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Providing safe drinking water to the Quebrada Arena Community of Panama

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Disclaimer:

This report titled "Providing Safe Drinking Water for the Quebrada Arena Community of Panama," represents the efforts of undergraduate students in Civil and Environmental Engineering Department of Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report ***should not*** be considered professional engineering.

Mission Statement

Yucca Engineering's mission is to provide practical solutions to better the lives of rural communities throughout the world. By implementing sustainable, cost effective solutions to issues of concern, Yucca Engineering strives to design systems focused on customer demands and needs in the eyes of both the community and engineer.

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Executive summary

Cerro Piedra, located in the Ngöbe-Buglé Comarca of western Panama, is home to the Quebrada Arena community which consists of approximately 200-250 people without a reliable source of safe drinking water. During August of 2013, Yucca Engineering travelled to the region to perform an assessment and feasibility study. The goals were to assess the current water situation and gather data on the community's needs and wants concerning a water supply system. Upon returning to the United States, Yucca Engineering began the design of a water distribution system in order to supply the Quebrada Arena community with safe and reliable drinking water. The results and conclusions are presented in this report.

The Quebrada Arena community of Cerro Piedra is a rural, indigenous community. Many members survive on subsistence farming, while others must travel out of the region in search of work. The community currently lacks any structured water supply system and instead relies on the multiple sources of groundwater throughout the region. However, during the dry season these sources become non-existent, except for one. The community wishes to use this source as the water supply for each family year-round. While in the Quebrada Arena community, Yucca Engineering surveyed a pipeline route proposed by community members. During this time, water availability and quality data was also collected. The time Yucca Engineering spent in country also gave the team the opportunity to meet Peace Corps Volunteers Christopher Kingsley and Jacob Midkiff, who provided crucial support throughout the project.

Analysis of the data collected while in Panama took place upon return to the United States. The survey data allowed elevation profiles of the proposed pipeline to be constructed, as well as Google Earth® maps of the system. EPANET modeling from the survey-data provided hydraulic analysis in order to ensure the pipeline would not only supply water throughout the community, but also have acceptable pressures. A challenge encountered was dangerous pressures due to an overall elevation difference of about 300 meters. Yucca Engineering addressed this issue by placing six pressure break tanks at key locations throughout the system in order to reduce the pressure in each section.

Other system components include a spring box for protection and capture of the source, as well as a storage tank in order to provide adequate supply to the community. An in-line chlorinator was added before the storage tank to introduce chemical disinfection to the water distribution system. This chlorinator design allows community members to add chlorine tablets that will last roughly one week each. Use of the chlorinator will remove multiple pathogens that may be present within the water supply.

At two points in the system, a ravine presents an obstacle to the water supply line. Without proper support, elevated pipelines may break. Yucca Engineering has designed two bridges for these crossings. Likewise, to mitigate damage to the pipeline, it is recommended that

the entire system be buried at a minimum of one foot below ground surface. In areas where the pipe must surface, a larger diameter casing pipe should be used in order to protect the pipe not only from UV ray damage, but also from other threats such as animals that may disturb the system.

Yucca Engineering has made these recommendations and designs in order to provide the Quebrada Arena community of Cerro Piedra with a clean, dependable water distribution system. The final cost to construct the project is approximately $12,300. This report will be submitted to the Peace Corps for further consideration and possible implementation.

1.0 Introduction

Access to clean, running drinking water is something that many people take for granted. Many areas of the world are afflicted with not having reliable or safe drinking water. To confront this global crisis, students from the Michigan Technological International Design (iDesign) Program traveled to different areas in Panama to design water distribution systems. This program focuses on rural communities that do not have the quality and quantity of water to meet international standards.

The community to which Yucca Engineering travelled was the Quebrada Arena of Cerro Piedra. The goal was to assess the current water situation and talk with community members in order to focus the project around their needs and desires. In order for the design to be implemented and operate correctly, the community must approve of the project. Without the approval of the community, the system has no real chance of being sustainable.

Currently, the community members have up to a 30 minute walk to retrieve water. This water which is used for bathing and laundering is also used for drinking and cooking, all done without treatment. Clearly, this is not an ideal situation, and disinfection before consumption is a necessity. This community also has a Peace Corps Volunteer who will encourage the community members to implement the distribution system and help make this design a reality.

One large obstacle with this project is that the majority of the design work took place in the United States. Members of the design team had little opportunity to meet with the community other than during the assessment trip. Yucca Engineering strived to keep the desires and needs of the Quebrada Arena community at the forefront of all design decisions. This criterion was a challenge due to cultural differences and communication barriers. However, the design team recognized that meeting this criterion was vital to the success of long term implementation of the project. The water distribution system has been designed to include a limited amount of resources with cost being a primary factor. Likewise, the design focuses on ease of operation and maintenance for the community members.

Yucca Engineering has made the entirety of these recommendations and designs in order to provide the Quebrada Arena community of Cerro Piedra with a dependable source of drinking water. The report will illustrate the preparation and the two week assessment in Panama, the post trip assessment, the proposed design, and any recommendations. This report will be submitted to the Peace Corps. Included within the report is discussion on community background, data analysis, design of proposed system, cost and materials, construction, a conclusion, and several appendices to provide additional detail if desired by the reader.

2.0 Study Context

In August of 2013, members of the Michigan Tech iDesign program traveled to Panama to address water availability issues in one of the most rural regions of the country. Four teams were assembled, and then traveled to remote regions of Panama to tackle issues such as water quality, water distribution, and transportation. Yucca Engineering traveled to the Ngöbe-Buglé Region of Western Panama, where an engineering solution was needed to solve the issue of inadequate water supply in a small community known as Quebrada Arena.

The Quebrada Arena community lies within the Ngöbe-Buglé region and is surrounded by large mountains, which isolate several nearby communities. For nearly 200 years, the community has resided in the Ngöbe-Buglé region, and today it is comprised of roughly 250 residents who live in 25-30 homes. Of those 250 residents, the majority are younger than 20 or older than 60. This is due to adults leaving the community in search of work in other regions of Panama. For those who that live in the community, travel to nearby towns to purchase goods is rare, so subsistence farming of rice, coffee, and yucca is commonly practiced, as well as raising livestock. Education is offered in the community for young children but older children attend a school in a neighboring community, sometimes hiking several miles.

Due to the Quebrada Arena's isolation, a native language known as Ngäbere is most often spoken. This has led to a lack of Spanish speaking members, creating employment difficulties for many members of the community. The women of the community often make handbags and dresses which they sell at markets for a small source of income. Within the community, there are two general stores, which sell basic home goods for cooking and cleaning; two pavilions serving as churches for weekly gatherings; and a one-room school house which is used throughout the week. Roads do not reach the community due to the extreme terrain, so several walking paths act as routes between houses and neighboring communities. Of the 25-30 homes within the community, a majority are constructed as one-room structures with metal roofs, wooden exteriors, and dirt floors. Each home has a kitchen that is usually unattached from the main house. Cooking is often done in large pots and is heated by wood fires.

Figure 1: Standard kitchen area within the community. Photo by Yucca Engineering.

Personal hygiene was observed as a top priority for community members. Showering in the nearby spring was done several times each day, and members frequently washed their hands, including before eating. Although there were several animals around the living quarters, feces was continuously removed and dirt floors were commonly swept throughout the day.

Figure 2: A woman washes a little boy's hands before he eats dinner. Photo by Yucca Engineering.

The purpose of Yucca Engineering's trip to the Quebrada Arena community was to establish a feasible solution to the community's lack of water during the dry season and difficult locations of water sources. Having several water sources through the nine month wet season, the community is able to gather water daily, at nearby locations, for cooking, cleaning, and drinking, using buckets. Unfortunately, this requires travel by foot and is typically done by young children and women. During the three month dry season, most of these sources stop supplying water. This lack of supply through the dry season creates great challenges for community members to obtain adequate quantities of potable water. Due to the lack of sources, women and children have no choice but to venture great distances for water, regardless of its quality. Another issue within the community is fecal matter from livestock contaminating sources from runoff. High intensity storms occur frequently, almost daily, during the wet season, and these storms cause high levels of runoff to flow into the water sources used for consumption by community members. Currently, there is no method for dealing with the fecal matter washed into the sources, so community members are forced to consume the potentially harmful water. In all, there are three primary issues within the community which have been addressed in the design: distant location of sources, limited availability of water in the dry season, and contamination from livestock runoff.

While the Quebrada Arena Community has lived relatively comfortable for generations, it has been acknowledged by members that improvements should be made in regards to the current water situation. By working with community members and Peace Corps Volunteer, Christopher Kingsley, Yucca Engineering approached the three problems (distance, availability, and quality) with open minds and the intent to produce an appropriate solution.

3.0 Data Collection and Analysis

Data collected for the Quebrada Arena water system included topography data along the proposed pipeline route, water source availability, and water quality information. Further data, such as community water usage and material costs were gathered after the assessment trip upon the team's return to the United States through communication with Peace Corps Volunteers.

3.1 Surveying

Topographical data for the proposed pipeline was gathered through use of rudimentary surveying techniques. Options available were the use of a Total Station, a theodolite survey, or an Abney level and a handheld GPS. The remoteness of the community, combined with harsh tropical weather and rugged terrain, led Yucca Engineering to choose the Abney level and GPS option for surveying, as seen in Figure 3.

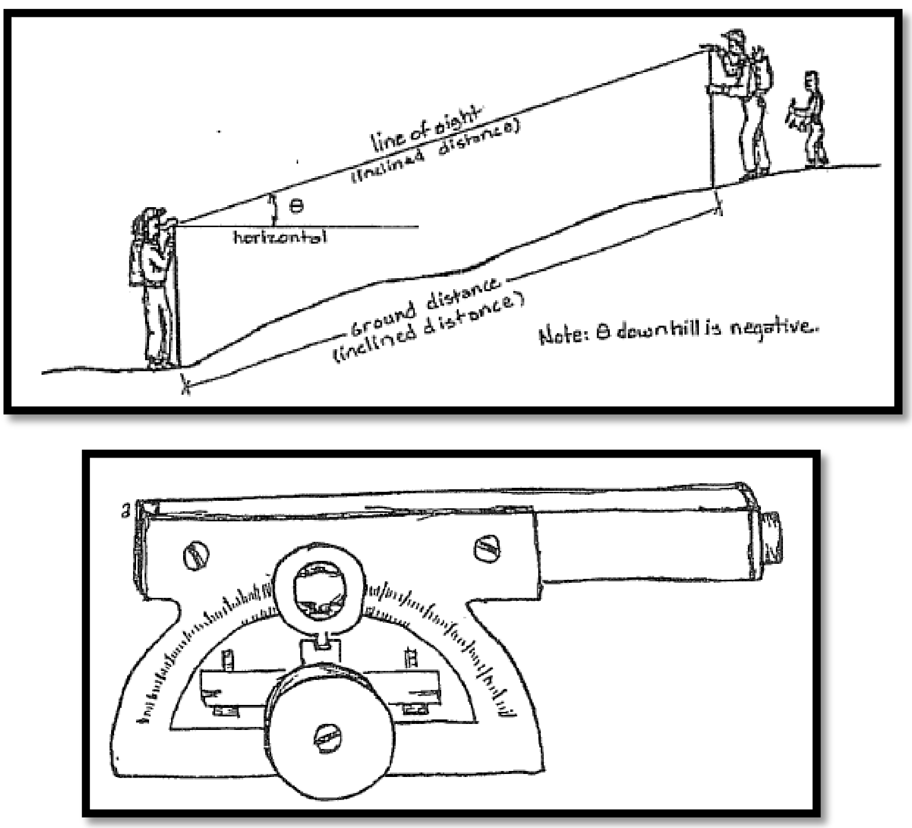


Figure 3: Abney Level diagram and use demonstration (Mihelcic et al 2001).

The Abney level relayed changes in slope over a set distance measured by tape. Starting from the proposed source, Yucca Engineering used this method to survey the entire proposed pipeline. The elevation of the source was given a value via the Garmin handheld 60CSx GPS of 383 meters above sea level. Each successive survey point from the proposed source was related back to the elevation of the source in order to calculate the change in elevation at each point. Figure 4 shows Yucca Engineering during the survey process.

Figure 4: Yucca Engineering Team Members using the tape and rod method to survey.

At each survey point, a GPS mark was also recorded in order to collect geographical coordinate data. These collected points were imported into Google Earth®, and a map of the pipeline route was developed as shown in Figure 5. It is important to note that Yucca Engineering recognizes the inaccuracy of GPS data for vertical measurements, yet relies on the data for horizontal positioning. Yucca Engineering completed 3 miles of survey while in Cerro Piedra. Survey data can be found in Appendix K. The elevation profile of the mainline of the water system is shown in Figure 6.

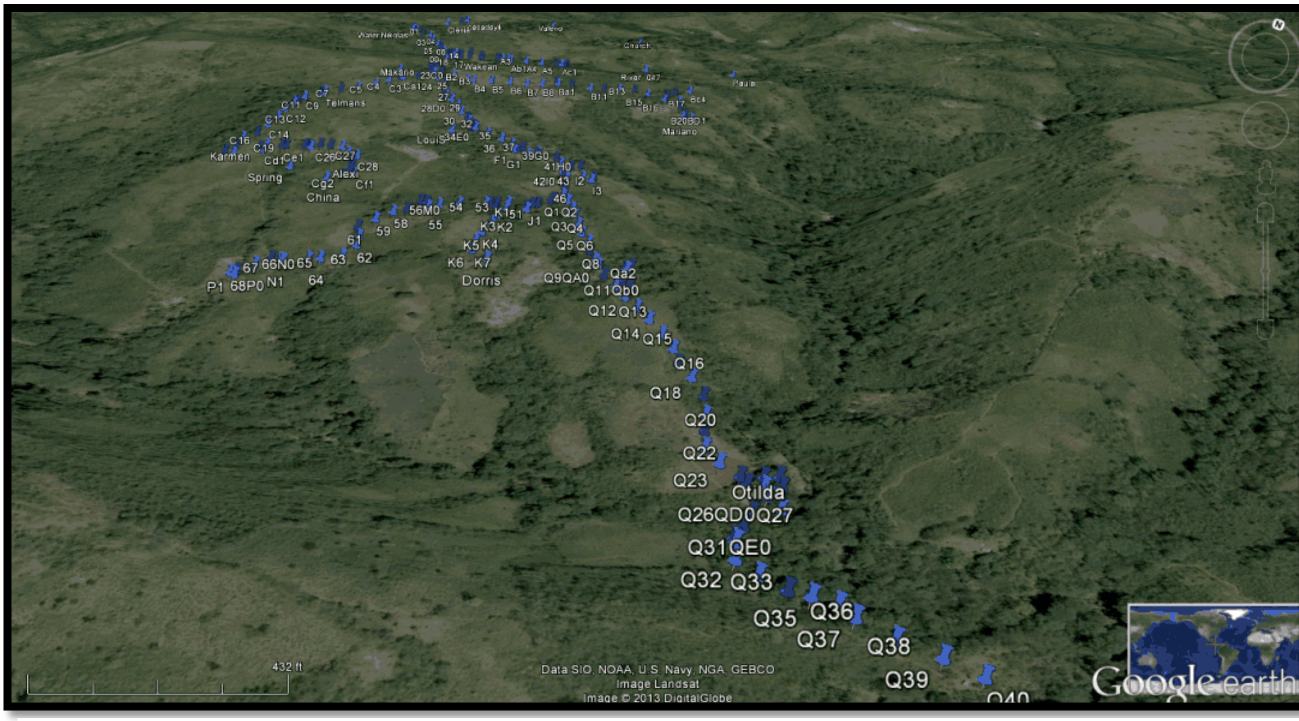


Figure 6: Map of the proposed pipeline using GPS coordinates in Google Earth.

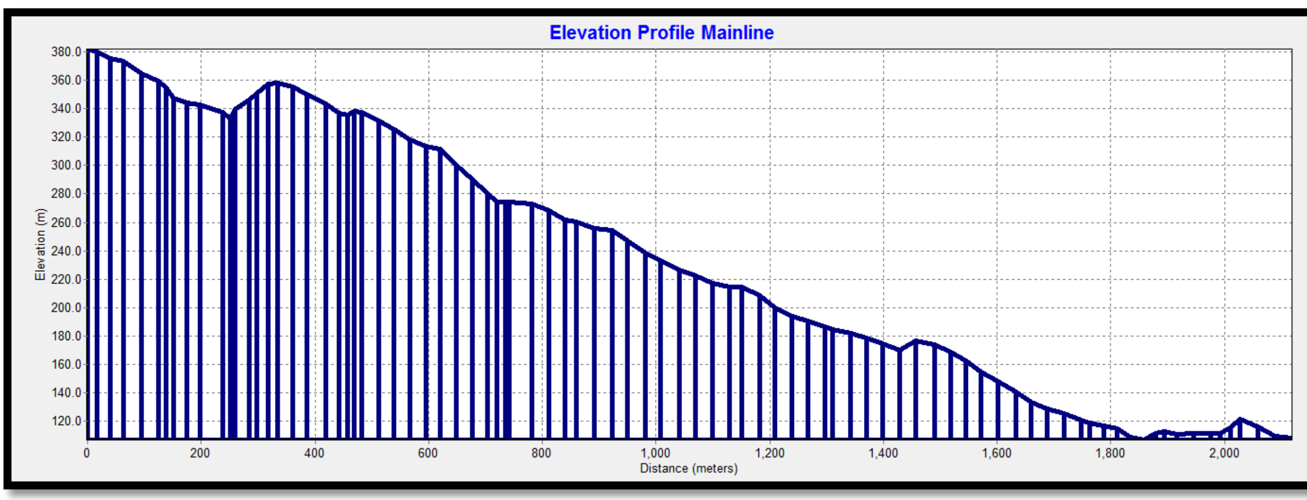


Figure 5: Elevation profile for the mainline of the water system.

3.2 Water Availability

The climate in the Ngöbe-Buglé Comarca creates two distinct seasons, dry and wet. The wet season lasts April – December, and the dry season lasts January - March. Yucca Engineering travelled to the Quebrada Arena community during the wet season and therefore noted a variety of natural water sources throughout the region. Unfortunately, the number and strength of these sources drops significantly during the dry season, leaving the Quebrada Arena community with only one reliable source for which to develop an aqueduct system. Rainfall collection was proposed by Yucca Engineering while in the region. However, it was relayed through Peace Corps Volunteer, Christopher Kingsley that the Quebrada Arena community was interested in an aqueduct system and has decided against rainwater harvesting. The proposed source is a natural groundwater spring which surfaces at a rocky outcropping near the top of Cerro Piedra, Figure 7.

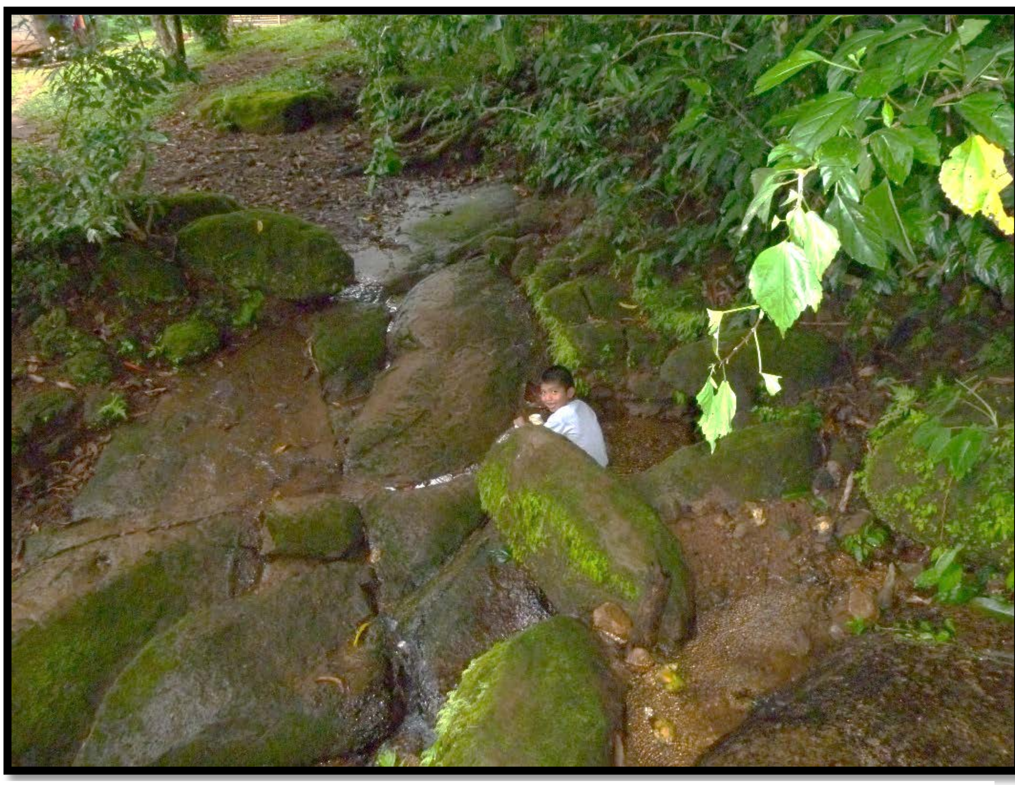


Figure 7: A young boy from the Quebrada Arena Community crouches by the proposed source.

Flow analysis of the source was conducted using the time-volume estimation method. Using banana tree leaves, bamboo sections, and rocks, Yucca Engineering contained roughly 90% of the source as it flowed over a rock surface. A five gallon bucket and a stopwatch were used for multiple flow measurement trials. The averaged data resulted in a constant flow of 60 gallons per minute, or about 230 liters per minute. This estimate is also viewed as conservative because not all of the flow from the source was contained during the trials. Upon return to the United States, Peace Corps Volunteer Jacob Midkiff related to Yucca Engineering that the average flow from the source during the dry season may be as low as one gallon per minute, or 3.8 liters per minute. A photo of the flow measurement trial can be seen in Figure 8.

Figure 8: Young children in the community watch Yucca Engineering measure water flow at the proposed source.

3.3 Water Quality

The assessment trip to the Cerro Piedra region also allowed Yucca Engineering to conduct water quality tests on the proposed source. Tests were conducted using 3M™ Petrifilm™ plates. Tests included sampling for both E. coli and total coliform. Samples were taken at multiple locations in order to gather an overall idea of water quality within the community. Testing methods began with sampling one mL of water from the location and placing it on the biofilm of the Petrifilm™ plates with a disposable pipette. After securing the sample in the Petrifilm™ plate, samples were pressed so that the water covered the entire plate, and the sample was labelled accordingly. Incubation of the samples occurred for a minimum of 24 hours using body heat. Colonies grown on the plates were then counted and recorded; results can be found in Appendix E. Coliform bacteria are common indicators for drinking water quality. The presence of these organisms lends to the possibility that further contamination is present within the water.

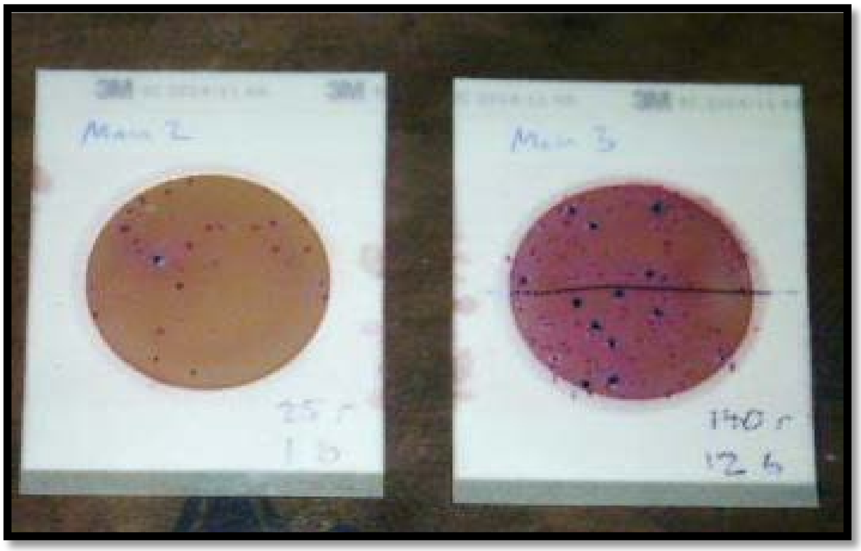


Figure 9: 3M™ Petrifilm™ Microbiological Quality Analysis Results

During the assessment trip, water quality tests of the main source and a secondary source were conducted. Samples were taken throughout the ten square-foot area in both stagnant and flowing water. Six sets of samples confirmed positive results for E.coli and total bacteria, both coliforms and non-coliforms. A summary of results is available in Appendix E. The confirmed existence of these organisms indicates that further contamination may be present within the water, which may cause serious health problems.

3.4 Population and Water Usage

The proposed pipeline includes 32 locations where water is demanded. These locations were indicated to Yucca Engineering by members of the Quebrada community. A population study was not completed during the assessment trip. The Ministerio de Salud, the Panamanian Ministry of Health (MINSA), assumes that the average population of the Ngöbe-Buglé Comarca is eight persons per household. Therefore, Yucca Engineering used this number, along with the number of households, for an overall population estimate of 256 persons. This number is conservative as it accounts for every household within the community as well as locations where houses have not yet been built but are planned.

Average daily water usage of the Quebrada Arena Community was calculated using the MINSA's recommendation of 30 gallons per person per day. Average daily water usage did not seem consistent, and not enough time was spent in the community for this assessment. However, Peace Corps Volunteer Christopher Kingsley forwarded water usage data he had collected during his years spent in the Ngöbe-Buglé Comarca, and this data can be found in Appendix C. The community he had spent time with was very similar to the Quebrada Arena community in culture and daily lifestyle. This average, combined with eight persons per household, gives an average daily demand of 240 gallons (908 liters) per day per household. The calculated water usage was combined with the given data in order to create hourly demand patterns that are likely more accurate for the Quebrada Arena community than a constant daily average. These can be found in Appendix C.

3.4 EPANET Model

The collected survey data for the Quebrada Arena community was modeled using EPANET 2.0 software. The collected survey data was transferred from an Excel® file to a text document, and then imported into EPANET. This maintained the correct elevation difference between each survey point as well as incorporated the coordinates from the GPS. The overall model can be seen in Figure 10.

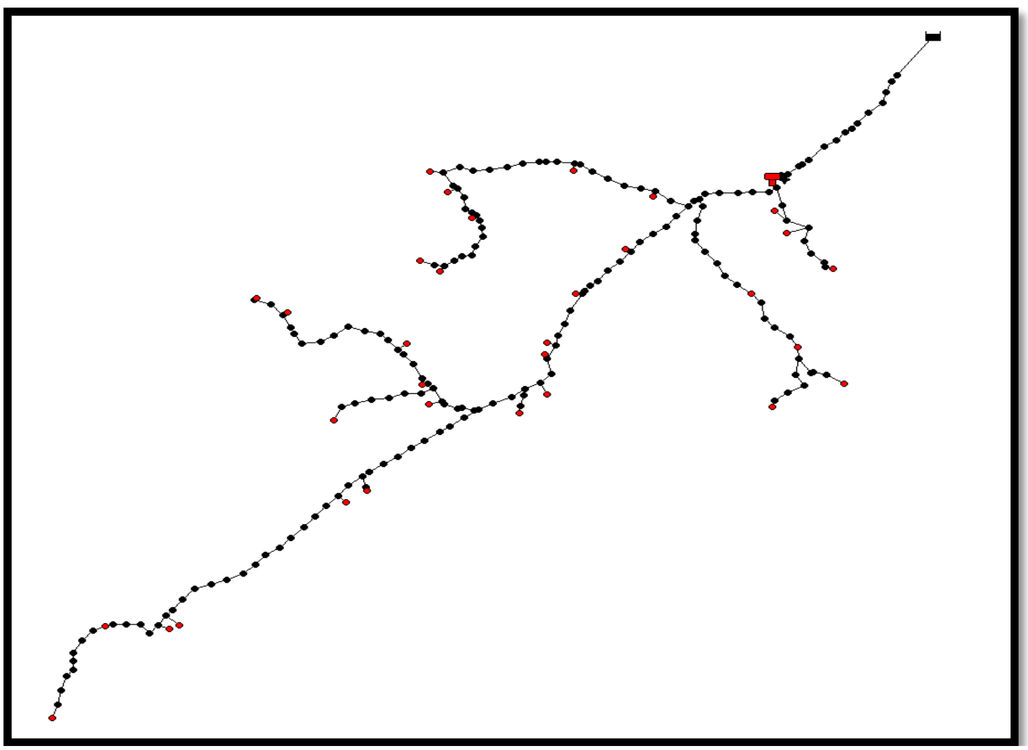


Figure 10: EPANET schematic of the proposed water distribution system. Tap stand locations are shown in red and the storage tank is the large rectangle shown in red.

Although EPANET does not take into account the horizontal position of points within the model, but rather only relies on distances between points and the associated elevations for analysis, the GPS coordinates were imported for visualization purposes only. Also incorporated into the model is an in-line chlorinator and a storage tank. Hydraulic properties applied to the model are shown in Table 1.

Table 1: EPANET hydraulic properties for modeling purposes.

Properties	Values
Friction Headloss Formula	Hazen-Williams
Roughness Coefficient	150
Storage Tank Volume	8 m^3
System Average Daily Demand	20.16 L/min (29,030 L/day)
Average Daily Demand Per Tap	0.63 L/min (907 L/day)

Likewise, the predetermined tap stand locations were each assigned water demands based on the analysis described in the previous section. EPANET then allows the user to simulate water flowing through the system over a period of time and produces results such as pressures and flow rates throughout the system. From these results hydraulic grade lines could be plotted to ensure that there is sufficient pressure for the system to flow properly, and not too much pressure that could cause pipes to burst or lead to unsafe conditions at tap stands.

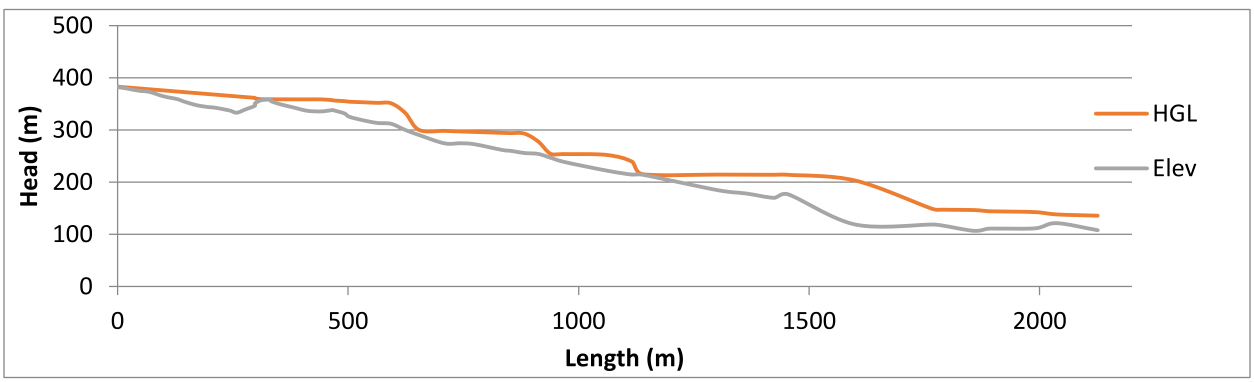


Figure 11: Hydraulic Grade Lines of Mainline. Each dip is where a pressure break tank is located.

4.0 Design of Gravity-Fed Water Distribution System

The design of the Quebrada Arena water distribution system incorporates multiple components. Each aspect of the design is focused on cost effectiveness, low maintenance, and quality of water. Based on conclusions made from the data analysis, a water distribution system was determined to be the most appropriate improvement for the Quebrada Arena Community, able to provide easily accessible, disinfected water to all community members. Discussion in this section provides detail on each design component and offers insight into why Yucca Engineering chose each feature.

4.1 Spring Box

Yucca Engineering has designed a spring box in order to protect the source from surface water contaminants. The spring box is a basic design with relatively low maintenance as displayed below in Figure 12.

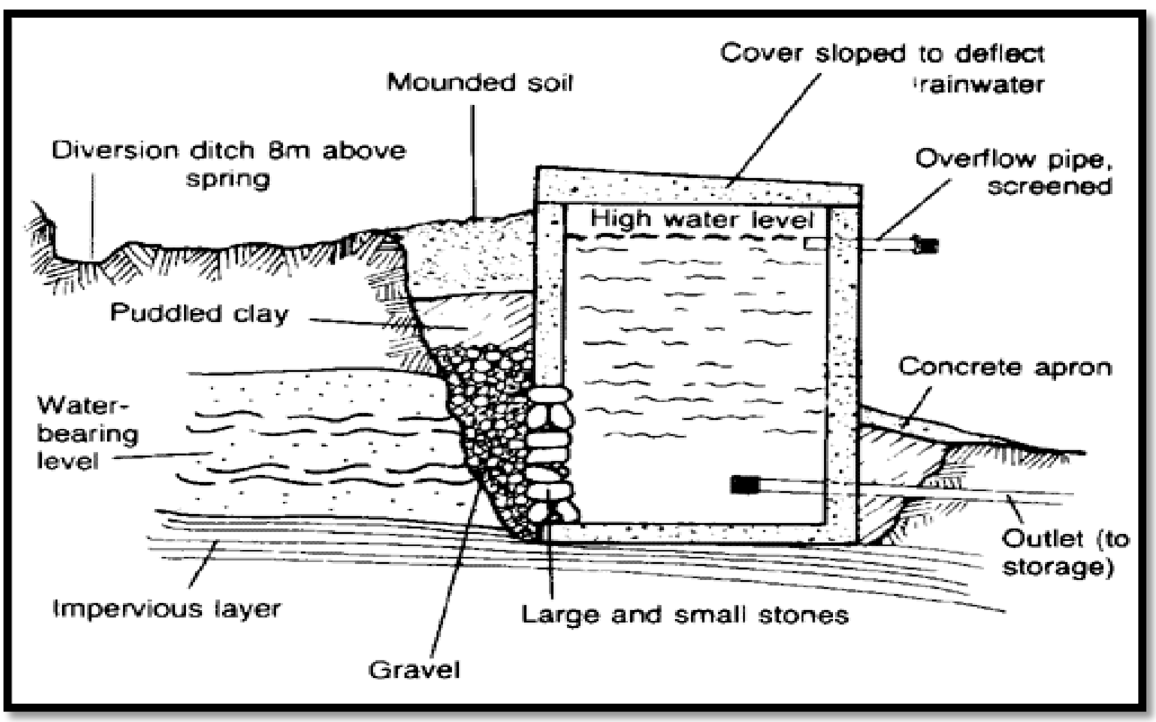


Figure 12: Spring Box Design. Photo by www.lifewater.org

The outflow of the spring box will be dependent on the available water volume of the spring, but it was designed for 38 liters/minute, which will leave the box through a 1" pipe to the storage tank. The spring box will be constructed of concrete and is located where the source surfaces. This placement will allow capture of the source as it travels through layers of gravel and then into the spring box. Once captured, water will exit the box either via an effluent pipe or the overflow pipe. The location of the box sits right at the water source where the spring water enters through an inlet after passing a gravel layer. This layer of gravel will serve as a preliminary physical treatment mechanism, removing large solids. A sand filter is not included in the design of the spring box, because the area at which the box will be located is quite small. Also, sand is not a readily available resource in this area. Removing sand filtration from the design allowed the size of the box to be reduced as well as limited the amount of resources that would be needed.

The spring box was designed for the demands of the community, not based on the wet or dry season flow data. Since the water will not be stored in the spring box, the capacity was not part of the design criteria. However, the spring box is an important feature of the entire design of the system since it serves as the only form of water capture and provides primary treatment for solids.

4.2 Pipeline Design

The pipeline travels over three miles. For simplicity, Yucca Engineering has broken the system into branches, as shown in Figure 13. The longest stretch of pipe, from the source to the lowest house on the system, is considered the mainline. Any other sections of the system that branch off from the mainline are labeled A-D. The pipeline will consist of three pipe sizes: ½”, 1”, and 2” (12.7 mm, 25.4 mm, and 50.8 mm, respectively). Yucca Engineering recommends SDR 26 PVC pipe due to the cost and pressure rating. However, implementation of higher rated pipe such as SCH 40 PVC would not hinder the system if chosen. SDR 26 PVC pipe is the least structurally strong pipe recommended in order to exceed the maximum pressures found within the system and still maintain a factor of safety. In order to protect the pipeline, it is recommended that the pipe have a minimum of one foot bury depth. Likewise, anytime the pipelines surfaces, such as at gully crossings or to avoid obstacles, it is recommended to encase the pipe. Pipe casing can be as simple as inserting the pipeline through another PVC pipe of a larger diameter. Casing pipes should be buried at least two linear feet before surfacing to ensure proper protection. Yucca Engineering estimates that casing pipes will be necessary at the following locations: both gully crossings; at the entrance, exit, and overflow of the storage tank; and at each pressure break tank.

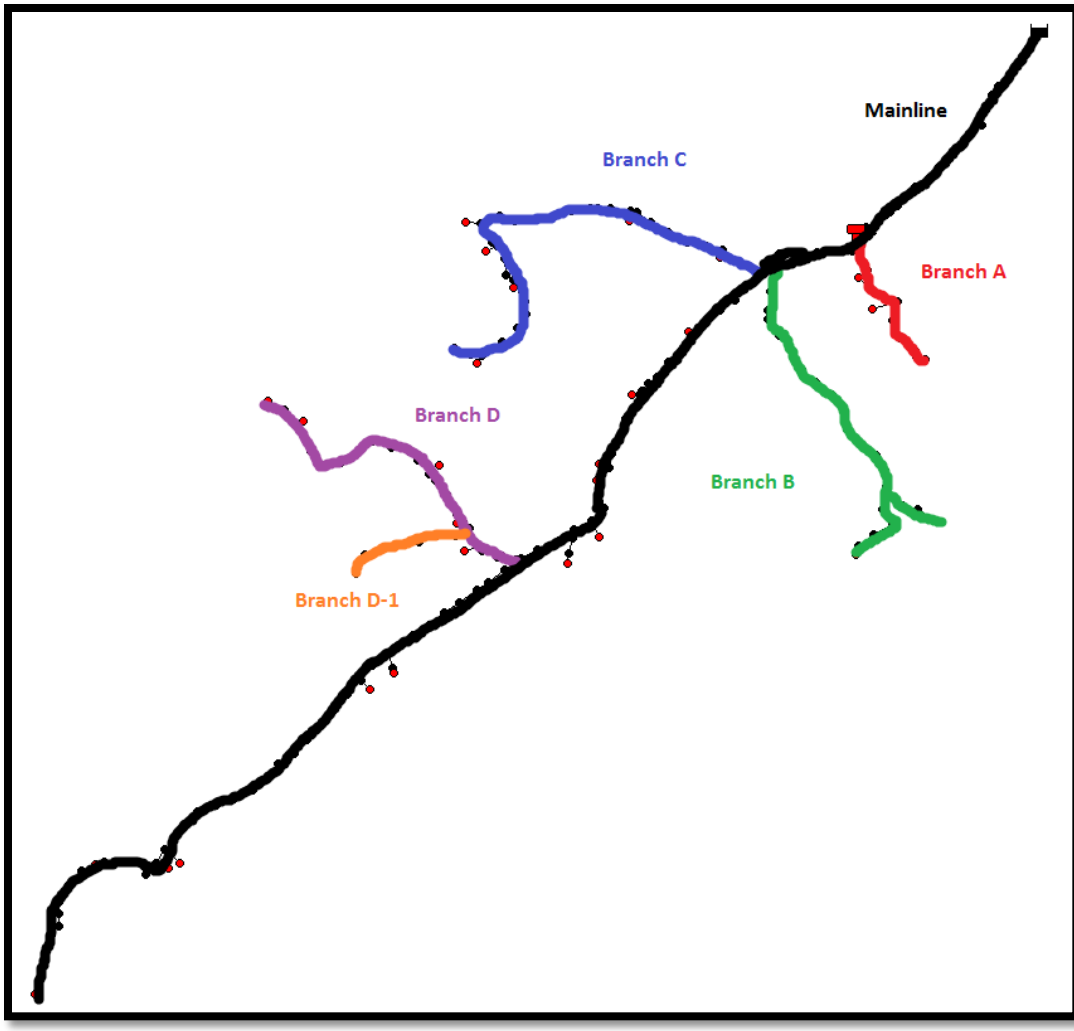


Figure 13: EPANET schematic detailing each branch of the system.

Within the system, Yucca Engineering recommends that every water service line leading to a tap stand consist of ½" pipe. Total pipe lengths of each size are shown in Table 2, and a schematic of pipe layout can be found in Figure 14. Peace Corps Volunteer Chris Kingsley recommended 20% of pipe length be added to the total length of pipe necessary. This contingency is added for unforeseen detours or additions to the pipeline.

Table 2: System pipe diameters and lengths.

Size	Length (m)	Length (ft)	%20 Contingency (m)	%20 Contingency (ft)
1/2"	1,256	4,119	1,512	4,960
1"	3,503	11,491	4,207	13,800
2"	138	450	165	540
Total Pipe Length	4,897	16,060	5,884	19,300

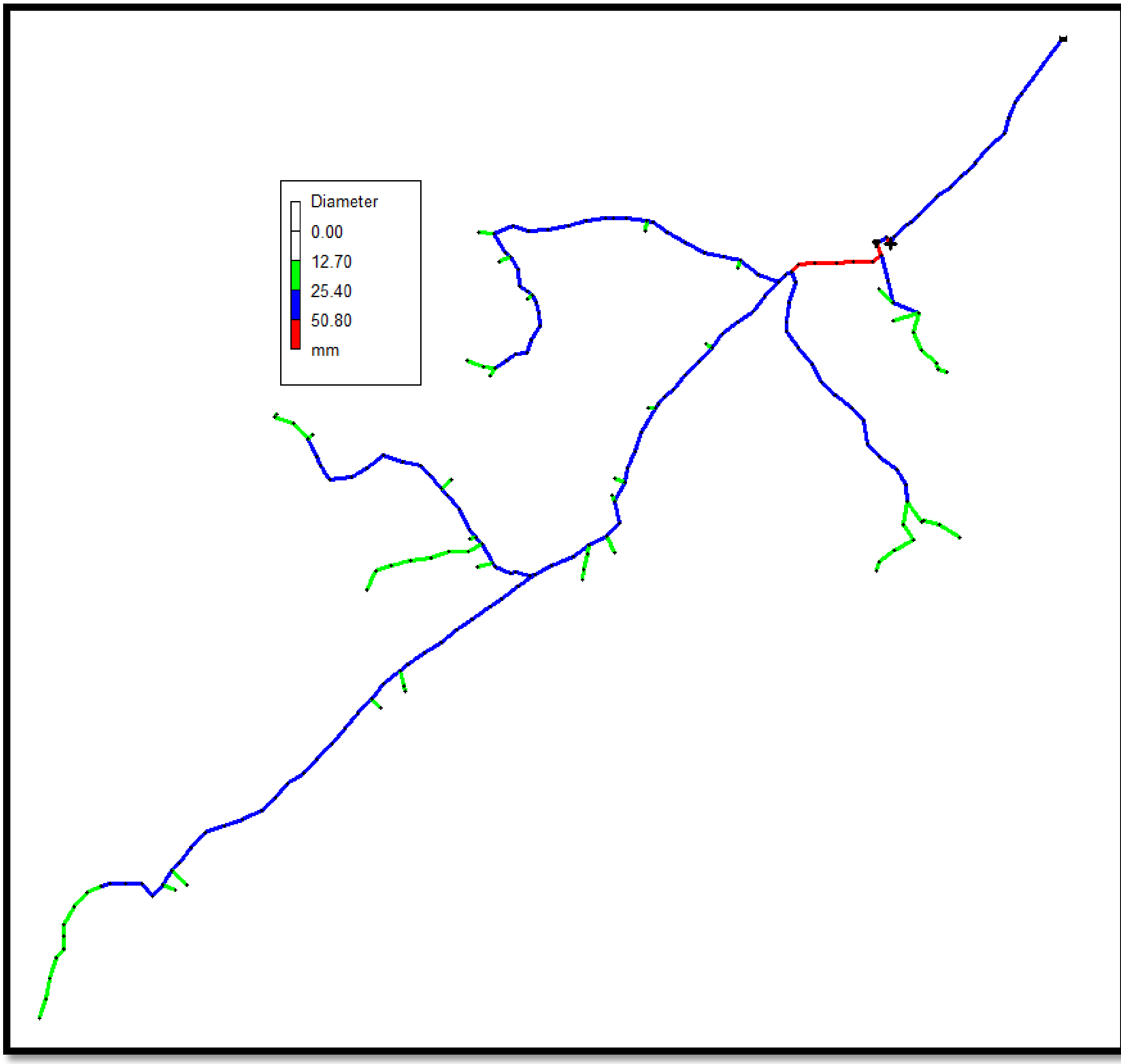


Figure 14: EPANET schematic detailing pipe sizes and layout

One potential problem encountered is enormous pressure values throughout the system. Figure 15 shows the pressure gradient throughout the original EPANET model when the entire system is shutoff, creating the highest pressures in a static setting. One design issue is that a typical faucet can only withstand 60 meters of pressure head (Mihelcic et al 2009). Referring to Figure 15, all tap stands located in the green or red regions would experience pressures greater than the allowable pressure. Likewise, the PVC pipe typically used for a system such as this also has a maximum operating pressure. To combat these issues, Yucca Engineering recommends implementing pressure break tanks throughout the system.

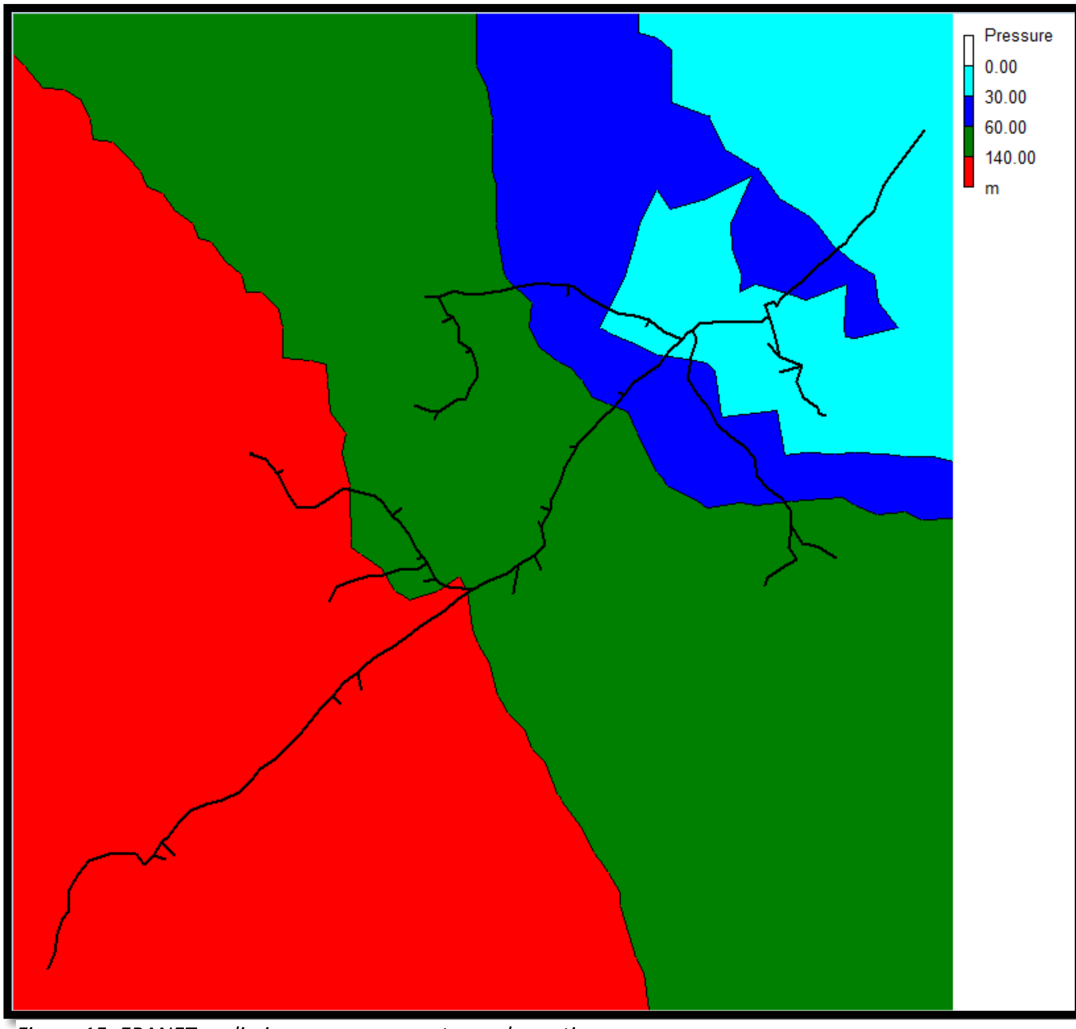


Figure 15: EPANET preliminary pressure contour schematic.

While the main issue was regarding excess pressure, too little pressure was also encountered in some locations. The first tap stand on branch A has an elevation difference of 1.34 meters between it and the storage tank. This creates a pressure at the tap stand of only 0.71 meters of head, which is below the minimum recommended pressure of ten meters of head for a gravity fed water system (Mihelcic et al, 2009). As the difference in elevation is so minimal, one way to increase pressure for this tap stand would be to build it shorter in height than the others, or elevate the storage tank. Due to the effort and cost involved with elevating the storage tank, building a shorter tap stand would be recommended. However, this still will not achieve the recommended minimum pressure of ten meters of head. A final option would involve locating the tap stand for this household further away but at a lower elevation.

To address high pressures, a total of six pressure break tanks were needed in order to maintain pressures within an acceptable range. The locations of the six tanks are shown in Figure 16. These were modeled in EPANET effectively through splitting the overall model into seven separate models, each starting where a break pressure tank would be located. These sub-section models and associated pressure contour schematics can be found in Appendix B.

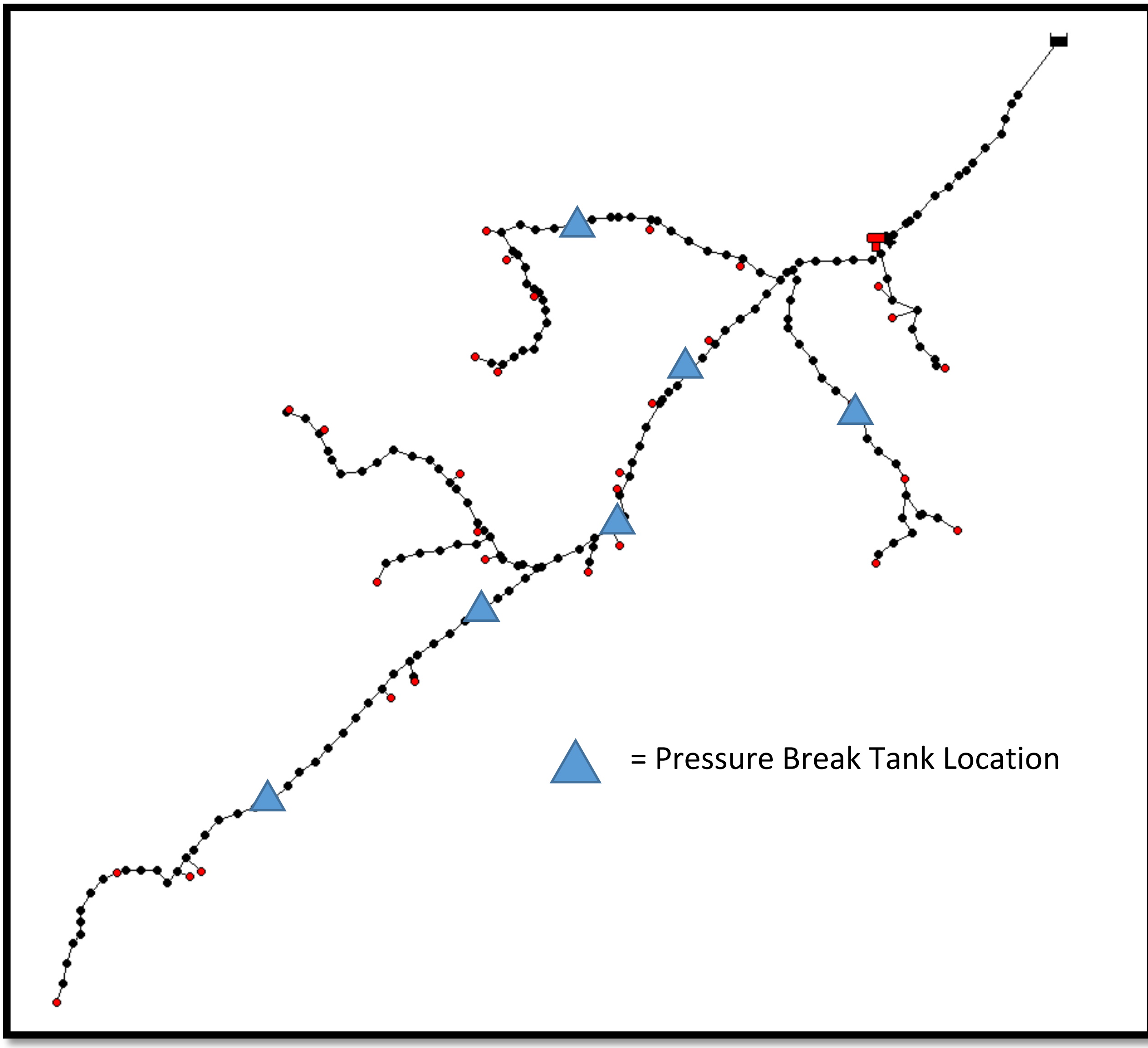


Figure 16: EPANET schematic detailing location of pressure break tanks.

4.3 Storage Tank

To provide the system with a way of storing water during the night hours and for treatment time, a storage tank will be constructed before any water leaves the mainline. The storage tank, shown in Figure 17, will be located 350 meters after and 32 meters lower than the spring box in a grassy opening. Based on the community's water demands throughout the day, the tank is designed to hold eight cubic meters of water, with 1.125 cubic meters of space for overflow and air. Tank design criteria can be found in Appendix D.

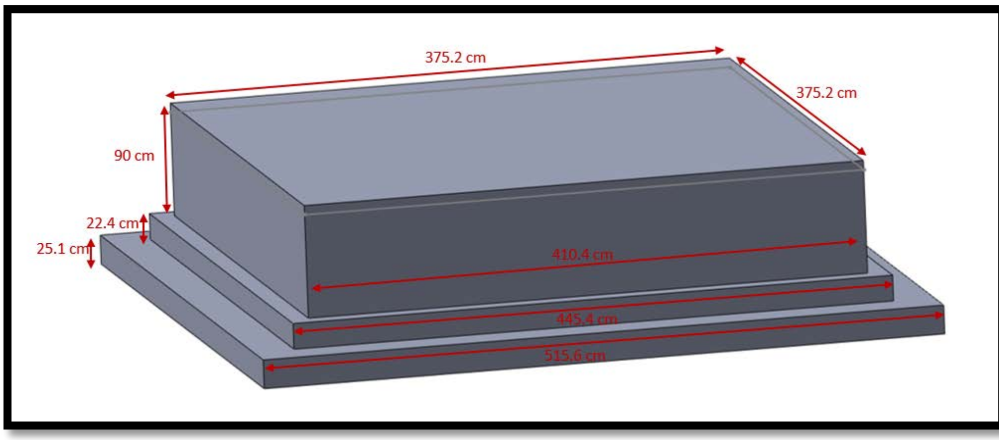


Figure 17: Storage Tank

Based on water usage data provided by the Peace Corps, it was determined that the community would essentially have no demand during the night hours. Due to this, the tank was designed to act as a storage device between the hours of 10 PM – 5 AM. By having water stored overnight, disinfection from the in-line chlorinator will have adequate contact time. Seen below in Figure 18 is the change in water level within the tank during a 24 hour period. As shown in the graph, the water level drops only 0.25m, maintaining at least 3000 L in reserve.

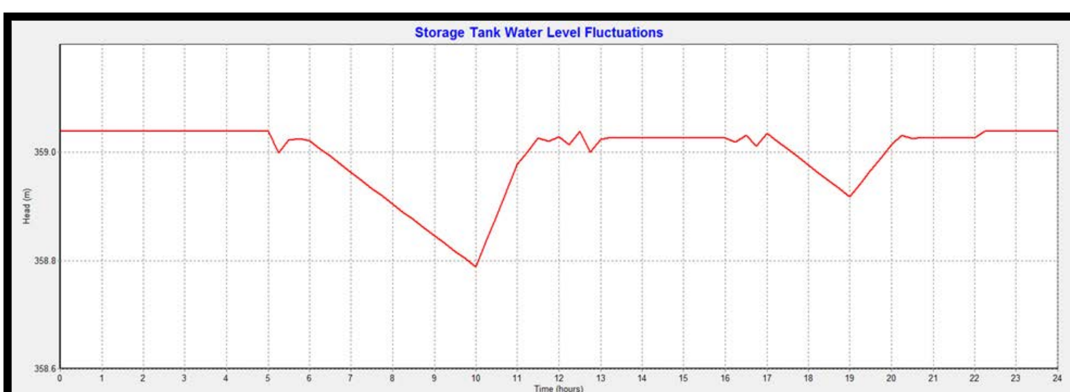


Figure 18: Storage Tank Water Level through a 24 hour period

4.4 Chlorinator

To complete a water system design, the team emphasizes using the in-line chlorinator to supply ample and clean drinking water. The main source of water, a spring coming out of large rocks at the top of the hill, had been briefly tested by the team for E. coli and total bacteria with 3M™ Petrifilm™ and was found to be contaminated. Positive results for E. coli and total bacteria is an indication that similar, less detectable microorganisms may be present. There are hundreds of known pathogens that are orally transmitted from drinking water (Table 1, p258, Gadgil 1998). Many of these microorganisms cause many serious health problems including diarrhea.

The water treatment method recommended for this system is an in-line chlorination device made entirely of PVC, as pictured in Figure 19. A 4" diameter tee will be connected to the conduction line for continuous disinfection just before the storage tank. Inside the capped tee sits a capsule with small holes that holds the locally available calcium hypochlorite tablets. As water flows through the chlorinator and capsule on the way to the storage tank, chlorine dissolves into the water. The combination of time and concentration of chlorine allows adequate disinfection for microorganisms to be killed.

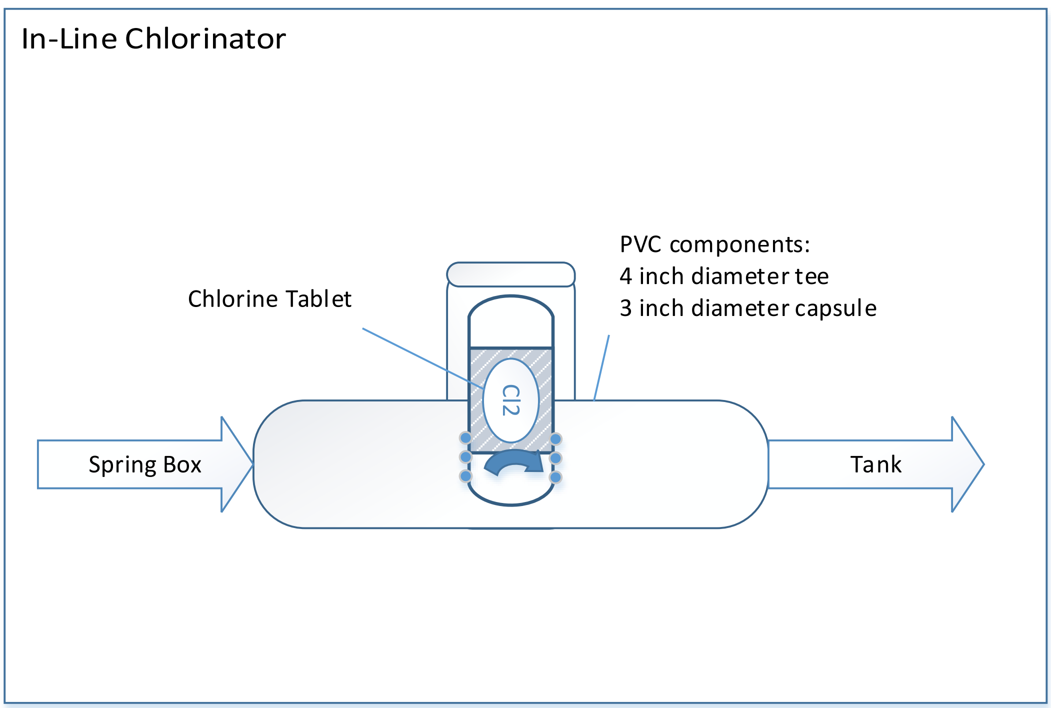


Figure 19: In-line chlorinator schematic showing the capped PVC tee with a chlorine tablet inside a capsule with bore holes, and the flow inlet from the spring box and outlet to the storage tank.

The chlorine tablets available are made of calcium hypochlorite and contain 60 percent free chlorine. They are manufactured by Provichlor (Ruequim) in Morelia, Mexico. The tablets are distributed by the Panamanian Ministry of Health (MINSA) nearby in San Felix at no cost for community members. Each tablet weighs 200 grams and is 3 inches in diameter. (Two new tablets can fit in the chlorinator capsule.) The tablet dissolves slowly as water is allowed to contact it. The higher the flow rate, the faster it dissolves. Empirical data demonstrates a dissolution rate of 0.34 g/1000L (Orner 2011). This data was interpolated onto this system's flow rate of 38 L/min, indicating the tablets will dissolve at 0.51 g/ 1000 L and each tablet is expected to last one week in this system.

The effectiveness of the chlorine disinfection depends on the CT value, a combination of concentration and treatment time. The storage tank has a been designed to have more than enough residence time to supply the community with enough water, as well as allow enough time for the free chlorine to disinfect properly. The storage tank has a residence time of 2.7 hours. Attached to the time component is a mixing factor called the baffle coefficient. Initially the team used a baffle coefficient of 1, but later concluded that a coefficient of 5% should be used for our flow set up (EPA 2010 p.6). This changes the effective chlorine effectiveness to C*T*u (concentration x time x baffle coefficient), leading to a value of 0.95 mg-min/L. This concentration is still adequate to disinfect most bacteria and viruses. The CT value is calculated as follows: 162 min*0.3*0.51 mg/L= 25 mg-min/L, which is sufficient to inactivate a majority of pathogens and viruses, as the required CT value for that is only 0.5 mg-min/L.

4.5 Pressure Break Tank

The proposed Quebrada Arena water distribution system has an overall elevation difference of 300 meters from the source to the lowest house on the pipeline. This creates a large pressure build up which may exceed the capabilities of the pipe or faucets and may cause failure in the system. The maximum pressure for SDR 26 PVC pipe is 112 meters of head, while faucets have a maximum pressure of 60 meters of head, for safety purposes, as mentioned above. To alleviate the excess pressures encountered in the pipelines, six pressure break tanks are recommended.

Figure 20: Example of a concrete break pressure tank. Note the influent line is also protected with concrete. Photo by mrkdv18-Flickr

A pressure break tank opens the pipeline up to the atmosphere as the water runs through the open-air tank. The gage pressure within the pipeline reduces to atmospheric pressure within the tank. Properly placing the tanks throughout the system allows for proper management of pressure and allows lower pressure-rated, and therefore less expensive, pipe to be used. Multiple concrete pressure break tanks are recommended for the Quebrada Arena water distribution system. An example of the pressure break tank can be found in Figure 20, while a schematic of a tank design for the system can be found in Appendix H. These pressure break tanks are to be made of concrete and coated with a waterproof sealant. The volume of the tanks will be 0.56 m^3, though capacity is only necessary to include all the components of the tank. The tank incorporates an influent and effluent pipe, which are both sized at 1" in order to allow an equal flow of water in and out of the tank, therefore eliminating air buildup. A float valve is located on the influent pipe in order to prevent overflow and therefore a waste of water in the system. This design provides durability from not only high pressure water flowing into the tank but also protects the pipeline when it surfaces for the tank. Correct placement of the pressure break tanks is vital in order to ensure adequate pressures throughout the system. A description of the pressure break tank locations and distances from landmarks along the pipeline can be found in Appendix B.

4.6 Gully Crossings

Two pipe suspension gully crossings were designed for the pipeline system to clear the span of two river beds. Figure 21 represents a standard suspension bridge being constructed. The first gully crossing lies between the source and the tank. It will span a length of 38 meters over a ravine with a 16 meter drop. The pipe crossing will have an allowable sag of two meters. To protect the main pipeline from UV deterioration and possible damage from exposure, a 2" SDR 26 PVC pipe will act as a casing around the main pipeline. Using a factor of safety of three for the total tension on the cable, a calculated maximum load of 900 lbs will be placed on the cable. To provide structural support against the total tension, a 1/8" cable with a 1x19 construction will absorb the loads due to the two pipelines and water. A total cable length of 79 meters will be required to span the length and support the pipeline every two meters. To counter the forces due to the pipeline and cable, an anchor will be located at each end of the bridge. A standard mass block anchor with dimensions of 0.9m x 0.9m x 1.2m and a density of 140lb/ft^3 is suggested. The total weight of the each anchor will be 5400 lbs, or 2450kg. This size anchor will adequately withstand the force exerted by the pipeline at each support. As stated previously, all force calculations were done with a factor of safety of three. A detailed cross section of the gully crossing can be found in the Appendix F.

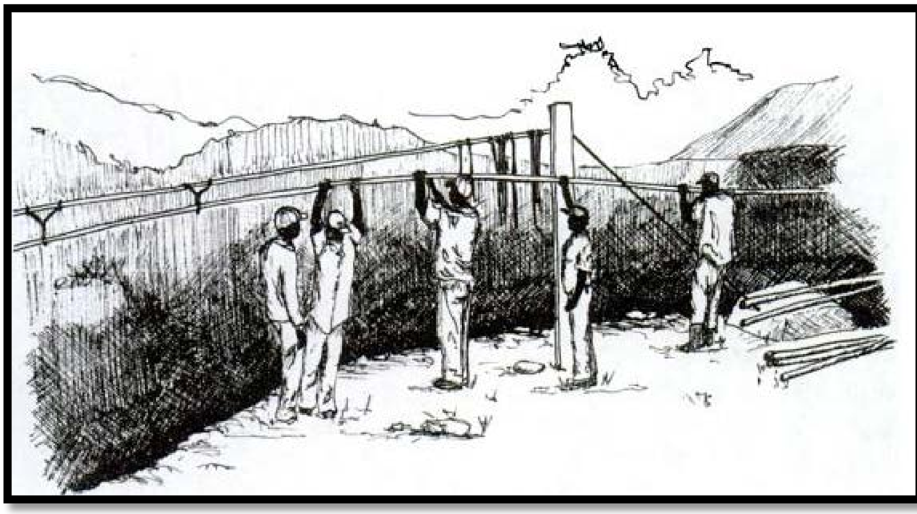


Figure 21: Sketch of construction of PVC suspension bridge (Mihelcic et al. 2001).

The second gully crossing lies near the end of the system on the mainline. It will span a length of 35 meters over ravine with a four meter drop. The pipe crossing will have an allowable sag of two meters. Similar to Bridge 1, Bridge 2 will have a 2" SDR 26 PVC pipe that will act as a casing around the main pipeline. To provide structural support, 1/8" cable with a 1x19 construction will withstand the loads due to the pipeline including water and casing. A total cable length of 59 meters will be required to span the length and support the pipeline. To counter the forces due to the pipeline and cable, an anchor will be located at each end of the bridge. A standard mass block anchor with dimensions of 0.9m x 1m x 0.9m and a density of 2400kg/m^3 was designed. This size anchor will adequately withstand the 756 lbs, or 343kg, force exerted by the pipeline at each support. A detailed cross section of the gully crossing can be found in the Appendix G.

4.7 Water Hammer and Air Release Valves

Air blockage may be encountered within a gravity fed water system and create an operational hazard. This occurs when pockets of air form in highly elevated points of the pipeline, eventually restricting or preventing flow. Since air is highly compressible, a Headloss occurs in the system wherever an air block occurs due to the pressure exerted into the air mass. This head loss may result in stopping the flow of the system. With a gravity fed system it is important to plan for the eventual introduction of air into the system. The proposed system does limit the effect of air blockages due to the large amount of head throughout the system, which promotes the travel of air throughout the pipeline, however, it cannot be relied upon. Therefore, air release valves (ARV) are recommended at five points along the pipeline.

ARV's allow air masses to be released from the system without losing any water from the system. Properly installed, ARV's do not weaken the pipeline nor impede the flow of water.

Locations for the ARV's were selected via the elevation profiles of the pipeline and can be seen in Appendix A. Design of the ARV's can be found in Appendix I.

Water hammer occurs when the flow to a tap stand is suddenly stopped. This cessation of flow creates a pressure buildup throughout the water system, which could damage the pipeline. To negate the effects of water hammer, faucets on the tap stands should be turned off slowly, allowing the flow to gradually come to a stop. Slow turning faucets may be implemented into the tap stands in order to provide this. Globe valve faucets with long stems enable all users of the system, such as children, to safely turn off a faucet without great concern of water hammer.

4.8 Tap Stand

To fulfill the objective of supplying water to the community in a manner which reduces travel to various sources, each home will have its own tap stand to serve as their access to water. In total, there will be 32 tap stands serving eight people each. The locations of each tap stand were indicated to Yucca Engineering by members of the Quebrada community. Typically, the tap stands will be placed where current community member houses are located. However, there are a few proposed tap stand locations at areas where houses will be constructed in the near future.

There are several forms of tap stands which vary drastically in regards to their structural integrity. For the Quebrada Arena, it is suggested that they install concrete tap stands with splash pads under the faucet to reduce erosion. A proposed design of the tap stands can be seen in Figure 22. The benefit of having a concrete tap stand is the prevention of damage to the PVC pipe because it is covered in the column. As seen in Figure 22, a 0.5" PVC pipe will run through the tap stand and then exit the concrete column 1 meter up. Extending out of the concrete will be the end of the 0.5" PVC pipe with a screw-faucet to control flow.

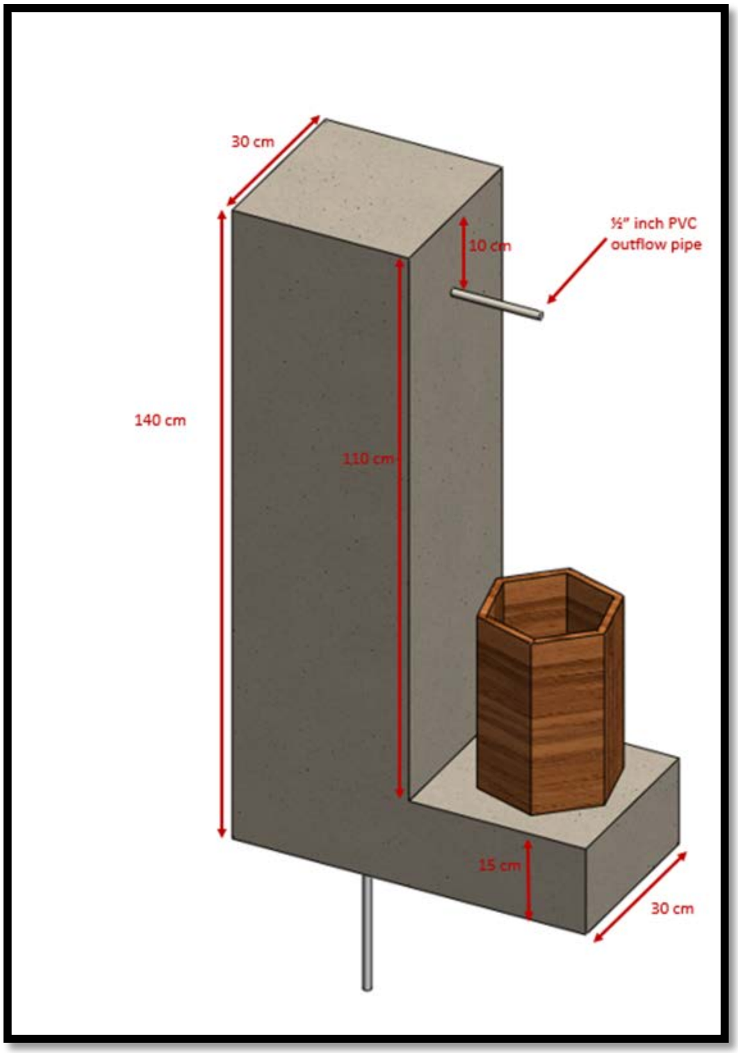


Figure 22: Proposed Tap Stand Design

5.0 Materials/ Cost

The overall estimated cost of the proposed system is $12,300. Table 3 shows the cost of each individual component of the system (note that the grand total is rounded to the nearest hundred). The largest individual cost will be the pipe at just over $5,000. Since the region is mostly clay soil, sand and gravel will have to be brought in. If any is found locally, additional labor will be required. Transportation costs are reasonable as each driver has to make a special trip to the community. However, the costs were given by Peace Corps Volunteer Jake Midkiff based on his time spent in the area.

Table 3: Sum of estimated costs of the water distribution system

Item	Description	Estimated Quantity	Unit	Unit Availability	Unit Cost	Total Cost
1	Spring Box (1)	1	Job	Job	$952.03	$952.00
2	Storage Tank (1)	1	Job	Job	$1,231.97	$1,232.00
3	Tap Stand (32)	32	Job	Job	$45.78	$1,465.00
4	Pressure Release Tanks (6)	6	Job	Job	$123.35	$740.00
5	Bridge Structure (2)	2	Job	Job	$327.42	$655.00
6	In-Line Chlorinator (1)	1	Job	Job	$28.76	$29.00
7	Pipeline (3.6 miles)	1	Job	Job	$5,070.18	$5,070.00
8	Air-Release Valve (5)	5	Job	Job	$5.50	$28.00
9	Transportation of Materials	15	Job	Job	$65.00	$975.00
					Total:	$11,146.00
					10% Overhead:	$1,114.00
					Grand Total:	**$12,300.00**

Labor is expected to be provided in-kind by the community members. Likewise, any skilled labor needed is expected to be donated by the Peace Corps. The detailed cost estimate, with a breakdown of each component of the system, can be found in Appendix J.

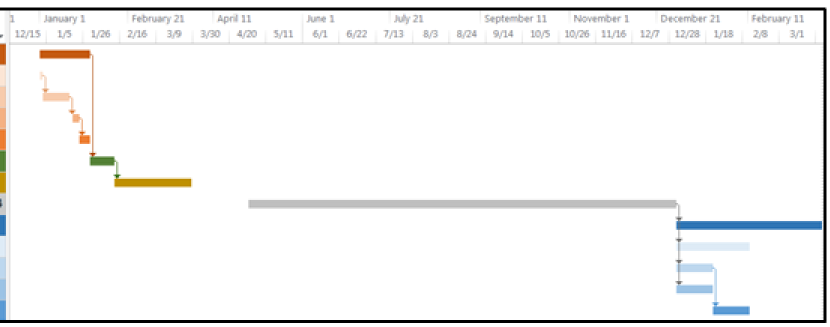
6.0 Construction/Schedule

For the system to be properly constructed within two dry seasons, it is necessary for the community to provide at least 5 laborers to assist a Peace Corps Volunteer. All durations discussed below are based on crews of at least 5.

From start to finish, it is expected that the installation of the system will need at least six months which spans the duration of two dry seasons (Figure 22). This time includes the digging and laying of 3.6 miles of pipeline, constructing the storage tank out of concrete blocks, erecting 32 concrete tap stands, building 6 pressure break tanks, and constructing the spring box. The task with the greatest duration will be laying the pipe. This is due to the anticipated slow pace for digging the trench for the pipe. The total time for laying the pipe is expected to last two months. This will only be possible if each member of the crew can maintain a pace of 100 feet per day. Additionally, as the pipe is being laid, the pressure break tanks and gully crossings will need to be constructed, adding significant time to this task. Because the exact location of the pipeline cannot be predetermined due to unforeseen circumstances, such as unexposed boulders, the pressure break tanks and gully crossings will have to be constructed once the final location of the pipe is known.

In the first dry season of construction, the storage tank, spring box, and tap stands will be constructed in this order. One dry season should be enough time for these three components to be properly constructed. For the second dry season, the remaining components will be

Task Name	Duration	Start	Finish
Construct Storage Tank	21 days	Wed 1/1/14	Wed 1/29/14
Place Gravel Foundation	2 days	Wed 1/1/14	Thu 1/2/14
Lay Blocks	11 days	Fri 1/3/14	Fri 1/17/14
Pour Concrete Floor	4 days	Mon 1/20/14	Thu 1/23/14
Pour Concrete Roof	4 days	Fri 1/24/14	Wed 1/29/14
Construct Spring Box	10 days	Thu 1/30/14	Wed 2/12/14
Construct Tap Stands	32 days	Thu 2/13/14	Fri 3/28/14
Wet Season	175 days	Thu 5/1/14	Wed 12/31/14
Lay Pipe	60 days	Thu 1/1/15	Wed 3/25/15
Dig Pipe Trench	30 days	Thu 1/1/15	Wed 2/11/15
Prepare Gully Crossing 1	15 days	Thu 1/1/15	Wed 1/21/15
Construct Pressure Break Tanks	15 days	Thu 1/1/15	Wed 1/21/15
Prepare Gully Crossing 2	15 days	Thu 1/22/15	Wed 2/11/15



constructed: laying the pipe, gully crossings, and pressure break tanks.

Figure 23: Construction Schedule lasting the duration of 2 dry-seasons

Once the system has been fully constructed and is running properly, minimal maintenance is expected to be needed. However, it is crucial for the pipeline to be constantly observed to ensure all piping is structurally sound and flowing without interruption. It is nearly inevitable that sections of piping will become damaged over time and will require replacement or maintenance. Additionally, all components of the design involving concrete will likely need maintenance to fix broken edges and water leaks.

7.0 Conclusions and Recommendations

The purpose of the iDesign Program is to improve current conditions and enhance those conditions through understanding what a community desires and designing a functional system based on engineering sustainability. With that in mind, when Yucca Engineering traveled to the Quebrada Arena in Panama, these principles were held paramount. Upon arrival in the country the team realized there was no water distribution system in place and no infrastructure that would aid in a distribution system. A practical design was needed to transport clean water to the homes in the community. Through the guidance of the Peace Corps volunteer and the desires from the community, Yucca Engineering set out for the data collection process that would allow for the design of a gravity fed water distribution system.

The designed distribution system is low maintenance, which will help increase the longevity and sustainability of the design. The major components of this system are the pipeline, designed using EPANET, a storage tank, a spring box, the in-line chlorinator, pressure break tanks, and 32 tap stands. As the design process began Yucca Engineering had to improvise and manipulate the parameters in order to produce a functioning design. With the homes in the community so spread out the engineering feasibility of a working design was certainly a constraint and perplexing at times. The pipeline which stretches over three miles of treacherous terrain entailed the most calculation and engineering judgment. Due to the extensive length of the pipeline and elevation differences, pressure break tanks were a necessary design implementation. The tanks allowed the water to continue to flow without bursting the pipeline or the taps located at the homes. With the appropriate pipe pressures the rest of the design will be able to function properly.

With a construction crew made up of 5 volunteers from the community members utilizing the system and the current Peace Corps volunteer overseeing and directing, the construction should take no longer than two dry seasons, or 6 months, to complete. The total cost for the entire design is $12,300. Together with fundraising and donated supplies Yucca Engineering is hopeful that the proposed design will in fact be constructed and implemented.

Yucca Engineering has many recommendations for the construction and maintenance of the distribution system. These recommendations are based on either safety or reducing the environmental impact. The first and very important recommendation is that the pipeline be buried at least two feet from the ground surface. This will protect the pipe from UV degradation, weather elements, and human and animal traffic. Also recommended is that any overflow from the spring box be diverted back to the source to reduce erosion of the nearby area. Any sort of erosion due to overflow is not desirable and diverting that water back to the source should be a top priority.

Another recommendation is that children and animals are kept away from the spring box and storage tank. Safety is a top priority and concern for Yucca Engineering and that is why our team cannot emphasize enough that no child should be near either the box nor tank at all times. The concern with animals being nearby is that any sort of contamination could be transferred to the community members who are using the water.

Finally, Yucca Engineering is hopeful that the Peace Corps volunteer will train community members in maintenance related concepts. These concepts would include observing the pipeline to ensure structure stability and fixing any concrete related issues, such as cracks or leaks, as stated previously.

Yucca Engineering is pleased with the design and hopeful the community for which it was designed to serve is quite pleased with the system. With these recommendations, the team feels confident that the design will function properly for an extended period of time.

8.0 Acknowledgements

Yucca Engineering would like to thank the following people for their continued support, advice, and expert knowledge throughout the entire project.

Department of Civil and Environmental Engineering

Dr. David Watkins (P.E.) and Mike Drewyor (P.E.)

International Senior Design forces one to explore new studies and learn without a lecture every day. Yet this project would not have been possible without Professor Drewyor and Dr. Watkin's constant mentorship and project expertise. Coaxing the team through each step of the design process, both lent a steady hand that ensured the overall project. Their unrelenting patience is greatly appreciated and exemplified the amazing faculty that Michigan Tech is known for.

Peace Corps Panama

Peace Corps Volunteer Christopher Kingsley

The week spent with Chris was filled with constant learning and challenges. Time spent playing Euchre in the Panamanian night was as equally enjoyable as learning the language Ngäbere while hiking a mountain. We wouldn't have been able to make it through the time spent in the community without his constant leadership.

Peace Corps Volunteer Jacob Midkiff

A Michigan Tech Student as well, Jake stumbled into our campsite towards the end of our time in Panama to say hello. After travelling back to the United States he was an infinite source of knowledge that luckily was just a short walk down the hallway.

Michigan Technological University Graduate Peace Corps Master's International Program

Graduate Student Mentor Zoe Miller

Guiding us through the hazards of the Spanish language, Zoe made the trip even more exciting. Countless times she intervened on our behalf as we struggled with a new language. Her presence along the trip reminded us to stay focused and on task.

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Appendix A Pipeline Elevation Profiles

The elevation profiles below are created by EPANET. Detailed is each branch as identified in Section 4.2 Pipeline Design. Each green diamond represents the location of an air release valve due to a local high point in elevation in the pipeline. The first high point shown on Figure A-1 is the location of the storage tank and therefore does not require an ARV.

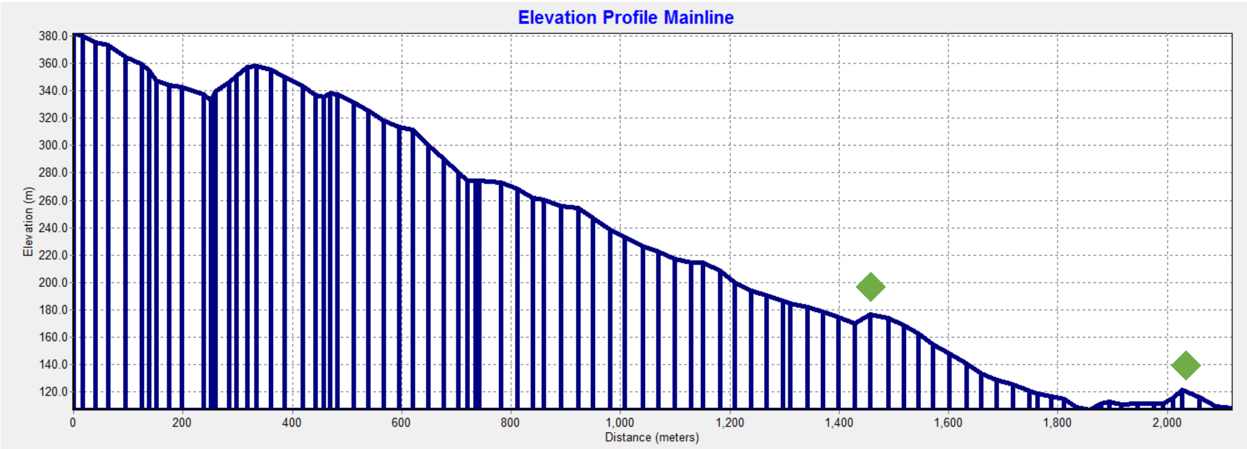

Figure A-1 Elevation profile for the mainline of the pipeline.

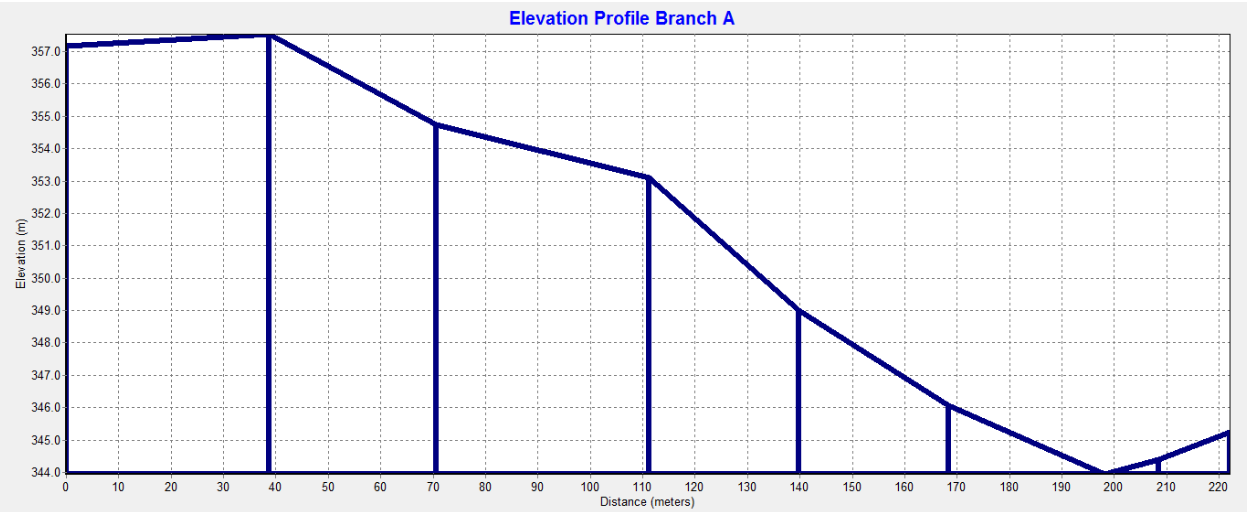

Figure A-2 Elevation profile for Branch A of the pipeline.

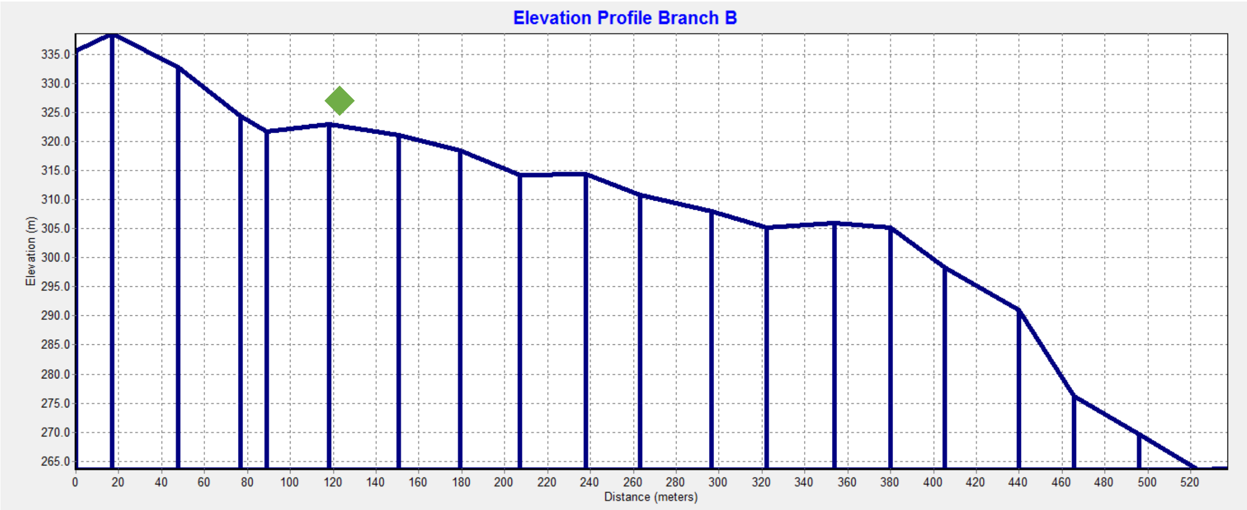

Figure A-3 Elevation profile for Branch B of the pipeline.

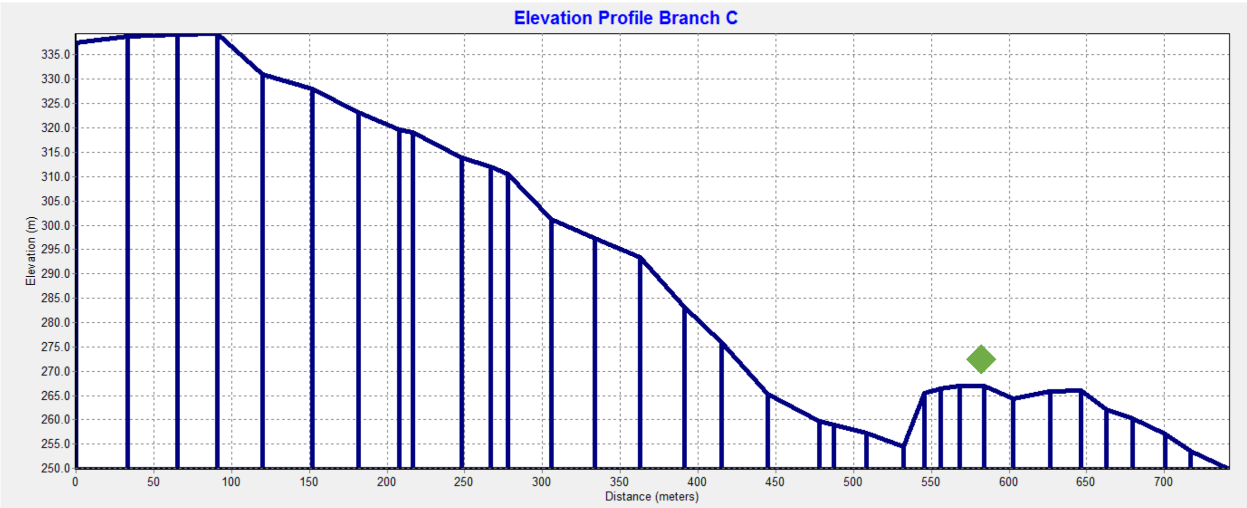

Figure A-4 Elevation profile for Branch C of the pipeline.

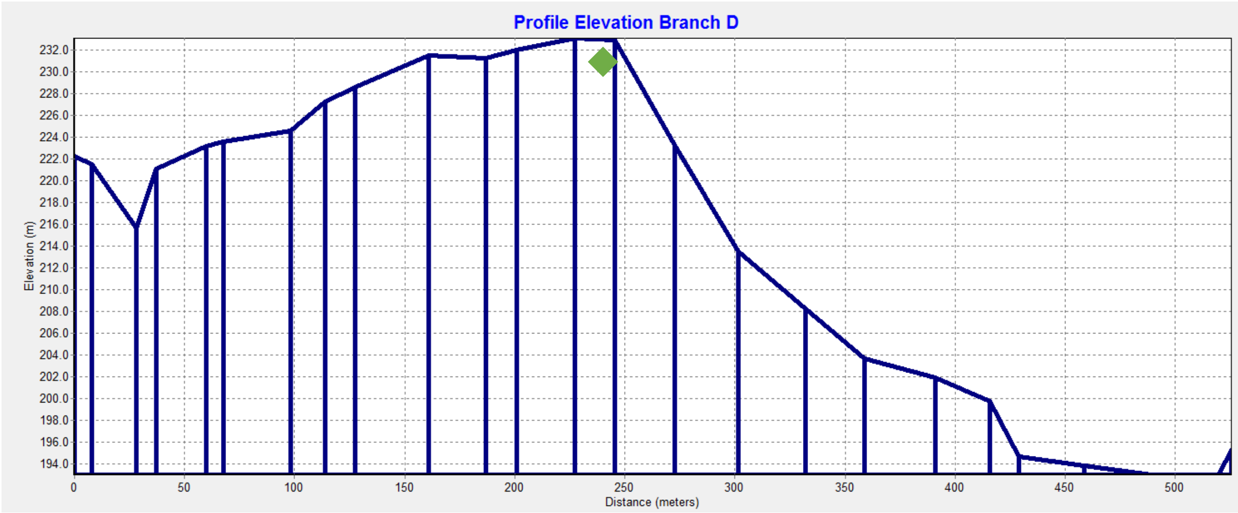

Figure A-5 Elevation profile for Branch D on the pipeline.

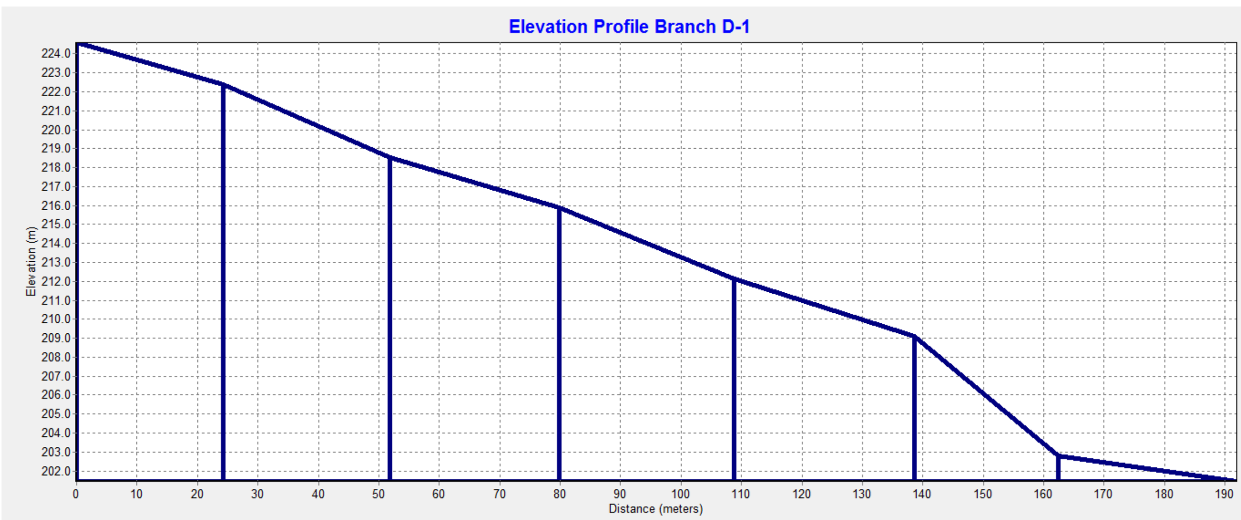

Figure A-6 Elevation profile for Branch D-1 on the pipeline.

Appendix B Pipeline Section Pressure Schematics

The pipeline detailed is divided into seven sections for modeling purposes. Each section has a subsequent contour pressure schematic. The beginning of each new modeling section represents the location of a pressure break tank.

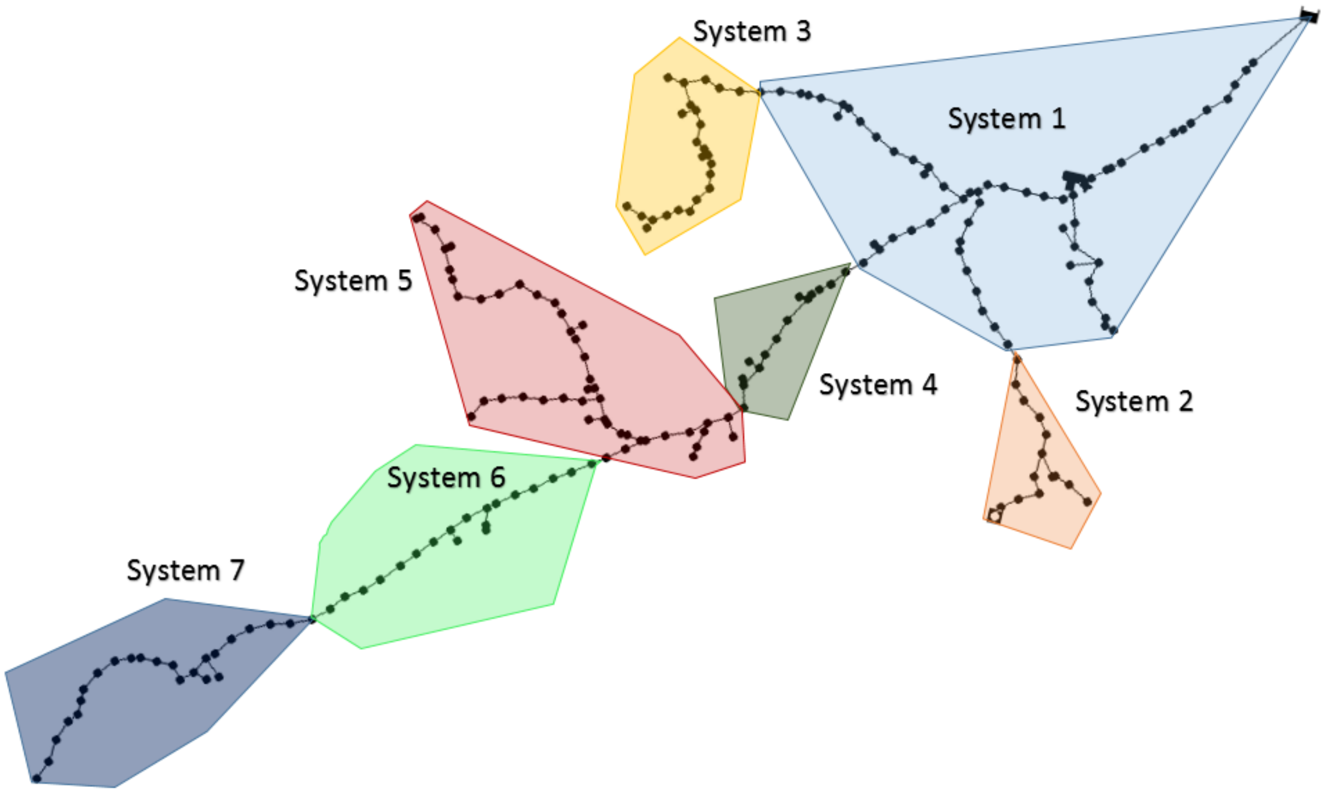

Figure B-1 EPANET schematic of the pipeline showing each separate sub system used for modeling purposes.

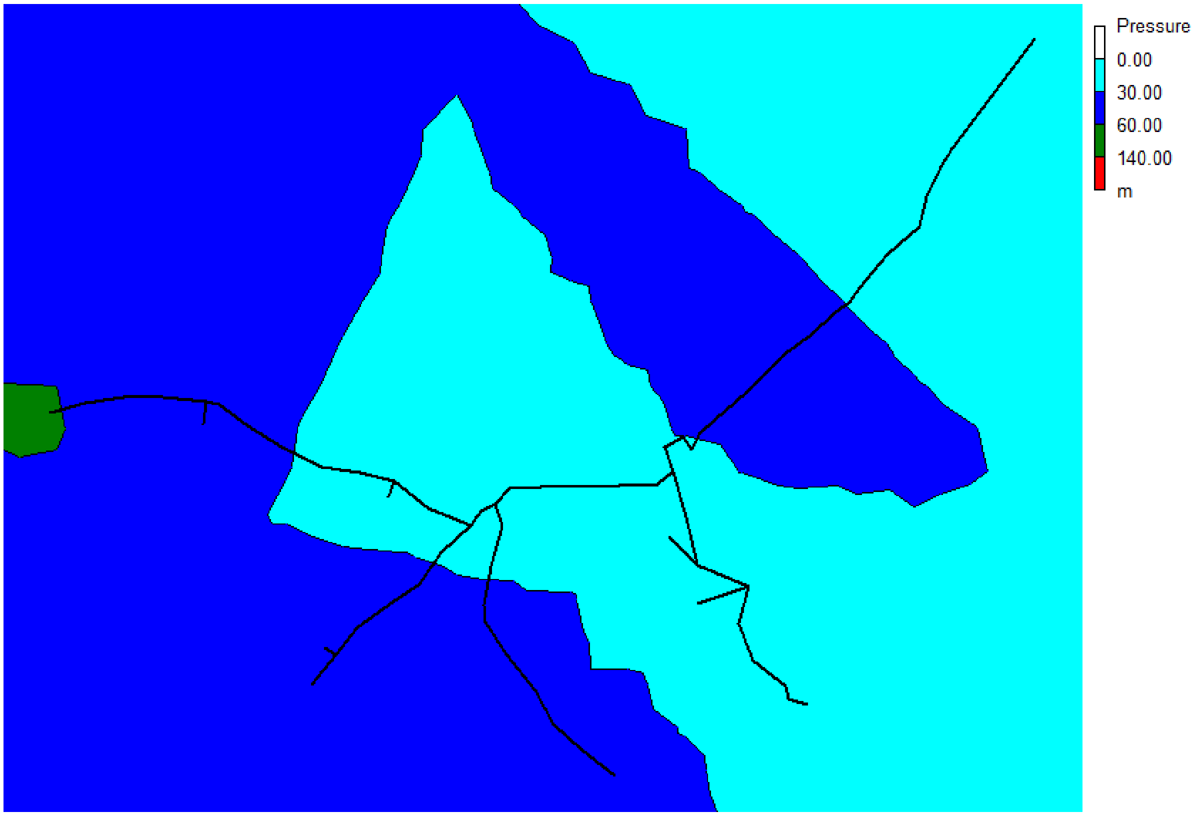

Figure B-3: Peak pressure values of system 1 after implementing a pressure break tank.

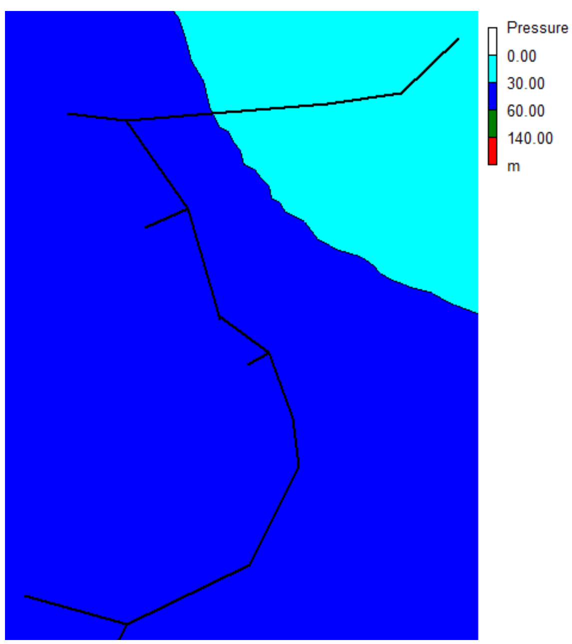

Figure B-2 Peak pressure values of system 3 after implementing a pressure break tank.

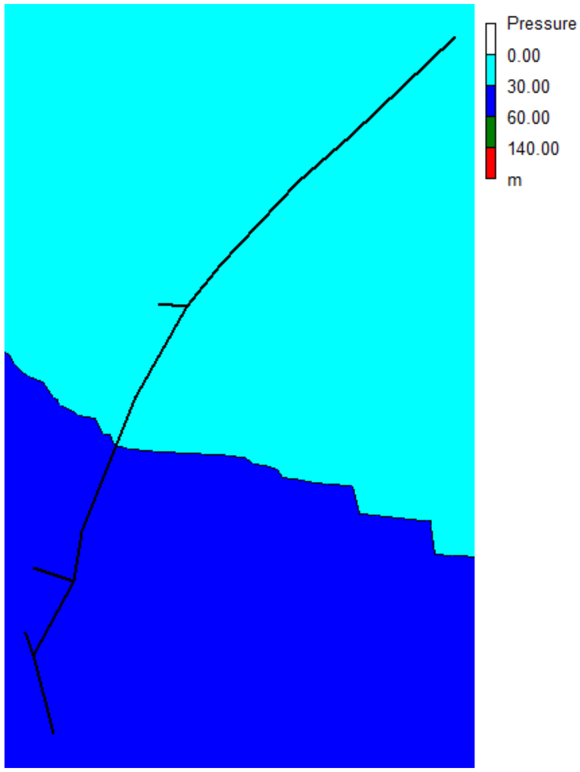

Figure B-4 Peak pressure values of system 4 after implementing a pressure break tank.

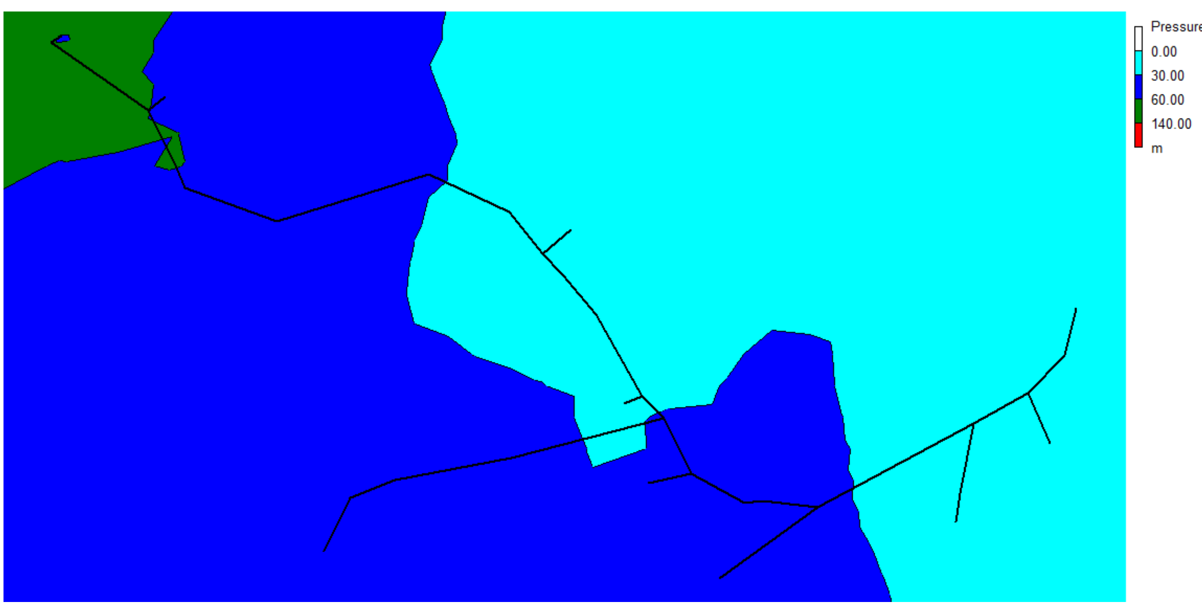

Figure B-5 Peak pressure values of system 5 after implementing a pressure break tank.

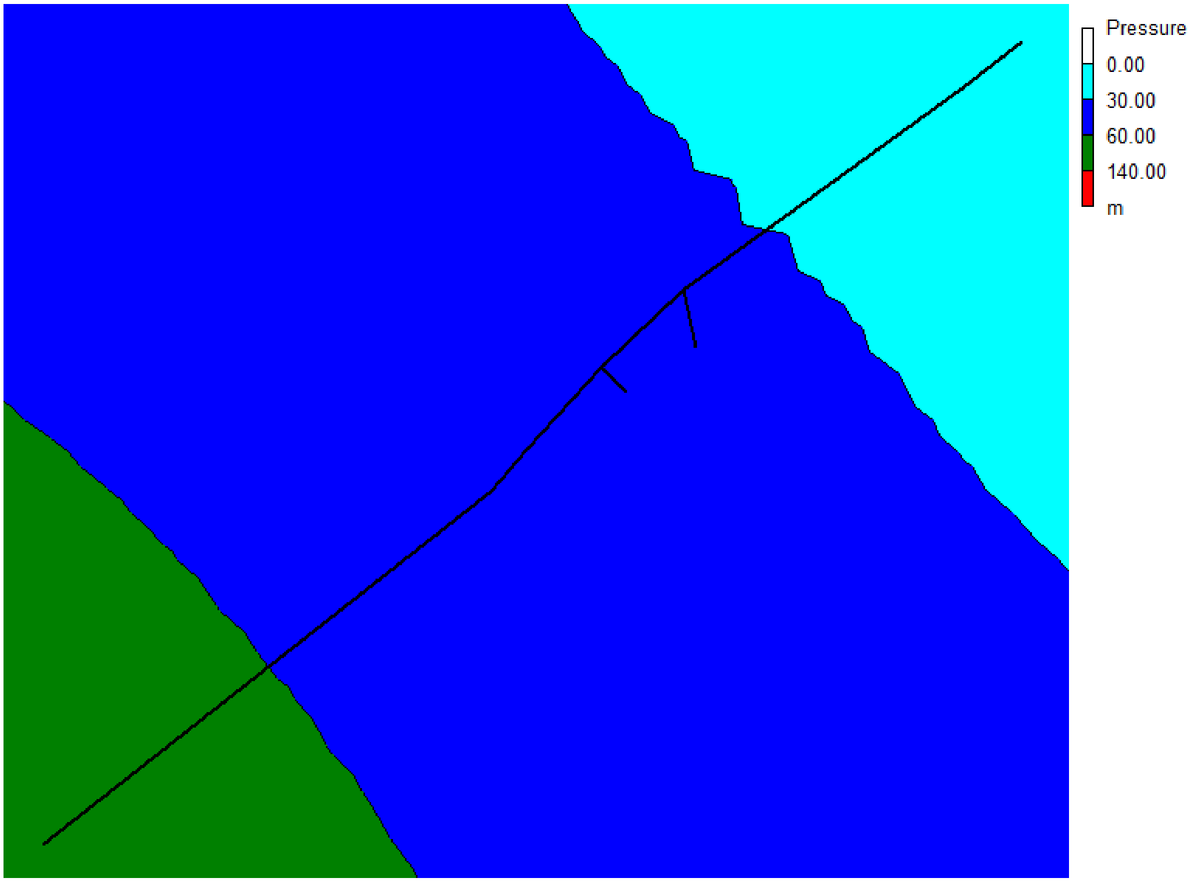

Figure B-6 Peak pressure values of system 6 after implementing a pressure break tank.

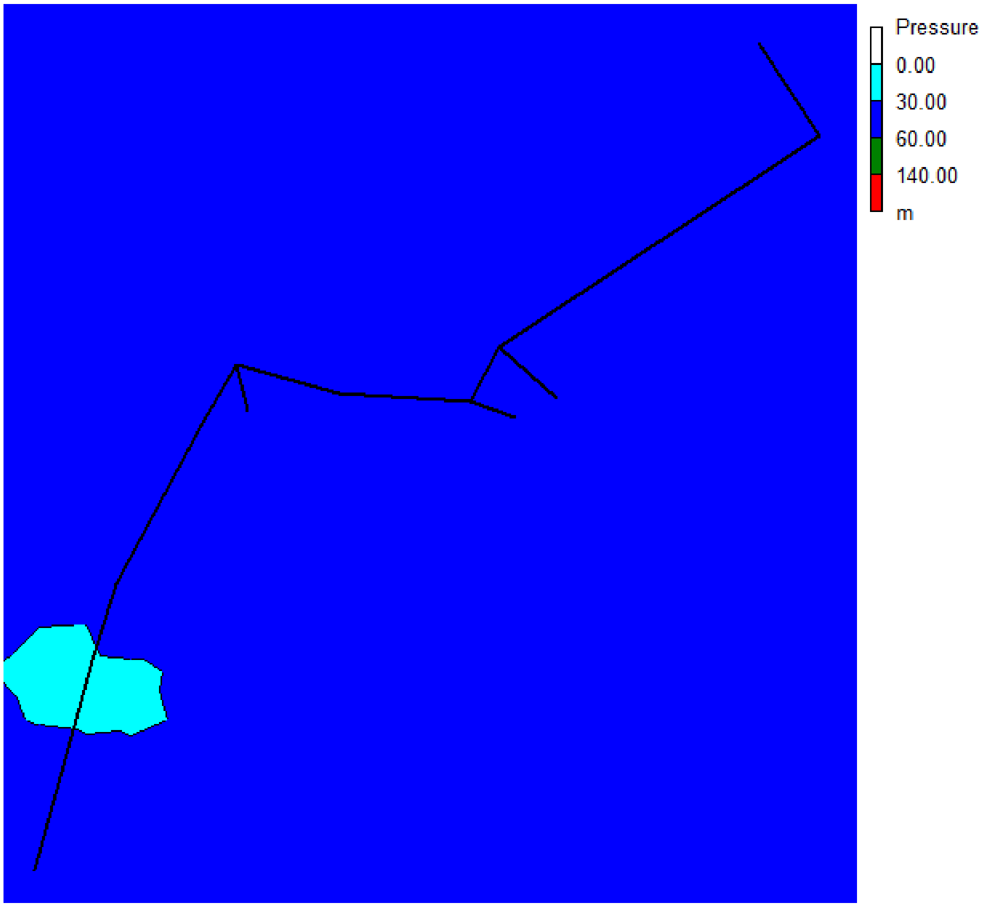

Figure B-7 Peak pressure values of system 7 after implementing a pressure break tank.

Appendix C Water Usage Data

Average water demand was calculated using MINSA assumptions that an average household contains 8 family members who each use 30 gallons of water per day. Peace Corps Volunteers Jake Midkiff and Chris Kingsley related to Yucca Engineering that this number was an overestimate. Taking this into consideration, Yucca Engineering decided to use this data in order maintain a margin of safety.

$$30\ Gallons\ per\ Person\ per\ Day * 8\ Person\ per\ Household = 240\ Gallons\ per\ Household\ per\ Day$$

$$240\ Gallons\ per\ Household\ per\ Day = 908.5\ Liters\ per\ Household\ per\ Day$$

$$908.5\ Liters\ per\ Household\ per\ Day = 0.63\ Liters\ per\ Household\ per\ Minute$$

$$Therefore, average\ tap\ demand\ is\ 0.63\ L/min$$

Peace Corps Volunteer Chris Kingsley provided Yucca Engineering with average water use data from the community he had lived in during his tour with the Peace Corps.

Table C-1 Daily water usage given by PCV Christopher Kingsley.

Tiempo del día	Activity	Amount of H20/House	Total Use at home	X 9 casas	Total Use (galones)
6:00am-11:00am	Breakfast	15 gallons	95 gallons	171 cubos	855 galones
	Wash Clothes	60 gallons			
	Bathe	20 gallons			
11:00am-3:00pm	Lunch	15 gallons	15 gal	27 cubos	135 galones
3:00pm-8:00pm	Bathe	20 gallons	35 gal	21 cubos	105 galones
	Dinner	15 gallons			

The data below was used to calculate use patterns compared to the calculated demand per tap of 0.63 L/min. This is an attempt to mimic the realism behind an average person's daily water use, i.e., someone would not leave a faucet running continuously throughout the day but rather demand more water during heavy use periods.

Table C-2 Usage rates applied to design demand of 30/gal/per/day.

	Total Use		
Time	gal / Hr	L /min	Demand Ratio
6-11 AM	23.75	1.5	2.36
11-2 PM	5	0.32	0.5
5-8 PM	11.6	0.74	1.2

Yucca Engineering applied the calculated ratios to the constant demand rate in order to generate daily water use patterns. Water use begins at 5 A.M. and continues until 10 P.M., with peaks during the morning and night. This pattern was input into in EPANET and applied to the water system model.

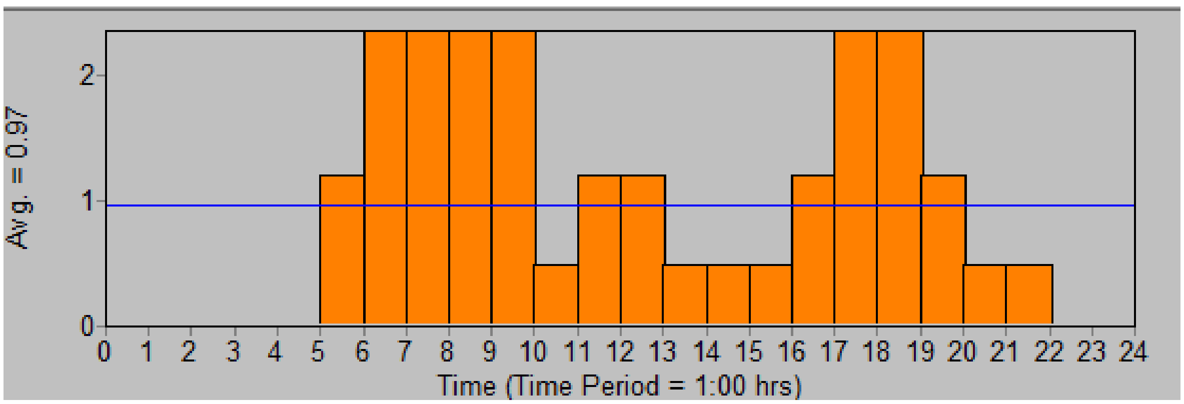

Figure C-1 Water use pattern for EPANET model.

The resultant data shows flow rates through any given faucet very similar to the demand pattern applied. The total volume of water throughout the period is roughly equal to the 908 liters had the demand flow rate of 0.63 L/min been constantly applied to a tap.

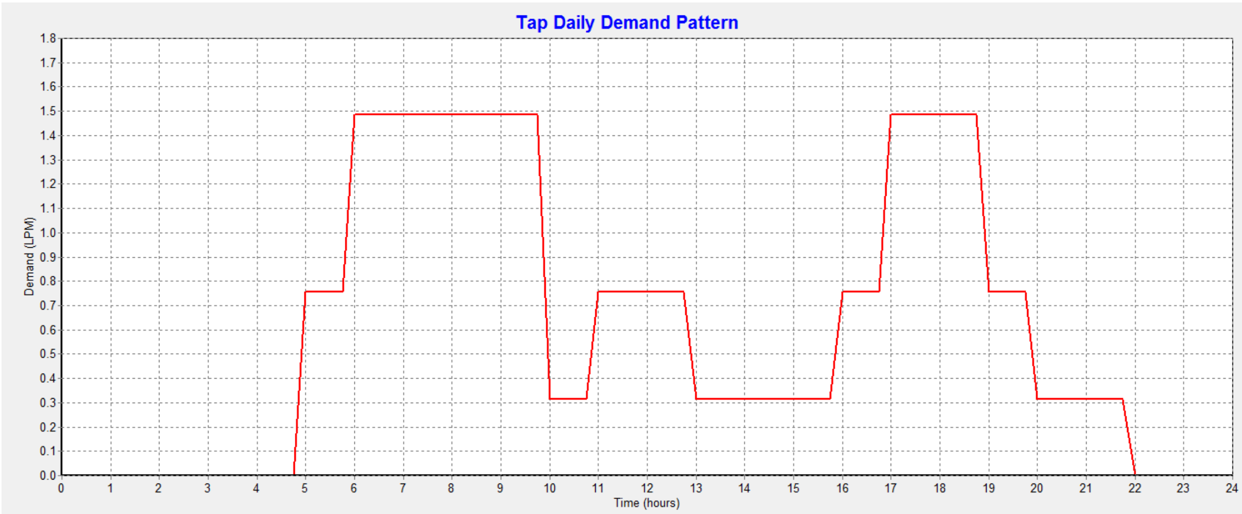

Figure C-2 Estimated daily water use at one household.

Appendix D Storage Tank Design

The inflow to the tank travels from the spring box through an inline chlorination system. This will be a 1” PVC pipe which will enter the tank from the roof. Influent water coming from the top will provide additional mixing in the tank as well as aeration to help with treatment. Due to the tanks ability to store water during the night hours, the designed inflow is able to be less than the maximum daily demand. After the water’s 2.7 hour residence time, the disinfected water will exit the tank through a 2” PVC pipe which will be located at the bottom of the tank and go directly underground. Due to constant inflow to the tank, even during times of no use, a 2” overflow pipe will need to be placed 0.9 meters from the bottom of the tank. In order to reduce erosion from excess overflow, Yucca Engineering advises the overflow pipe be extended from the tank underground to a nearby ravine. The last feature of the tank is a drainage pipe which will be located in one of the bottom corners of the tank. This drainage pipe will serve as a way to empty the tank in times of maintenance and cleaning.

The physical characteristics of the storage tank were designed to provide low maintenance for the community and to be as simple to construct as possible. For these reasons, the tank has been designed to rest on a 10 cm gravel bed below an 8 cm concrete floor which will be slanted towards the drainage pipe. For the walls of the tank, reinforced concrete blocks are suggested to be used with a concrete mortar and water sealant on both the interior and exterior. The tank will be topped with a concrete slab similar to that of the floor and will have an access door large enough for an adult. Design calculations, as well as rebar layout, for the floor and roof slabs and a detailed layout of the suggested concrete blocks for the walls can be found below.

Appendix E Chlorination and Microbial Data

Table E-1: Empirical dissolution data (Orner, 2011) Used to calculate dissolution rate of chlorine.

Empirical dissolution data: Orner 2011					
Orner 2011, Appendix C.5: Comparison of Actual Duration of Chlorine Tablet against Claimed Duration of Tablet based on Manufacturer's Claim of 2 g dissolved Chlorine per 1000 L of water passing through Chlorinator in field studies 1-7 of Communities of Quebrada Mina and Calabazal					
Field Study	Flow (LPM)	Duration of tablet (days)	Volume of flow over tablet (L)	Starting weight (g)	Rate of dissolution (g/1000L)
5 - Calabazal	60.18	7	606630	206	0.34
6 - Calabazal	60.18	7	606630	204	0.34
7 - Calabazal	60.18	7	606630	206	0.34
			606614		**0.340**
Yucca Eng - 1	38.7	7	390096	200	**0.513**

Table E-2: Yucca Engineering - Water Quality Tests using 3M Petrifilm, incubated 24 hours on body.

Yucca Engineering - Water Quality Tests using 3M Petrifilm, incubated 24 hours on body	Main 1 (pond)	Main 2 (upstream)	Main 3 (puddle)	**Main Source Average**	Shower 1 (pond)	Shower 2 (upstream)	Shower 3 (puddle)	**Secondary Source Average**
Test 1: 6:30 PM August 22								
Total Bacteria	66	147	296	**170**	25	432	284	**247**
E. coli	1	3	20	**8**	0	1	20	**7**
Test 2: 7:30 AM August 23								
Total Bacteria	18	25	140	**61**	10	16	-	**13**
E.coli	3	1	12	**5**	0	0	-	**0**

Table E-2 shows results of the brief microbial assessment on the proposed main source and secondary source (shower) that was performed by Yucca Engineering during the assessment trip in August. Tests were conducted using 3M™ EC Petrifilm™ plates. Samples were taken at multiple locations in order to gather an overall idea of water quality within the community. Testing methods began with sampling one mL of water from the location and placing it on the biofilm of the Petrifilm™ plates with a disposable pipette. After securing the sample in the Petrifilm™ plate, samples were pressed so that the water covered the entire plate and labeled accordingly. Incubation of the samples occurred for 24 hours using body heat. The plates were stacked between cardboard and a rubber band and secured against the skin of a volunteer. Colonies grown on the plates were then counted and recorded. Results above show averages at each source. This data is limited but Yucca Engineering believes that positive indication of bacterial contamination would hold true if further study is conducted.

Concentration Time (CT) Calculations

Effective Chlorine Disinfection is evaluated using the equation

$$Concentration \times Time \times Baffle\ coefficient$$

1) Concentration of Chlorine=Rate of dissolution=0.513g/1000L
   (Appendix E: Empirical dissolution data: Orner 2011.)

2) Residence time of water in storage tank= 2.7 hr =166 minutes
   (Appendix D: Storage tank design)

3) Baffle Coefficient:

A baffle coefficient accounts for the mixing factor in the system. The storage tank here has the inlet in the ceiling and outlet on the opposite wall from the bottom of the tank. As seen in Figure E-1, the baffle coefficient used in this case is 0.3. The use of this coefficient completes the disinfection analysis. This is a conservative assumption for our system and acts as a safety factor for how much the effective free chlorine will be mixed before leaving the tank.

$$\frac{0.513\mathrm{g}}{1000\mathrm{L}} \times 166min \times 0.3 = 25.5\,\frac{\mathrm{mg-min}}{\mathrm{L}}$$

This as an adequate disinfection CT value for most pathogens.

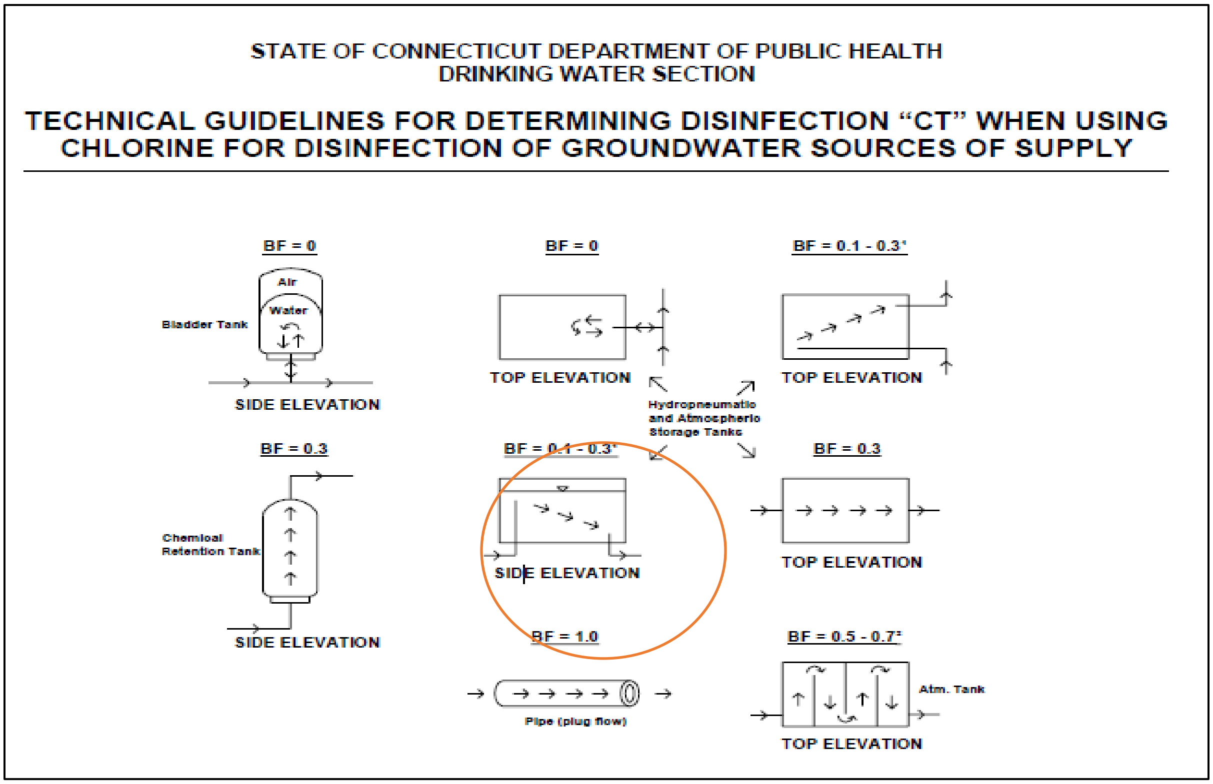

Figure E-1 Baffle Coefficients for different types of tanks. (US Department of Health 2010)

The overall CT factor incorporates the baffle coefficient.

Appendix F Bridge Design for Gully Crossing 1

Bridge calculations were performed for both gully crossings and accounted for horizontal tension (1), angle of tension (2), total tension (3), vertical tension (4), and the moment about the bridge tower (5) to find the dimensions of the concrete anchors. To ensure adequate support, a factor of safety of three was used when calculating the dimensions for the concrete anchors.

<u>BRIDGE 1 CALCULATOINS</u>

Force Calculations:

$H = \frac{wL^2}{8*d} = \frac{(0.21\ plf + 0.43\ plf + 0.34\ plf)*(125\ ft)^2}{8*6.56\ ft} = 289\ lb$ (1)

$\theta = 〚tan〛 \wedge - \ ((4*d))/L) = \ 〚tan〛 \wedge - \ ((4*6.56\ ft))/125) = 12°$ (2)

$T_t = \frac{H}{\cos(\theta)} = \frac{289\ lb}{\cos(12°)} = 295\ lb$ (3)

$V = \sin(\theta) * T_t = \sin(12) * 295\ lb = 61\ lb$ (4)

Anchor Calculations:

$\sum M = 0 = [H*h*SF] - \left[l*w*h*\ d_{conc.}*\frac{l}{2}\right] = [289\ lb*3\ ft*3] - \left[l*3*3\ ft*\ 150\ pcf*\frac{l}{2}\right] = 2601 - 675*l^2$ (5)

$\Rightarrow L = 4\ ft$

In Summary:

Forces:		
H=	289 lb.	131 kg
V=	61 lb.	28 kg
T_t=	295 lb	134 kg

Anchor:		
$d_{conc.}$=	150 pcf	2000 kgcm
h=	3 ft	0.9 m
L=	4 ft	1.2 m
w=	3 ft	0.9 m

Appendix G Bridge Design for Gully Crossing 2

Bridge calculations were performed for both gully crossings and accounted for horizontal tension (1), angle of tension (2), total tension (3), vertical tension (4), and the moment about the bridge tower (5) to find the dimensions of the concrete anchors. To ensure adequate support, a factor of safety of three was used when calculating the dimensions for the concrete anchors.

<u>BRIDGE 2 CALCULATOINS</u>

Force Calculations:

$H = \frac{wL^2}{8*d} = \frac{(0.21plf + 0.43\ plf + 0.34\ plf)*(115\ ft)^2}{8*6.56\ ft} = 246\ lb$ (1)

$\theta = \llbracket tan \rrbracket \wedge - \ ((4*d))/L) = \llbracket tan \rrbracket \wedge - \ ((4*6.56\ ft))/115) = 13°$ (2)

$T_t = \frac{H}{\cos(\theta)} = \frac{246\ lb}{\cos(13°)} = 252\ lb$ (3)

$V = \sin(\theta) * T_t = \sin(13) * 252\ lb = 56\ lb$ (4)

Anchor Calculations:

$\sum M = 0 = [H*h*SF] - \left[l*w*h*\ d_{conc.}*\frac{l}{2}\right] = [246\ lb*3\ ft*3] - \left[l*3.28*3\ ft*\ 150\ pcf*\frac{l}{2}\right] = 2214 - 738*l^2$ (5)

$\Rightarrow L = 3\ ft$

In Summary:

Forces:		
H=	246 lb	111 kg
V=	56 lb	25 kg
T_t=	252 lb	114 kg

Anchor:		
$d_{conc.}$=	150 pcf	2000 kgcm
h=	3 ft	0.9 m
L=	3 ft	0.9 m
w=	3.28 ft	1.0 m

Appendix H Pressure Break Tank Design

Appendix I Air Release Valve Design

The ARV is composed of a 1" capped tee that branches off the main pipeline. Both the cap and the vertical tee have smaller diameter inner cross sections than the nominal inner diameter of the pipe. The ball shown in the figure below will be trapped in the two pipe sections above and below it. When water level rises in the vertical pipe, the ball will be forced upward, plugging the valve and closes the system. This occurs because the ball is able to seal off the open end of the vertical pipe. If air is in the system, the ball will fall to the lower hole until water forces the air out the top.

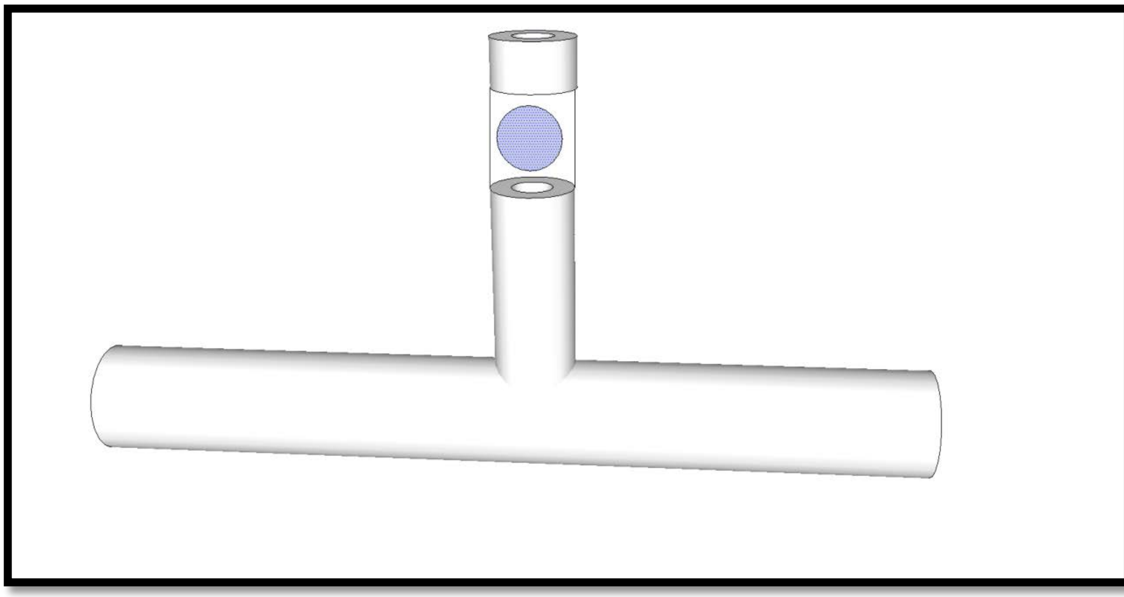

Figure I-1: Air Release Valve design, inspired by Michigan Tech student Victor Boron

Appendix J Cost Estimate

Table J-1 Breakdown of the overall cost estimate for the project.

Sum of Cost Schedules by System Component

Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	Spring Box (1)	1	Job	Job	$ 952.03	$ 952.00
2	Storage Tank (1)	1	Job	Job	$ 1,231.97	$ 1,232.00
3	Tap Stand (32)	32	Job	Job	$ 45.78	$ 1,465.00
4	Pressure Release Tank (6)	6	Job	Job	$ 123.35	$ 740.00
5	Bridge Structure (2)	2	Job	Job	$ 327.42	$ 655.00
6	In-Line Chlorinator(1)	1	Job	Job	$ 28.76	$ 29.00
7	Pipeline (3.6 miles)	1	Job	Job	$ 5,070.18	$ 5,070.00
8	Air-Release Valve (5)	5	Job	Job	$ 5.50	$ 28.00
9	Transportation of Materials	15	Job	Job	$ 65.00	$ 975.00
					Total:	$ 11,146.00
					10% Overhead:	$ 1,114.00
					Grand Total:	**$ 12,300.00**

Sum of Materials for Construction

Material	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	1" SDR 26 PVC	13900	Feet	20' Sections	$0.25	$3,468.05
2	Cascajo (Premix Sand and Gravel)	227	Cubic Feet	5 Gal Bucket	$10.00	$2,270.00
3	Concrete	133.6	bags	100 lb bag	$9.25	$1,235.80
5	1/2" SDR 26 PVC	4960	Feet	20' Sections	$0.25	$1,240.00
6	2" SDR 26 PVC	790	Feet	20' Sections	$0.70	$554.58
7	Concrete Block	696	#	Block 20x15x40cm	$0.70	$487.20
8	Gravel for foundation	576	Cubic Feet	Cubic Feet	$0.80	$460.80
9	Gravel for filtration	35	Ft^3	5 Gal Bucket	$10.00	$350.00
10	Metal Faucet - 1/2"	32	Item	Item	7.95	$254.40
11	6mm Rebar	2136	Feet	20 Feet Sections	$0.08	$170.88
12	Float Valve	6	#	Item	$22.00	$132.00
13	1/8" Cable	458	Feet	Feet	$0.26	$119.08
14	Sealer	1	Gallon	Gallon	$100.00	$100.00
15	SDR 26 PVC TEE 1",1"-	24	Item	Item	$4.00	$96.00
16	1/2" SCH 40 PVC	260	Feet	20' Sections	$0.25	$65.00
17	SDR 26 PVC TEE 1",1"-1"	7	Item	Item	$4.00	$28.00
18	SDR 26 PVC TEE 1/2",1/2"-	4	Item	Item	$4.00	$16.00
19	SDR 26 1/2" 90 DEG	64	Item	Item	$0.20	$12.80
20	Metal Faucet - 2"	1	#	Faucet	$10.00	$10.00
21	Ball Float	5	Item	Item	$1.50	$7.50
22	3" PVC Nipple	3	3", 72mm union	Item	$2.15	$6.45
23	1"-4" PVC Reducer	2	2" to 4" available	Item	$3.00	$6.00
24	1"x2" PVC reducer	2	0	Item	$2.98	$5.96
25	4" PVC TEE	1	4", 102mm	Item	$5.00	$5.00
26	4" PVC Cap	1	4", 102mm	Item	$4.95	$4.95
27	SDR 26 PVC TEE 2",2" - 1"	1	Item	Item	$4.50	$4.50
28	SDR 26 PVC TEE 1",1"-2"	1	Item	Item	$4.00	$4.00
29	3" PVC Cap	2	3", lisa cover	Item	$1.60	$3.20
30	1" SDR 26 Cap	5	Item	Item	$0.18	$0.90

Schedule A - Pipeline

Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost ($/ft)	Total Cost
1	2" SDR 26 PVC	540	Feet	20' Sections	$0.70	$379.08
2	1" SDR 26 PVC	13800	Feet	20' Sections	$0.25	$3,443.10
3	1/2" SDR 26 PVC	4960	Feet	20' Sections	$0.25	$1,240.00
4	SDR 26 PVC TEE 2",2" - 1"	1	Item	Item	$4.50	$4.00
5	SDR 26 PVC TEE 1",1"-2"	1	Item	Item	$4.00	$4.00
6	SDR 26 PVC TEE 1",1"-1/2"	24	Item	Item	$4.00	$96.00
7	SDR 26 PVC TEE 1/2",1/2"-1"	4	Item	Item	$4.00	$16.00
8	SDR 26 PVC TEE 1",1"-1"	2	Item	Item	$4.00	$8.00
					Total:	**$5,070.18**

Schedule B - Spring Box

Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	Gravel for filtration	35	Ft^3	5 Gal Bucket	$10.00	$350.00
2	Cascajo (Premix Sand and Gravel)	31	Ft^3	5 Gal Bucket	$10.00	$310.00
3	6mm Rebar	66	Feet	20 Feet Sections	$0.08	$5.28
4	Concrete	31.0	bags	100 lb bag	$9.25	$286.75
					Total:	**$952.03**

Schedule C - Storage Tank						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	Concrete-Floor	5.0	Bags	100 lb bag	$9.25	$46.25
2	Concrete-Roof	6.0	Bags	100 lb bag	$9.25	$55.50
3	6mm Rebar-Floor	380	Feet	20 Feet Sections	$0.08	$30.40
4	6mm Rebar-Roof	660	Feet	20 Feet Sections	$0.08	$52.80
5	Cascajo (Premix Sand and Gravel)	11	Cubic Feet	5 Gal Bucket	$10.00	$110.00
6	Concrete Block	480	#	Block 20x15x40cm	$0.70	$336.00
7	Concrete for Mortar	5.0	Bags	100 lb bag	$9.25	$46.25
8	Gravel	516	Cubic Feet	Cubic Feet	$0.80	$412.80
9	Overflow Pipe - 1" SDR 26 PVC	100	Feet	20' Sections	$0.25	$24.95
10	Sealer	1	Gallon	Gallon	$100.00	$100.00
11	Drainage Pipe - 2" SDR 26 PVC	10	Feet	20' Sections	$0.70	$7.02
12	Metal Faucet - 2"	1	#	Faucet	$10.00	$10.00
					Total:	**$1,231.97**

Schedule D - Pressure Release Tanks						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	Concrete	18	Bags	100 lb. Bag	$9.25	$166.50
2	Concrete Block	216	#	Block 20x15x40 cm	$0.70	$151.20
3	6mm Rebar (Ceiling/Floor)	780	Feet	20' Section	$0.08	$62.40
4	Cascajo (Premix Sand and Gravel)	18	Cubic Feet	5 Gal Bucket	$10.00	$180.00
6	Gravel	60	Cubic Feet	Cubic Feet	$0.80	$48.00
7	Float Valve	6	#	Item	$22.00	$132.00
					Total:	**$740.10**

Schedule E - Air Release Valves						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	SDR 26 PVC TEE 1",1"-1"	5	Item	Item	$4.00	$20.00
2	Ball Float	5	Item	Item	$1.50	$7.50
3	1" SDR 26 Cap	5	Item	Item	$0.18	$0.90
					Total:	**$27.50**

Schedule F - Tap Stands						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	1/2" SCH 40 PVC	260.0	Feet	20' Sections	$0.25	$65.00
2	Concrete	58	Bag	100 lb bag	$9.25	$532.80
4	Rebar	250	Feet	20 Foot Sections	$0.08	$20.00
5	Cascajo (Premix Sand and Gravel)	58	Cubic Feet	5 Gal Bucket	$10.00	$580.00
5	Metal Faucet - 1/2"	32	Item	Item	$7.95	$254.40
9	SDR 26 1/2" 90 DEG ELBOW	64	Item	Item	$0.20	$12.80
					Total:	**$1,465.00**

Schedule G - Bridge Structure (1)						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	1/8" Cable	278	Feet	Feet	$0.26	$72.28
2	Concrete	6	Bags	100 lb bag	$9.25	$55.50
3	2" Casing Pipe	125	Feet	Feet	$1.15	$143.44
4	Cascajo (Premix Sand and Gravel)	6	Cubic Feet	5 Gal Bucket	$10.00	$60.00
					Total:	**$331.22**

Schedule H - Bridge Structure (2)						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	1/18 Cable	180	Feet	Feet	$0.53	$95.40
2	Concrete	5	Bags	100 lb bag	$9.25	$46.25
3	2" Casing Pipe	115	Feet	Feet	$1.15	$131.96
4	Cascajo (Premix Sand and Gravel)	5	Cubic Feet	5 Gal Bucket	$10.00	$50.00
					Total:	**$323.61**

Schedule I - Chlorinator						
Item	Description	Estimated Quanitity	Unit	Unit Availability	Unit Cost	Total Cost
1	4" PVC TEE	1	4", 102mm		$5.00	$5.00
2	4" PVC Cap	1	4", 102mm		4.95	$2.15
3	3" PVC Cap	2	3", lisa cover		$1.60	$3.20
4	3" PVC Nipple	3	3", 72mm union		$2.15	$6.45
5	1"-4" PVC Reducer	2	2" to 4" available only		$3.00	$6.00
6	1"x2" PVC reducer	2			$2.98	$5.96
					Total:	**$28.76**

Appendix K Compiled Survey Data

Table K-1 Compiled raw data from the assessment trip.

Main Pipeline fom Source					Red Data Points are the same physical point, with two labels, indicating a branch there.			Highlight Indicates End of Section of Pipe / Pluma		
	GPS DATA						SURVEYING DATA			
Point	Lat	Lon	Elev (m)	Change in Elev from Previous Pt	Total Change in Elevation	Length to Next Pt. (m)	FS to next Pt	BS from next Pt	Angle	Change in Elev from Previous Pt
0	8.34794	81.95106	382	-	-	17.15	-7.0	7.0	-7	0.00
1	8.34786	81.95094	380	-2	-2	28.25	-10.0	9.0	-9.5	-2.09
2	8.34777	81.95074	376	-4	-6	22.65	-6.0	5.0	-5.5	-4.66
3	8.34772	81.95054	375	-1	-7	30.55	-16.0	16.0	-16	-2.17
4	8.34750	81.95035	366	-9	-16	30.4	-11.0	10.0	-10.5	-8.42
5	8.34733	81.95014	359	-7	-23	14.2	-19.0	18.0	-18.5	-5.54
6	8.34726	81.95004	353	-6	-29	26.5	-15.0	15.0	-15	-4.51
7	8.34716	81.94997	348	-5	-34	23.7	-9.0	8.0	-8.5	-6.86
8	8.34701	81.94982	342	-6	-40	18.8	-5.5	5.0	-5.25	-3.50
9	8.34684	81.94970	337	-5	-45	30.5	-10.0	10.0	-10	-1.72
10	8.34659	81.94945	335	-2	-47	15.36	-16.0	15.0	-15.5	-5.30
11	8.34649	81.94936	331	-4	-51	18.55	20.0	-19.0	19.5	-4.10
12	8.34644	81.94932	335	4	-47	20.6	19.5	-20.0	19.75	6.19
13	8.34627	81.94917	341	6	-41	14.4	18.5	-18.5	18.5	6.96
14	8.34622	81.94906	344	3	-38	20.15	18.0	-18.5	18.25	4.57
15	8.34610	81.94891	348	4	-34	17.9	3.0	-2.0	2.5	6.31
16	8.34599	81.94883	350	2	-32	30.4	-4.5	5.0	-4.75	0.78
A0	8.34599	81.94883	350	2	-32	30.4	-0.5	1.0	-0.75	0.78
A1	8.34619	81.94857	349	-1	-33	30.5	-5.5	5.0	-5.25	-0.40
Aa0	8.34619	81.94857	349	-1	-33	17.9	-4.0	4.0	-4	-0.40
Aa1	8.34607	81.94848	348	-1	-34	-	-	-	-	-1.25
A2	8.34626	81.94829	348	0	-33	22.2	-4.5	4.0	-4.25	-2.79
A3	8.34660	81.94815	346	-2	-35	30.5	-8.5	7.0	-7.75	-1.65
Ab0	8.34660	81.94815	346	-2	-35	15.8	-5.5	5.0	-5.25	-1.65
Ab1	8.34626	81.94804	345	-1	-36	-	-	-	-	-1.45
A4	8.34653	81.94790	345	0	-35	30.5	-6.0	5.0	-5.5	-4.11
A5	8.34663	81.94766	337	-8	-43	30.5	-4.0	4.0	-4	-2.92
A6	8.34684	81.94749	335	-2	-45	13	1.0	-1.0	2	-2.13
A7	8.34686	81.94740	336	1	-44	10	-3.5	4.0	-3.75	0.45
A8	8.34698	81.94737	336	0	-44	-	-	-	-	-0.65
17	8.34574	81.94882	348	-2	-34	30.5	-11.0	10.0	-10.5	-2.52
18	8.34551	81.94881	343	-5	-39	30.4	-13.0	12.0	-12.5	-5.56
19	8.34522	81.94881	337	-6	-45	24.25	-16.0	15.0	-15.5	-6.58
20	8.34501	81.94880	332	-5	-50	3.5	-19.5	21.0	-20.25	-6.48
21	8.34501	81.94878	330	-2	-52	22.45	7.0	-6.0	6.5	-1.21
B0	8.345	81.9488	330	-2	-52	25.8	7.0	-6.0	6.5	-1.21
B1	8.34497	81.94855	333	3	-49	30.4	-11.0	11.0	-11	2.92
B2	8.34489	81.94828	328	-5	-54	30.5	-16.0	16.0	-16	-5.80
B3	8.34485	81.94802	319	-9	-63	10.1	-15.5	15.0	-15.25	-8.41
B4	8.34486	81.94791	316	-3	-66	30.5	2.0	-3.0	2.5	-2.66
B5	8.34503	81.94770	315	-1	-67	30.4	-3.0	4.0	-3.5	1.33
B6	8.34519	81.94746	313	-2	-69	30.5	-5.0	5.0	-5	-1.86
B7	8.34531	81.94723	311	-2	-71	30.5	-9.0	7.0	-8	-2.66
B8	8.34550	81.94706	307	-4	-75	27.4	-3.0	3.0	-3	-4.24
B9	8.34572	81.94689	306	-1	-76	27.9	-4.0	4.5	-4.25	-1.43

B9	8.34572	81.94689	306	-1	-76	27.9	-4.0	4.5	-4.25	-1.43
B10	8.34587	81.94672	303	-3	-79	30.6	-5.5	5.0	-5.25	-2.07
B11	8.34592	81.94642	300	-3	-82	26.8	-6.5	5.0	-5.75	-2.80
B12	8.34608	81.94625	297	-3	-85	30.4	1.5	-1.0	1.25	-2.69
B13	8.34631	81.94608	297	0	-85	29.9	-4.0	4.5	-4.25	0.66
B14	8.34644	81.94588	295	-2	-87	29.9	-10.0	10.5	-10.25	-2.22
B15	8.34645	81.94565	290	-5	-92	29.7	-14.5	14.0	-14.25	-5.32
Bc0	8.34645	81.94565	290	-5	-92	26.1	-23.0	24.0	-23.5	-5.32
Bc1	8.34664	81.94538	282	-8	-100	13.5	-20.0	19.0	-19.5	-10.41
Bc2	8.34667	81.94540	279	-3	-103	26.7	17.5	-13.0	15.25	-4.51
Bc3	8.34687	81.94534	285	6	-97	25	4.0	-4.0	4	7.02
Bc4	8.34714	81.94518	286	1	-96	-	–	–	–	1.74
B16	8.34641	81.94534	287	1	-95	29.95	-29.5	30.0	-29.75	-7.31
B17	8.34653	81.94514	272	-15	-110	30.2	-13.0	12.0	-12.5	-14.86
B18	8.34629	81.94501	266	-6	-116	30.5	-12.0	11.0	-11.5	-6.54
B19	8.34609	81.94486	259	-7	-123	13.4	-6.0	6.0	-6	-6.08
B20	8.34605	81.94474	257	-2	-125		–	–	–	-1.40
22	8.34483	81.94865	318	-12	-64	10.6	-4.0	3.5	-3.75	2.54
23	8.34476	81.94855	318	0	-64	30.5	-12.0	9.5	-10.75	-0.69
Co	8.3448	81.9486	318	0	-64	29.4	1.0	-2.0	2.5	-0.69
C1	8.34448	81.94866	321	3	-61	30.2	1.0	-1.0	1	1.28
C2	8.34425	81.94884	322	1	-60	28.1	-7.0	7.5	0.25	0.53
Ca0	8.34425	81.94884	322	1	-60	8	-1.5	1.0	-0.25	0.53
Ca1	8.34426	81.94879	321	-1	-61	-	-	-	-	-0.03
C3	8.34403	81.94890	318	-4	-64	30.5	-16.0	16.0	-16	0.12
C4	8.34377	81.94894	312	-6	-70	30.5	-6.0	5.0	-5.5	-8.41
C5	8.34351	81.94907	308	-4	-74	30.5	-8.5	9.5	-9	-2.92
C6	8.34328	81.94921	303	-5	-79	30.5	-7.5	6.0	-6.75	-4.77
C7	8.34309	81.94935	300	-3	-82	6.6	-4.5	5.0	-4.75	-3.58
C8	8.34301	81.94937	300	0	-82	30.5	-10.0	10.0	-10	-0.55
Cb0	8.34301	81.94937	300	0	-82	6.7	-9.0	9.0	-9	-0.55
Cb1	8.34299	81.94933	300	0	-82	-	-	-	-	-1.05
C9	8.34273	81.94940	296	-4	-86	17.2	-6.5	6.0	-6.25	-5.30
C10	8.34256	81.94940	293	-3	-89	11.3	-7.0	7.0	-7	-1.87
C11	8.34246	81.94940	292	-1	-90	30.1	-18.0	18.5	-18.25	-1.38
C12	8.34221	81.94936	283	-9	-99	30.1	-8.0	7.0	-7.5	-9.43
C13	8.34197	81.94929	280	-3	-102	29.25	-8.0	7.0	-7.5	-3.93
C14	8.34171	81.94925	276	-4	-106	30.5	-20.0	19.0	-19.5	-3.82
C15	8.34145	81.94922	266	-10	-116	24.7	-17.5	17.0	-17.25	-10.18
C16	8.34125	81.94929	257	-9	-125	30.4	-21.0	20.0	-20.5	-7.32
C17	8.34100	81.94919	247	-10	-135	30.3	-11.0	10.0	-10.5	-10.65
Cc0	8.34100	81.94919	247	-10	-135	18.6	-7.5	8.0	-7.75	-10.65
Cc1	8.34840	81.94923	245	-2	-137	-	-	-	-	-2.51
C18	8.34115	81.94893	239	-8	-143	8	-6.0	5.0	-5.5	-5.52

C18	8.34115	81.94893	239	-8	-143	8	-6.0	5.0	-5.5	-5.52
C19	8.34122	81.94888	238	-1	-144	21.3	-4.0	5.0	-4.5	-0.77
Cd0	8.34122	81.94888	238	-1	-144	17.5	-7.0	-6.5	-0.25	-0.77
Cd1	8.34107	81.94881	237	-1	-145	-	-	-	-	-0.08
C20	8.34132	81.94872	238	0	-144	10.5	-16.0	16.0	-16	-1.67
C21	8.34133	81.94850	236	-2	-146	25.6	13.0	-12.0	25.5	-2.89
C22	8.34143	81.94843	241	5	-141	9	6.5	-6.0	6.25	11.02
C23	8.34146	81.94836	240	-1	-142	13.9	3.0	-2.0	2.5	0.98
Ce0	8.34146	81.94836	240	-1	-142	5.8	-6.0	5.0	-0.5	0.98
Ce1	8.34143	81.94833	240	0	-142	-	-	-	-	-0.05
C24	8.34156	81.94828	240	0	-142	13.6	-8.0	7.5	-0.25	0.61
C25	8.34159	81.94814	238	-2	-144	17.4	-9.0	8.5	-8.75	-0.06
C26	8.34161	81.94797	236	-2	-146	25.6	1.0	-4.0	3.5	-2.65
C27	8.34149	81.94779	234	-2	-148	19.9	-0.5	1.0	0.25	1.56
C28	8.34144	81.94762	236	2	-146	21.2	-11.0	10.0	-10.5	0.09
C29	8.34129	81.94760	232	-4	-150	14.8	-7.0	7.0	-7	-3.86
C30	8.34117	81.94751	229	-3	-153	20.6	-8.5	9.0	-8.75	-1.80
C31	8.34101	81.94741	226	-3	-156	18.7	-11.5	10.5	-11	-3.13
Cf0	8.34101	81.94741	226	-3	-156	11.7	-11.5	12.0	-11.75	-3.13
Cf1	8.34095	81.94730	222	-4	-160	-	-	-	-	-2.38
C32	8.34086	81.94743	221	-5	-161	25.8	-12.5	11.0	-11.75	-3.57
C33	8.34065	81.94751	216	-5	-166	-	-	-	-	-5.25
24	8.34456	81.94837	320	2	-62	30.4	-12.0	12.5	-12.25	-5.69
25	8.34442	81.94816	312	-8	-70	29.8	-14.0	12.5	-13.25	-6.45
26	8.34422	81.94802	308	-4	-74	30.6	-10.0	9.0	-9.5	-6.83
27	8.34400	81.94787	303	-5	-79	23.7	-8.0	7.0	-7.5	-5.05
28	8.34387	81.94769	301	-2	-81	30	-20.0	20.0	-20	-3.09
D0	8.34387	81.94769	301	-2	-81	2	6.0	-6.0	6	-3.09
D1	8.34387	81.94770	301	0	-81	2	-	-	-	0.21
29	8.34371	81.94749	290	-11	-92	30	-19.5	18.5	-19	-10.26
30	8.34352	81.94732	281	-9	-101	29.4	-19.5	19.0	-19.25	-9.77
31	8.34337	81.94713	271	-10	-111	29	-13.0	11.5	-12.25	-9.69
32	8.34325	81.94703	266	-5	-116	19.5	0.5	0.0	0.25	-6.15
33	8.34316	81.94694	266	0	-116	15.4	-8.5	9.0	0	0.09
34	8.34313	81.94688	265	-1	-117	30.5	-3.0	4.0	-3.5	0.00
E0	8.34313	81.94688	265	-1.0	-117.0	10.4	-4.0	3.0	-3.5	0.00
E1	8.34303	81.94689	265	0.0	-117.0	-	-	-	-	-0.63
35	8.34295	81.94656	264	-1.0	-118.0	30.5	-9.0	8.5	-8.8	-1.86
36	8.34287	81.94630	259	-5.0	-123.0	30.5	-13.5	11.0	-12.3	-4.64
37	8.34276	81.94608	253	-6.0	-129.0	16.8	-6.0	4.0	-5.0	-6.47
38	8.34273	81.94590	252	-1.0	-130.0	30.0	-8.0	8.0	-8.0	-1.46
F0	8.34273	81.94590	252	-1.0	-130.0	15.4	1.0	-2.0	2.5	-1.46
F1	8.34259	81.94595	249	-3.0	-133.0	-	-	-	-	0.67

39	8.34259	81.94564	246	-6.0	-136.0	30.5	-3.0	4.0	-3.5	-4.18
G0	8.34259	81.94564	246	-6.0	-136.0	16.2	-1	1.0	-1	-4.18
G1	8.34256	81.94572	245	-1.0	-137.0	-	-	-	-	-0.28
40	8.34266	81.94536	243	-3.0	-139.0	26.8	-15.5	16.0	-15.8	-1.86
41	8.34250	81.94251	235	-8.0	-147.0	29.7	-16.5	15.0	-15.8	-7.27
H0	8.3	81.9	235.0	-8.0	-147.0	26.7	-12.0	12.0	-12.0	-7.27
H1	8.3	81.9	231.0	-4.0	-151.0	-	-	-	-	-5.55
42	8.34225	81.94506	227	-8.0	-155.0	30.3	-11.5	9.5	-10.5	-8.06
I0	8.3423	81.9451	227	-8	-155	7.2	-8.5	7.0	-7.75	-8.06
I1	8.3422	81.945	224	-3	-158	30.2	-7	7.5	-7.25	-0.97
I2	8.34219	81.94474	223	-1	-159	14.5	-6.0	5.0	-5.5	-3.81
I3	8.34217	81.94461	222	-1	-160	-	-	-	-	-1.39
43	8.34206	81.94491	224	-3.0	-158.0	30.5	-13.0	12.0	-12.5	-5.52
44	8.34177	81.94479	218	-6.0	-164.0	30.5	-8.5	8.0	-8.3	-6.60
45	8.34155	81.94467	214	-4.0	-168.0	12.5	-4.0	2.5	-3.3	-4.38
Q0	8.3416	81.9447	214	-4	-168	30.0	-9.5	9.0	-9	-4.38
Q1	8.34132	81.94452	205	-9	-177	30.0	-5.5	6.0	-6	-4.82
Q2	8.34111	81.94435	201	-4	-181	23.6	-1.0	0.0	-1	-3.01
Q3	8.34095	81.94424	201	0	-181	30.0	-12.5	10.0	-11	-0.21
Q4	8.34072	81.94408	195	-6	-187	30.0	-18.0	15.0	-17	-5.85
Q5	8.34052	81.94394	187	-8	-195	30.0	-13.0	11.0	-12	-8.52
Q6	8.34031	81.94376	180	-7	-202	30.0	-6.5	5.0	-6	-6.24
Q7	8.34009	81.94364	177	-3	-205	30.0	-8.0	6.5	-7	-3.01
Q8	8.33988	81.94348	173	-4	-209	13.5	-10.5	9.0	-10	-3.79
Q9	8.33978	81.94339	171	-2	-211	30.0	-5.5	5.0	-5	-2.29
Qa0	8.33978	81.94339	171	-2	-211	30.0	-7.0	7.0	-7	-2.29
Qa1	8.33982	81.94170	170	-1	-212	4.0	-10.0	8.5	-9.3	-3.66
QA2	8.33984	81.94312	169	-2	-213	-	-	-	-	-3.66
Q10	8.33956	81.94322	170	-1	-212	30.5	-7.0	6.0	-7	-2.75
Q11	8.33940	81.94302	167	-3	-215	30.5	-7.0	6.0	-7	-3.45
Qb0				-3	-215	17.4	-3.5	3.5	-4	-3.45
Qb1	8.33952	81.94290	165	-2	-217	-	-	-	-	-1.06
Q12	8.33922	81.94283	163	-4	-219	30.3	-10.0	8.0	-9	-3.45
Q13	8.33905	81.94263	157	-6	-225	30.3	11.5	9.5	13	-4.74
Q14	8.33888	81.94243	152	-5	-230	30.5	-6.0	5.0	-6	6.56
Q15	8.33868	81.94221	149	-3	-233	30.0	-9.5	9.0	-9	-2.92
Q16	8.33850	81.94203	145	-4	-237	26.7	-13.0	13.0	-13	-4.82
Q17	8.33829	81.94190	138	-7	-244	30.3	-16.0	15.0	-16	-6.01
Q18	8.33814	81.94171	130	-8	-252	28.4	-13.0	14.0	-14	-8.10
Q19	8.33795	81.94153	123	-7	-259	30.5	-14.0	14.0	-14	-6.63
Q20	8.33769	81.94141	115	-8	-267	30.5	-15.5	13.5	-15	-7.38
Q21	8.33746	81.94134	108	-7	-274	30.5	-9.0	7.5	-8	-7.64
Q22	8.33721	81.94124	103	-5	-279	30.0	-8.0	5.0	-7	-4.38

Q23	8.33702	81.94105	99	-4	-283	30.5	-9.0	8.5	-9	-3.40
Q24	8.33686	81.94083	94	-5	-288	17.0	-7.0	6.0	-7	-4.64
Q25	8.33676	81.94074	91	-3	-291	22.0	-6.0	4.0	-5	-1.92
Qc0	8.33676	81.94074	91	-3	-291	27.4	-1.0	0.0	-1	-1.92
Qc1	8.33697	81.94055	90	-1	-292	-	-	-	-	-0.24
Q26	8.33665	81.94054	88	-3	-294	23.7	-6.0	5.0	-6	-1.92
Qd0	8.33665	81.94054	88	-3	-294	18.0	-2.5	1.0	-2	-1.92
Qd1	8.33682	81.94048	80	-8	-302	-	-	-	-	-0.55
Q27	8.33651	81.94040	87	-1	-295	23.7	-15.0	13.5	-14	-2.27
Q28	8.33637	81.94057	84	-3	-298	20.6	-6.0	5.0	-6	-5.83
Q29	8.33616	81.94057	82	-2	-300	26.0	9.0	-11.0	10	-1.97
Q30	8.33596	81.94057	85	3	-297	5.5	-0.5	0.0	0	4.51
Q31	8.33592	81.94054	84	-1	-298	30.0	-1.0	0.0	-1	-0.02
Q32	8.33565	81.94045	83	-1	-299	29.5	0.0	-1.0	1	-0.26
Q33	8.33548	81.94025	82	-1	-300	30.5	0.0	-1.0	1	0.26
Q34	8.33534	81.94001	82	0	-300	13.1	0.0	-1.0	1	0.27
Q35	8.33534	81.93986	82	0	-300	20.5	10.0	-11.0	11	0.11
Q36	8.33534	81.93969	84	2	-298	24.5	14.0	-14.0	14	3.74
Q37	8.33525	81.93957	90	6	-292	29.0	-10.0	10.0	-10	5.93
Q38	8.33516	81.93931	86	-4	-296	30.0	-14.0	13.0	-14	-5.04
Q39	8.33512	81.93903	80	-6	-302	30.0	-6.0	5.0	-6	-7.00
Q40	8.33503	81.93878	77	-9	-311	-	-	-	-	-2.88
46	8.34148	81.94466	213	-1.0	-169.0	19.2	-17.5	18.0	-17.8	-0.71
47	8.34130	81.94470	207	-6.0	-175.0	11.3	14.5	-14.0	28.8	-5.85
48	8.34122	81.94469	222	15.0	-160.0	22.0	4.5	-6.0	5.3	5.44
49	8.34103	81.94477	224	2.0	-158.0	9.9	2.0	-3.0	2.5	2.01
50	8.34098	81.94482	222	-2.0	-160.0	30.0	1.5	-2.5	2.0	0.43
J0	8.341	81.9448	222	-2.0	-160	19.3	-2.0	1.0	-1.5	0.43
J1	8.3408	81.9448	221	-1	-161	-	-	-	-	-0.51
51	8.34086	81.94507	219	-3.0	-163.0	30.0	5.0	-5.0	5.0	1.05
K0	8.3409	81.9451	219	-3	-163	23.2	-6.0	5.0	-5.5	1.05
K1	8.3407	81.945	217	-2	-165	29.6	-8.0	7.0	-7.5	-2.22
K2	8.3404	81.945	214	-3	-168	23	-7.0	6.0	-6.5	-3.86
K3	8.3402	81.9449	208	-6	-174	30	-7.5	7.0	-7.25	-2.60
K4	8.3399	81.9449	206	-2	-176	30	-6.5	5.0	-5.75	-3.79
K5	8.3397	81.9448	201	-5	-181	28	-13.5	12.5	-13	-3.01
K6	8.3395	81.9447	192	-9	-190	27.35	-7.0	5.0	-6	-6.30
K7	8.3393	81.9445	187	-5	-195	-	-	-	-	-2.86
52	8.34076	81.94517	208	-11.0	-174.0	15.9	5.0	-5.0	5.0	2.61
L0	8.3	81.9	208.0	-11.0	-174.0	11.0	1.0	-1.0	2.0	2.61
L1	8.3	81.9	206.0	-2.0	-176.0	-	-	-	-	0.38
53	8.34069	81.94527	211	3.0	-171.0	29.0	5.5	-6.0	5.8	1.39
54	8.34055	81.94554	211	0.0	-171.0	30.0	-1.0	0.0	-0.5	2.91
55	8.34040	81.94572	208	-3.0	-174.0	11.7	3.5	-4.0	3.8	-0.26
56	8.34031	81.94581	207	-1.0	-175.0	29.9	2.0	-2.0	2.0	0.77

M0	8.3403	81.9458	207	-1	-175	19.3	7.0	-6.0	13.5	0.77
M1	8.3404	81.9459	208	1	-174	-	-	-	-	4.51
57	8.34016	81.94600	206	-1.0	-176.0	16.4	-5.0	4.0	-0.5	1.04
58	8.34004	81.94611	207	1.0	-175.0	28.3	-20.0	20.0	-20.0	-0.14
59	8.33980	81.94617	198	-9.0	-184.0	30.0	-19.0	19.0	-19.0	-9.68
60	8.33955	81.9462	191	-7.0	-191.0	30.0	-11.0	9.0	-10.0	-9.77
61	8.33933	81.94607	185	-6.0	-197.0	25.0	-11.0	10.0	-10.5	-5.21
62	8.33912	81.94595	180	-5.0	-202.0	30.4	-4.0	2.5	-3.3	-4.56
63	8.33883	81.94592	178	-2.0	-204.0	21.8	-6.5	5.0	-5.8	-1.72
64	8.33871	81.94611	175	-3.0	-207.0	17.0	-18.0	17.0	-17.5	-2.18
65	8.33866	81.94622	170	-5.0	-212.0	30.0	-2.0	1.0	-1.5	-5.11
66	8.33854	81.94646	167	-3.0	-215.0	28.0	-1.5	2.0	-1.8	-0.79
N0	8.3385	81.9465	167	-3	-215	4.2	2	-2.0	4	-0.79
N1	8.3385	81.9465	167	0	-215	-	-	-	-	0.29
67	8.33836	81.94667	166	-1.0	-216.0	28.0	0.0	0.0	0.0	-0.86
68	8.33810	81.94676	168	2.0	-214.0	11.7	3.5	-4.0	3.8	0.00
69	8.33807	81.94669	167	-1.0	-215.0	-	-	-	-	0.77