacturers.

MANUAL OF STANDARD PROCEDURES

Once the electrification project is completed the only need fro personnel will be to occasionally add a service drop, a small extension to the system, or to perform the routine maintenance and trouble shooting. It will be most helpful for the local workers that are assisting with this project if you prepare a manual that lists the particular steps to follow for a specific job. This manual should list all the installation, maintenance, and trouble shooting thasks that these workers will need to perform. With each of these tasks should be:

1. the procedures to follow
2. the tools and/or materials required
3. the safety precautions that must be observed/

PROJECT MAINTENANCE

LESSON NO. 1

LESSON OBJECTIVE: Describe and discuss trouble shooting procedures.

TOPIC	INSTRUCTIONAL PROCEDURE	SUPPLEMENTAL MATERIALS / RELATED READING
Definition of Trouble Shooting	Define the basic parts of trouble shooting. 1. Recognizing trouble 2. Locating and determining type of trouble 3. Correcting trouble	
Precautions	Discuss the precautions that must be observed in the correction and location of troubles. Review the safety rules of Section 2.	
Symptoms	List the symptoms of trouble in an electrical system. Discuss the causes of these symptoms.	
Locating and Classifying Faults	Describe the systematic approach to trouble shooting that must be followed to locate and determine the type of fault. 1. Test the sections of system for the trouble 2. Isolate the section where the trouble is 3. Isolate the location of the trouble in the section	

PROJECT MAINTENANCE

LESSON NO. 2

LESSON OBJECTIVE: Demonstrate construction techniques and use of test equipment.

TOPIC	INSTRUCTIONAL PROCEDURE	SUPPLEMENTAL MATERIALS / RELATED READING
Test Lamps	Demonstrate how to make a test lamp. Demonstrate and discuss methods of connecting a test lamp to determine the presence of power, the identification of grounded and ungrounded lines and the presence of blown fuses. Have trainees practice using test lamps on various circuits.	Carr, Sec. 1, pp. 56-79.
Continuity Testers	Demonstrate how to make a simple continuity tester from a bell and batteries. Demonstrate and discuss methods of connecting a continuity tester to discover shorted lines, open lines and grounded lines. Have trainees practice using continuity testers on various circuits.	
Meters	Demonstrate and discuss methods of connecting meters to the electrical system when being used for test purposes. Have trainees practice connecting meters for use in trouble shooting various circuits.	

PROJECT MAINTENANCE

LESSON NO. 3

LESSON OBJECTIVE: Discuss the procedures to follow when correcting the trouble just located.

TOPIC	INSTRUCTIONAL PROCEDURE	SUPPLEMENTAL MATERIALS RELATED READING
Trouble Correction	Discuss the underlying reasons for system trouble, the causes of the discovered trouble. Discuss how to locate the causes of system malfunctions.	
Correction Techniques	Review the installation techniques that will be needed for trouble correction. Have trainees locate and correct typical faults that have been purposely introduced by the instructor in the sample system.	

PROJECT MAINTENANCE

LESSON NO. 4

LESSON OBJECTIVE: Describe and discuss maintenance procedures.

TOPIC	INSTRUCTIONAL PROCEDURE	SUPPLEMENTAL MATERIALS / RELATED READING
Definition of Preventive Maintenance	Define the parts of preventive maintenance.	
	List the faults to look for in a visual inspection of the system.	Kurtz, Sec. 21.
	Show examples of each of the faults.	
	Using the manufacturer's operation manual for the transformer, generator and motors install d during the training session, discuss and demonstrate the procedures for maintaining these pieces of equipment.	
System Operation Manual	Discuss the need for an operator's manual for the system just installed.	
	Have trainees prepare the outline of an operator's manual.	
	List precautions to follow in writing the manual for use by local people.	

Appendix H - Turbine Adjustments After Installation

For case A, the PAT flow rate is much lower than the design flow rate, and the power output will therefore be much lower than for the other cases. Case B results in the head and flow being close to the desired values, but there will be a drop in efficiency. In case C, the flow rate required is relatively large and there may not be enough water to keep the generator running during times of drought. When there is sufficient flow, the PAT output power will be greater than required, which means that a larger generator will be needed.

Of the four cases, the most suitable is D, because the head and flow are close to the desired head and flow, and there will be less drop in efficiency compared with case B. This is due to the shape of the efficiency curve in turbine mode (see Fig. 20). The efficiency of a PAT at 80% of bep flow will normally be lower than at 120% of bep flow.

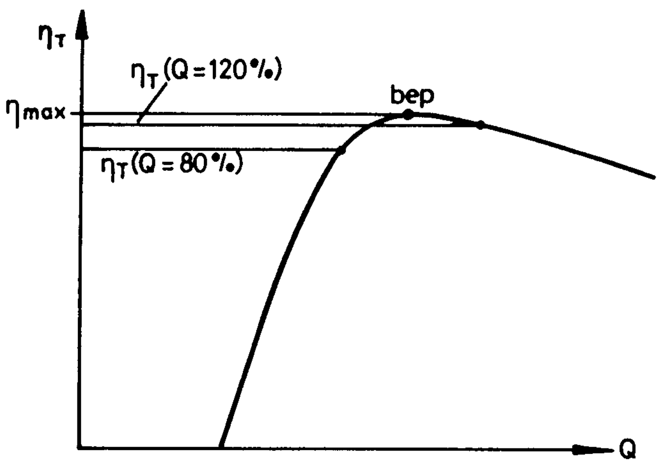


Fig. 20. Typical pump as turbine efficiency curve.

It is useful to note that, where there is a relatively large loss in the penstock, the effects of a poor turbine performance prediction are reduced, because a lower flow rate will be compensated by a larger net head at the turbine. This is the case in the above example, where the head loss in the penstock has been taken as 20% at the desired operating point. Where a site has been designed with a low friction loss in the penstock, the effects of poor turbine prediction on the power output, flow required and turbine efficiency will be more than in this example.

Adjustments to a Pump as Turbine after Installation

If a PAT has been installed without accurate testing and fails to produce the output power required, then it is usually possible to find out in what way the actual performance differs from the required performance. Knowing this, it may be possible to improve the match between the PAT performance and the site conditions. For most standard centrifugal pumps the turbine operation is similar to the curves shown in Fig 18. The various options, and some methods for improving the performance are listed below.

1. PAT flow is less than predicted

In this case the performance is similar to A in Fig. 19, and there is little that can be done to improve the PAT performance. The user must either be satisfied with the output being lower than expected, or obtain a PAT that runs efficiently at a higher flow rate.

2. PAT runs at expected flow rate, but power output is down

In this case, there are three possible reasons for the poor performance. A simple test can be used to find out what is happening. Increase the running speed of the PAT, and measure the power output while keeping the voltage as nearly as possible constant. For a system with an induction generator, the speed can be increased by decreasing the generator capacitance.

If the power output increases slightly, then the PAT is similar to case D in Fig. 19. In this case, the PAT can be run with the reduced value of capacitance, and the generator speed can be allowed to increase by up to 10%.

If the power output remains the same, then the PAT maximum efficiency is lower than expected. Some improvement may be obtained by dismantling the pump and cleaning the casing and impeller to give better surface finishes.

If the power output decreases, then the PAT is similar to case B in Fig. 19, where the head required by the PAT is greater than that available. Some improvement in performance may be obtained by turning down the outside diameter of the impeller. This is best done in steps of perhaps 5%, and then re-tested. The impeller should in any case not be reduced in diameter by more than 10%.

3. PAT flow greater than predicted, but power output the same
In this case, the PAT operation is similar to case C in Fig. 19. The speed of the turbine should be kept as low as possible, to reduce the head and flow requirement. However, the electrical frequency should not be less than 98% of the rated value. The performance may be improved by inserting a conical sleeve into the inlet side of the PAT casing (the pump outlet). This will reduce the flow area at the PAT inlet, and therefore reduce the flow requirement. On some sites it may be possible to divert more water into the intake of the scheme so that it can run at larger flow rate than the original design.

APPENDIX A:
Pump as Turbine Operation at Reduced Flow

Once a PAT has been selected and installed at a particular site, it will run at a fixed flow rate and head, at the point where the site net head matches with the PAT head. If the flow rate at the site falls below this value, then the intake will draw air, as shown in Fig. A1, and the pump will run at a lower head until the penstock refills itself.

As an example, on a site with a gross head of 63 m, the PATs will operate down to a head of around 35 m before flow surges in the penstock cause the system to become unstable. At this head the flow can be as little as 75% of the normal flow, but the power output will have fallen to around 25% of normal, because of the drop in efficiency.

However, some flexibility of the operating conditions can be achieved as long as air does not become trapped in the penstock, which causes flow surges or even a complete break in the flow of water.

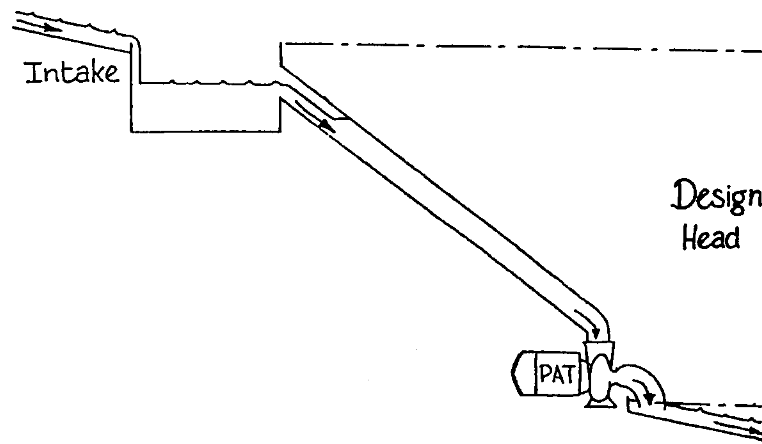


Fig. A1. Operation of a PAT at reduced flow

Appendix I - Calculations

Hydrology and Power at the Waterfall -

1. **Flow in the river:**

   Broad crested weir [16] -

Equation 1:

$$Q = C_w P(d^{3/2})$$

Where Q = flow rate in the pool

C_w is assumed to be 1.7 SI units or 3.0 BG units [16]

P = width of weir = 3.17 ft

d = depth of flow = 1.92 ft

$$\mathbf{25.3\,\frac{ft^3}{sec}} = 3.0 * 3.17\text{ ft} * (1.92\text{ ft})^{3/2}$$

2. **Velocity in the Pipeline**

   Velocity [16] -

Equation 2:

$$V = \frac{Q}{A}$$

Where V is velocity in the pipe

Q is assumed = 10 cfs for design purposes (This assumption is later used in selecting a turbine along with available head)

A = area of pipe = 0.785 ft^2 for 1 foot diameter pipe

$$\mathbf{12.7\,\frac{ft}{s}} = \frac{10\,cfs}{0.785\,ft^2}$$

3. **Head Available to Turbine**

   Derived Energy Equation [16] -

Equation 3:

$$H_{\boldsymbol{t}} = H_0 - H_L - \frac{{V_1}^2}{2g}$$

Minor and Major losses [16] -

Equation 4:

$$H_L = \sum k_i \frac{{V_1}^2}{2g} + f\frac{L}{D}\frac{{V_1}^2}{2g}$$

Where f = 0.009 for PVC [16]

k = 0.5 for 90° bends [16]

k = 0.37 for 45 bends [16]

g = $32.2\frac{ft}{s^2}$

If using half way rock for turbine:

$$\mathbf{3.07\ ft} = 0.5\frac{(12.7\frac{ft}{s})^2}{2*32.2\frac{ft}{s^2}} + 0.37\frac{\left(12.7\frac{ft}{s}\right)^2}{2*32.2\frac{ft}{s^2}} + 0.009\frac{\left(12.7\frac{ft}{s}\right)^2}{2*32.2\frac{ft}{s^2}}(\frac{2.5ft}{1ft} + \frac{32ft}{1ft} + \frac{5ft}{1ft})$$

If using entire waterfall drop (approx. 40') – approximately double pipe lengths:

$$\mathbf{5.7\ ft} = 0.5\frac{(12.7\frac{ft}{s})^2}{2*32.2\frac{ft}{s^2}} + (2)0.37\frac{\left(12.7\frac{ft}{s}\right)^2}{2*32.2\frac{ft}{s^2}} + 0.009\frac{\left(12.7\frac{ft}{s}\right)^2}{2*32.2\frac{ft}{s^2}}(\frac{2.5ft}{1ft} + \frac{43ft}{1ft} + \frac{30ft}{1ft} + \frac{40ft}{1ft})$$

Calculation of total head available to turbine:

$$H_{\boldsymbol{t}} = H_0 - H_L - \frac{{V_1}^2}{2g}$$

If using half way rock for turbine:

$$\mathbf{11.4\ ft} = 17\ ft - 3.07ft - \frac{(12.7\frac{ft}{s})^2}{2*32.2\frac{ft}{s^2}}$$

If using entire waterfall drop for turbine:

$$\mathbf{37.8\ ft} = 46\ ft - 5.7\ ft - \frac{(12.7\frac{ft}{s})^2}{2*32.2\frac{ft}{s^2}}$$

4. Potential power generation:

With using 1 ft diameter PVC pipe:

Equation 5:

$$P = H * Q * \eta * C$$

Where P = power (kW)

H = head available to system

Q = flow in the pipe

η = 0.5 assumed efficiency (in decimal equivalent)

C = power constant = 0.085 (English units)

Using half way rock for turbine:

$$\mathbf{4.845\,kW} = 11.4\,ft * 10.0\,\frac{ft^3}{sec} * 0.5 * \ 0.085$$

Using entire drop of waterfall:

$$\mathbf{16.1\ kW} = 37.8\,ft * 10.0\,\frac{ft^3}{sec} * 0.5 * \ 0.085$$

Table A1: Transmission Calculations for the Overall System

All Aluminum Conductor						**Per Unit**		**Overall System**	
Cable Size	Resistance		System Constants			Distance (ft) =	1000	Distance (ft) =	12973
	DC @ 20	**AC @ 75**	Current (A)	Voltage (V)	Power (W)	Voltage Drop (V)	Power Loss (W)	Voltage Drop (V)	Power Loss (W)
1/0	0.16400	0.20000	25	600	15000	5.000	125.000	64.865	1621.625
2/0	0.13000	0.15900	25	600	15000	3.975	99.375	51.568	1289.192
3/0	0.10300	0.12600	25	600	15000	3.150	78.750	40.865	1021.624
4/0	0.08170	0.09999	25	600	15000	2.500	62.494	32.429	810.731

Table A2: Transmission Calculations for the Sub - Systems

All Aluminum Conductor						**Mamey**		**Jakes & Host Family**		**Kindergarten**		**Arena**	
Cable Size	Resistance		System Constants			Distance (ft) =	3701	Distance (ft) =	3859	Distance (ft) =	6553	Distance (ft) =	7900
	DC @ 20	AC @ 75	Current (A)	Voltage (V)	Power (W)	Voltage Drop (V)	Power Loss (W)	Voltage Drop (V)	Power Loss (W)	Voltage Drop (V)	Power Loss (W)	Voltage Drop (V)	Power Loss (W)
1/0	0.16400	0.20000	25	600	15000	18.505	462.625	19.295	482.375	32.765	819.125	39.500	987.500
2/0	0.13000	0.15900	25	600	15000	14.711	367.787	15.340	383.488	26.048	651.204	31.403	785.063
3/0	0.10300	0.12600	25	600	15000	11.658	291.454	12.156	303.896	20.642	516.049	24.885	622.125
4/0	0.08170	0.09999	25	600	15000	9.252	231.289	9.647	241.163	16.381	409.522	19.748	493.701

Transmission Calculations –

Cable Size 1/0

Voltage Drop (V) per unit:

Equation 6:

$$\boldsymbol{Voltage\ Drop\ (V)} = Resistance * System\ Current\ (A)$$
$$\boldsymbol{5.000\ V} = 0.20000 * 25A$$

Power Loss (W) per unit:

Equation 7:

$$\boldsymbol{Power\ Loss\ (W)} = Resistance * System\ Current\ (A)^2$$
$$\boldsymbol{125.000\ W} = 0.20000 * 25A^2$$

Voltage Drop (V) Overall system:

Equation 8:

$$\boldsymbol{Voltage\ Drop\ (V)} = Overall\ Distance * \frac{Voltage\ Drop\ (V)}{Unit\ length}$$
$$\boldsymbol{64.865\ V} = 12973\ ft * \frac{5.000\ V}{1000\ ft}$$

Power Loss (W) Overall system:

Equation 9:

$$\boldsymbol{Power\ Loss\ (W)} = Overall\ Distance * \frac{Power\ Loss\ (W)}{Unit\ Length}$$
$$\boldsymbol{1621.625\ W} = 12973\ ft * \frac{125.000\ W}{1000\ ft}$$

Voltage Drop (V) Mamey:

$$\boldsymbol{Voltage\ Drop\ (V)} = Overall\ Distance * \frac{Voltage\ Drop\ (V)}{Unit\ length}$$
$$\boldsymbol{18.505\ V} = 3701\ ft * \frac{5.000\ V}{1000\ ft}$$

Power Loss (W) Mamey:

$$\boldsymbol{Power\ Loss\ (W)} = Overall\ Distance * \frac{Power\ Loss\ (W)}{Unit\ Length}$$

$$\mathbf{462.625\ W} = 3701\ ft * \frac{125.000\ W}{10000\ ft}$$

Voltage Drop (V) Jake & Host Family:

$$\boldsymbol{Voltage\ Drop\ (V)} = Overall\ Distance * \frac{Voltage\ Drop\ (V)}{Unit\ length}$$

$$\mathbf{19.295\ V} = 3859\ ft * \frac{5.000\ V}{1000\ ft}$$

Power Loss (W) Jake & Host Family:

$$\boldsymbol{Power\ Loss\ (W)} = Overall\ Distance * \frac{Power\ Loss\ (W)}{Unit\ Length}$$

$$\mathbf{482.375\ W} = 3859\ ft * \frac{125.000\ W}{1000\ ft}$$

Voltage Drop (V) Kindergarten:

$$\boldsymbol{Voltage\ Drop\ (V)} = Overall\ Distance * \frac{Voltage\ Drop\ (V)}{Unit\ length}$$

$$\mathbf{32.765\ V} = 6553\ ft * \frac{5.000\ V}{1000\ ft}$$

Power Loss (W) Kindergarten:

$$\boldsymbol{Power\ Loss\ (W)} = Overall\ Distance * \frac{Power\ Loss\ (W)}{Unit\ Length}$$

$$\mathbf{819.125\ W} = 6553\ ft * \frac{125.000\ W}{1000\ ft}$$

Voltage Drop (V) Arena:

$$\boldsymbol{Voltage\ Drop\ (V)} = Overall\ Distance * \frac{Voltage\ Drop\ (V)}{Unit\ length}$$

$$\mathbf{39.500\ V} = 7900\ ft * (5.000\ V/(1000\ ft))$$

Power Loss (W) Arena:

$$\boldsymbol{Power\ Loss\ (W)} = Overall\ Distance * \frac{Power\ Loss\ (W)}{Unit\ Length}$$

$$\mathbf{987.500\ W} = 7900\ ft * \frac{125.000\ W}{1000\ ft}$$

Turbine Shelter Slab Design -

l_{slab} = 8 ft

w_{slab} = 6 ft

$W_{mechanical}$ = 2500 lb

Dead load on slab -

$$dead\ load = \frac{2500lb}{6ft * 8ft} = 52\frac{lb}{ft^2}$$

Live load on slab -

$$live\ load = 120\frac{lb}{ft^2}$$

$$f'_c = 3000psi$$

$$h_{min} = \frac{length}{20}$$

$$\boldsymbol{5in} = \frac{8ft * {}^{12in}/_{1ft}}{20}$$

Slab Self Weight at 1 ft increments:

$$W_{SW} = h_{min} * unit\ of w_{slab} * unit\ weight\ of\ concrete$$

$$\boldsymbol{62.5\frac{lb}{ft}} = \frac{5in * 1ft * {}^{12in}/_{1ft}}{144\frac{in^2}{ft^2}} * 150\frac{lb}{ft^3}$$

$$W_u = 1.2W_d + 1.6W_L$$

$$\boldsymbol{0.302\frac{k}{ft}} = 302\frac{lb}{ft} = 1.2 * \left(62.5\frac{lb}{ft} + 120\frac{lb}{ft^2} * 1ft\right) + 1.6 * \left(52\frac{lb}{ft^2} * 1ft\right)$$

$$M_{u=}\frac{W_u * l^2}{8}$$

$$\boldsymbol{2.4kin} = \frac{0.302\frac{k}{ft} * (8ft)^2}{8}$$

$$M_{n\ req=}\frac{M_u}{\varphi} = \frac{2.4kin}{0.9} = 2.7\frac{kin}{ft}$$

$$M_{n=}A_s f_y(d - \frac{a}{2})$$

$$d = h_{min} - cover - \frac{d_b}{2}$$

$$\mathbf{3.3125in} = 5in - 1\frac{1}{2}in - \frac{3}{8}in * \frac{1}{2}$$

Area of reinforcing steel required -

$$A_{s\,req} = \frac{M_{n\,req}}{f_y(0.925d)}$$

$$\mathbf{0.1556\frac{in^2}{ft}} = \frac{2.7kin/ft}{60ksi * 0.925 * 3.3125in}$$

$$M_{n=}A_s f_y(d - \frac{a}{2})$$

Spacing on center -

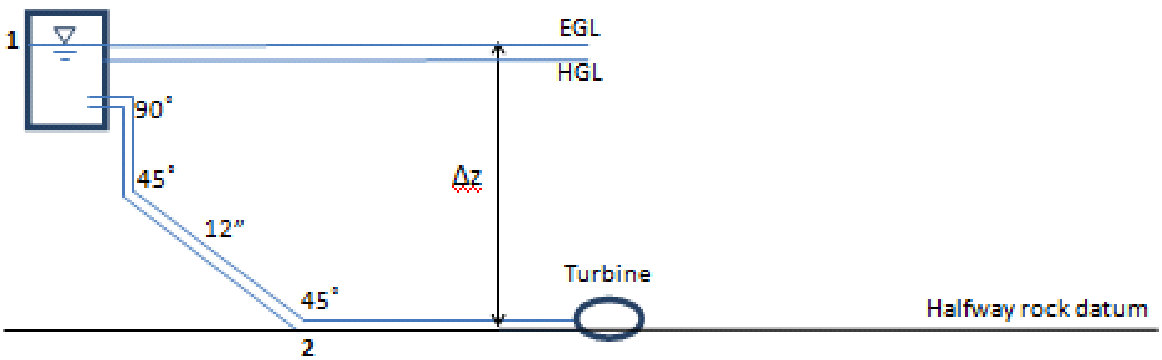
$$A_{s\,req\,\#3} = \frac{0.1556\frac{in^2}{ft}}{1ft * 12in/1ft} = \frac{0.11in^2}{x}$$

$$\mathbf{8in\ spacing} = x$$

Forces at Penstock Bends -

Energy Continuity Equation for flow in a pipeline [15]

$$\cancelto{0}{\frac{V_1^2}{2g}} + \cancelto{0}{\frac{P_1}{\gamma}} + z_1 = \frac{V_2{}^2}{2g} + \frac{P_2}{\gamma} + z_2 + f\frac{L}{D}(\frac{V_2{}^2}{2g})$$



$$V = \frac{Q}{A}$$

$$\mathbf{12.7\ ft/s} = \frac{10\ cfs}{\pi * \frac{(1\ ft)^2}{4}}$$

$$\mathbf{16.5\ ft} = z_1 - z_2$$

$$\mathbf{16.5\ ft} = \frac{\left(12.7\frac{ft}{s}\right)^2}{2 * 32.2\frac{ft}{s^2}} + \frac{p_2}{62.4\frac{lb}{ft^3}} + 0.01 * \frac{41.3ft}{1ft} * \frac{\left(12.7\frac{ft}{s}\right)^2 2.7}{2 * 32.2\frac{ft}{s^2}} + (0.5 + 0.37) * \frac{\left(12.7\frac{ft}{s}\right)^2 2.7}{2 * 32.2\frac{ft}{s^2}}$$

$$P_2 = 672\ psi$$

$P_2 = 4.7\ psi$ @ bend on halfway rock

Thrust block design in accordance with (Water Agencies' Standards)

Pipeline thrust at bends:

$$T = 0.5\pi p d^2(\frac{sin\Delta}{2})$$

Where:

T = resultant thrust force (lb)

p = internal pressure (psi)

d = outside diameter of pipe (in)

Δ = angle (degrees)

$$\mathbf{406.8\ \mathit{lbs}} = 0.5\pi(4.7\ psi)(12\ in)^2 * \frac{\sin 45^\circ}{2}$$

Soiling bearing pressure of granite (halfway rock) = 10,000 psi

Required min area (ft^2) that concrete thrust block must bear against undisturbed soil:

$$A = \frac{T}{S_b}(SF)$$

Where:

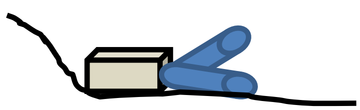
A = area of thrust block (ft^2)

T = resultant thrust force (lb)

S_b = soil bearing pressure

SF = safety factor (1.5)

$$\mathbf{0.6\ ft^2} = \frac{406.8lb}{10{,}000psi} * 1.5$$



Halfway Rock

A 3 inch by 3 inch bearing surface is required.

A minimum thrust block size recommended is a 6 inch by 6 inch by 15 inch concrete thrust block for the 135˚ bend in penstock on halfway rock. This thrust block is recommended by El Tigre Engineering as more of a means to stabilize the PVC pipe than act as a absorber of the forces from the water since little pressure builds up in the pipe.

Appendix J - Transmission Line Data

Table B1: GPS Waypoints in Communities

Location	Northing	Easting	Latitude (ft)	Longitude (ft)	Elevation (ft)	Distance (ft)
AR1	8° 20.291'	81° 56.451'	3,024,826	29,726,228	282	
AR2	8° 20.382'	81° 56.511'	3,025,552	29,726,591	356	435
Marcassi	8° 20.449'	81° 56.590'	3,025,915	29,726,954	474	398
Arena Town Center	8° 20.623'	81° 56.717'	3,027,003	29,727,679	768	831
Arena Border	8° 20.939'	81° 56.771'	3,028,817	29,728,042	1,040	1,774
Cerro Piedra Church	8° 21.024'	81° 56.814'	3,029,180	29,728,405	1,066	398
Kindergarten	8° 21.006'	81° 57.020'	3,029,180	29,729,493	1,223	1,082
CP1	8° 21.050'	81° 56.926'	3,029,542	29,729,130	1,223	324
Futbol y Tienda	8° 21.109'	81° 56.761'	3,029,905	29,728,042	1,213	1,046
MM1	8° 21.237'	81° 56.588'	3,030,630	29,726,954	1,137	1,009
Diojena	8° 21.341'	81° 56.548'	3,031,356	29,726,591	1,211	287
Jake	8° 21.390'	81° 56.596'	3,031,719	29,726,954	1,212	398
Host Family	8° 21.405'	81° 56.562'	3,031,719	29,726,954	1,124	100
Waterfall	8° 21.154'	81° 56.199'	3,029,905	29,724,777	755	2,350
Inline System	8° 21.270'	81° 56.182'	3,030,993	29,724,414	861	251
Carlos	8° 21.449'	81° 56.253'	3,031,719	29,725,140	1,268	796
Mamey Tienda	8° 21.558'	81° 56.210'	3,032,445	29,724,777	1,125	287
Julian	8° 21.762'	81° 56.401'	3,033,896	29,725,865	1,153	1,220
Garciela	8° 21.936'	81° 56.592'	3,034,984	29,726,591	1,523	833
Juana	8° 21.533'	81° 56.581'	3,032,445	29,726,591	1,266	103
Mamey Border	8° 21.149'	81° 56.720'	3,029,905	29,727,679	1,256	463
Bridge	8° 21.313'	81° 56.179'	3,030,993	29,724,414	771	3138
Martin	8° 21.395'	81° 56.252'	3,031,719	29,725,140	1,001	796
					Total:	**18,319 ft**
						3.47 miles

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