CERRO ORTIGA II GRAVITY-FED WATER SYSTEM

Cerro Ortiga, Ngöbe-Buglé Panama

PLUMA INC.

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CEE4916 Fall 2016

Pluma Inc. Final Report

iDesign Final Report Fall 2016

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Disclaimer:

This report, titled "Cerro Ortiga II Gravity-Fed Water System", represents the efforts of undergraduate students in the Civil, Environmental, Geological, and Mechanical 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.

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Executive Summary

The following report analyzes the Cerro Ortiga II community and their previous water system. It outlines a new design for providing reliable, clean, and safe water through a gravity-fed water system. The system contains a spring box, chlorinator, holding tank, piping, air valves, pressure reducing valves, and multiple pipe bridges.

The students of Pluma Inc. traveled to the Cerro Ortiga II community in Panama to survey the system in August 2016. The team gathered elevation data, GPS coordinates, and recommendations from the community members. These recommendations have been considered, and Pluma Inc. has tried to incorporate the desired elements outlined from the community members. The design provides running water to the 78 community members who have shown desire to be connected to the water line.

The visit with the help of Peace Corps volunteer, Marlana Hinkley, allowed Pluma Inc. to gather necessary data to maximize the volume of water captured. The goal of this report is to outline, in detail, the necessary materials and construction elements needed to build a successful system.

The system will include a newly designed spring box, holding tank, chlorinator system, and pipeline. The line consists of five pipe crossings that will be supported using a cable suspension system. The pipeline will feature shut-off valves, an air reducing valve, and a pressure reducing valve. The holding tank and spring box will be made of reinforced concrete, and have been resized to reduce cost and accommodate the population size.

The total estimated cost of the system is $7,200. The community will be applying for a grant to receive an amount up to $8,000 to pay for the system. The construction is scheduled to begin on August 1, 2017 and ends on November 1, 2017.

1.0 Introduction

The engineering students of Pluma Inc. traveled to Panama through International Senior Design (iDesign). They are all students at Michigan Technological University in the fields of Environmental Engineering, Geological Engineering, and Mechanical Engineering. The report that Pluma Inc. has completed consists of a finalized design for a gravity-fed water system for a rural community in Cerro Ortiga II, Panama.

A previous gravity-fed water system was constructed for the Cerro Ortiga II community 14 years ago. Previous infrastructure remains; however, the system is damaged and not functioning. The tanks are cracked, pipes are cut, and exposed pipe is damaged from sunlight. Pluma Inc. has proposed a completely new design for the water system and suggests gathering new materials due to the extensive damage to the previous system. The community members will be applying for a grant from the Panamanian government or a non-governmental organization at a maximum amount of $8,000.

This report was written to design a gravity-fed water system for the Cerro Ortiga II community located in Ngöbe-Buglé, Panama. The report includes the final design which will be used to apply for a grant to assist in building this water system in Cerro Ortiga II. This design will provide 20 gallons of water per person each day. The report indicates all of the design elements needed to produce a working gravity-fed water system that can provide enough clean water for the community members to drink, cook, and clean with when needed. The purpose of this report is to explain the system components, provide a cost estimate and project schedule for building the system, a construction manual on how to assemble the system, and provide recommendations on necessary maintenance.

2.0 Project Context

2.1 Community Background-Cerro Ortiga

Cerro Ortiga II is a subsection of the larger Cerro Ortiga community and is located in the Comarca of Ngöbe-Buglé, shown in Figure 1. The community consists of approximately 600 citizens. The exact number of houses is unknown, but each family usually contains about 10 family members. The Cerro Ortiga community sprawls across approximately 15-20 square miles. Issues that this community faces are their remote location, lack of sanitation and clean water sources, and lack of water during the dry season.

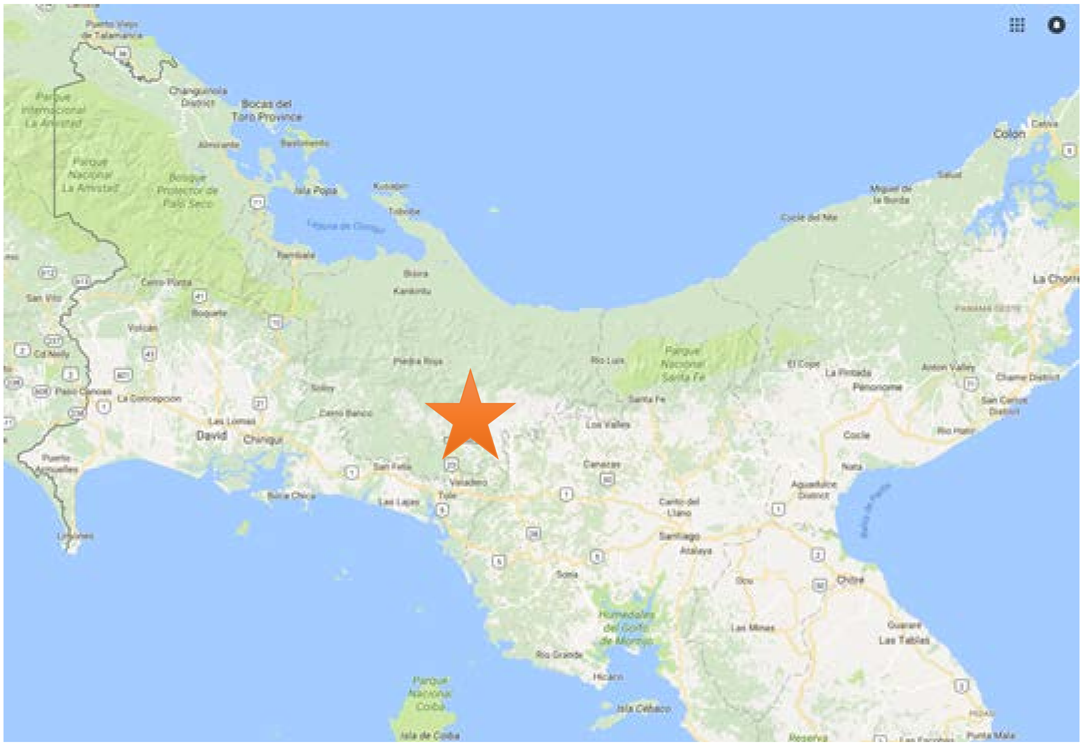


Figure 1. Location of Cerro Ortiga in Panama

Google Maps. *Panama*. Web. 13 November 2016

Cerro Ortiga is a 1.5-to-2- hour hike from the nearest bus stop. The bus stop is about a 20-minute bus/taxi ride from San Felix, which is a larger city that houses supermarkets, health clinics, and bus stops to larger cities such as Panama City and David. This long hike to the Comarca consists of many steep up-hills and down-hills. The hiking trail has rocky terrain and is extremely slippery when it is raining. This long hike is an issue when community members need medical attention, and makes it difficult to transport materials into the site for construction. The remote location and difficult terrain poses a problem for delivering construction materials to the site when expanding water lines, constructing school buildings, and building more structurally stable houses. During the rainy season (May-January), it storms consistently every afternoon. These storms provide a significant amount of water to the community members. However, the community members face severe water shortages during the dry season (February-April).

The common language of the indigenous community is Ngäbere. The members in the Comarca are of Ngäbe descent and grew up speaking this language with family members and other community members. Spanish is taught in the school system, and most community members know Spanish, which makes communication easier with government officials and the larger communities in the area. However, Spanish knowledge is limited and the vocabulary of the community members is lacking. English classes are also given in the school system, but English is not mastered and is rarely used in the Comarca.

2.2 Education

The school system for Cerro Ortiga is similar to many other indigenous systems in the region. The school is a 15-minute hike from central Cerro Ortiga. The school building contains classrooms for children in kindergarten through 9th grade. When the students reach 10th grade, they must hike 1.5 hours to a high school in a surrounding community. This strenuous commute to school creates issues for children to continue education, and many students stop going to school after 9th grade.

The public teaching system in Panama works on a point based scale. The teachers are all given a point score based on teaching ability, test scores, and previous work experiences. The teachers with the highest points in Panama have the first pick of teaching positions. The positions are at every public school in Panama, including the indigenous schools. With Cerro Ortiga being a relatively poor community, lacking in resources and a long commute from basic needs, the teachers that usually come to work in the Cerro Ortiga school systems are teachers with lower point values. The teachers live on site Monday-Thursday and have the option to stay through Friday. Some teachers were previous Ngäbere community members and have completed school and obtained a salary position. These teachers usually choose to return to indigenous communities.

Pluma Inc. visited the school while in Cerro Ortiga. School is in session from Monday-Thursday from 8am-12pm. Some classes are held on Friday, but the teachers determine this on a class-by-class basis. Pluma Inc. visited the school on Friday August 12th, 2016. The school atmosphere was chaotic. The school building and classroom were structurally lacking, and the classrooms were all open to one another. The schoolrooms were separated by grades, but they did not have separate rooms or even walls. Children were wandering around the schoolyard while class was in session, and the children were all easily distracted by their surroundings while sitting at their desks. The classrooms can be seen in Figures 2 and 3 below.

Figure 2. Classroom in Cerro Ortiga (Photo by: Hailey Goupille)

Figure 3. Cerro Ortiga School (Photo by: Hailey Goupille)

2.3 Work Life

The children do not always attend school because many have to work. The children help from a very young age with caretaking of other children, subsistence farming, cleaning of clothes, and preparation of meals. When children are able to walk, they begin to help with household duties. This can discourage education, if education is not seen as a priority.

Each family is different, but most members of the community are subsistence farmers. The common items farmed are rice, cacao, coffee, plantains, bananas, corn, yucca, and animals. Chickens, pigs, roosters, turkeys, and horses were all seen on site. The men and children do most of the farming, but women help occasionally. Women's duties are to be caretakers. Women typically care for the house and children, along with doing the majority of the cooking.

Both men and women have a trade making hats and kras, respectively. The men make hats out of a special plant found in the jungle. This is a trade that is taught and mastered. Most hats can be sold for $10-$40 per hat. Kras are bags that are made from rice sacks that are woven into bags. Kras can be sold for $15-$30 per bag. Women in the community wear traditional dresses called "naguas," which are made by each family. Some women have old-fashioned sewing machines, but many women sew their naguas by hand. Naguas are usually very colorful and go down to a woman's ankles. The men in the community typically wear clothes such as jeans and T-shirts, which they buy in the city.

2.4 Tradition and Community Life

Women and men are seen as equal within the community. Both genders recognize the importance of the work that men and women complete. Men do most of the labor jobs and hike much more than the women, but women could also be seen hiking in and out of Cerro Ortiga.

Men and women do not have marriages but enter unions. A man only has one union at a time to one woman. The unions are not arranged, and the people in the community choose their partners freely. Men and women are free to decide when a union will occur and how long the union will last. Women begin having children between ages 14-20 and often have up to ten children in their lifetime. Many men will leave their union and children when a woman becomes old and will find a younger woman in the community to produce children with. Because of this, older women are often left alone to care for their house and family. The community members are very generous and help each other in times of need, and it is common for extended family to live together or near each other.

The area has been heavily hunted, and very few wild animals remain. This prevents protein from being a factor in many community members' diets. The people in the community typically eat rice, beans, yucca, and bananas for every meal. With little left to hunt, the community members must rely on their farmed goods to sustain themselves. Local resources are used to build houses, so traditional building materials are not used to design houses. A picture of a nicer house in the community is shown in Figure 4. Homes usually consist of two huts – one as a kitchen/living space and one as a bedroom. No running water is incorporated in any homes and water is gathered by rainwater collection or from the spring source. People in the community go to the bathroom, bathe, and wash their clothes in nearby streams, and they do not currently treat any of their water.

Figure 4. Cerro Ortiga Home (Photo by: Hailey Goupille)

Figure 5. Community Store (Photo by: Hailey Goupille)

2.5 Government Aid

The Panamanian government helps aid the community with monthly stipends and other resources. The government gives each family $120/month to help sustain themselves. For each child in school who obtains good grades, the child's family receives $80/year to be used for school supplies. This money is often not used for school supplies because the family can spend it at their own discretion. School costs $5/year for each child, which all families should be able to afford.

Every 3 months, the government schedules a free health care clinic at the primary school. The clinic provides check-ups, dental care, HIV/AIDS testing, and vaccinations. The government also provided materials and engineers to help build a water supply system back in 2001. Engineers in Panama usually attend university for 2 years instead of the traditional 4 years, but the engineering students are in a specific program related to a field of study such as water supply or construction.

There was a previous water system built by the Panamanian Ministry of Health (MINSA). This water system consists of a concrete spring box, tank, chlorinator, and some pipeline. The previous infrastructure is represented in Figure 6 and Figure 7 below. The spring box's clean out valve was severed to allow for water to pool in front of the spring box. This area in front is used as a laundry area by members not on the water line. This design aspect is important to consider to prevent damage to the new system. A rainwater catchment system, which is discussed in further detail in section 4.4, will provide an area for the community members to continue doing laundry.

Figure 6. Existing Spring Box Provided from the Panamanian Ministry of Health (Photo by: Hailey Goupille)

Figure 7. Existing Holding Tank Provided from the Panamanian Ministry of Health (Photo by: Hailey Goupille)

The previous system used 1.5-inch PVC pipeline and a 4,500-gallon tank. The spring box volume was approximately a 340 gallons. This previous infrastructure was much too large for the amount of flow and number of community members that it served. The pipe was buried, but was exposed throughout parts of the system. A pipe bridge was previously constructed, which is shown in Figure 8. The pipeline crossing the river is damaged and severely sagging due to lack of support. The PVC had been damaged by sunlight and exposure to severe storms. The tap stands at community members' homes were not supported and easily breakable.

Figure 8. Existing Pipe Bridge (Photo by: Hailey Goupille)

The system was reported to have not been working for 14 years prior to Pluma's visit. It functioned previously for one year. The exact cause of failure of the previous system is unknown. The spring may have stopped providing sufficient water, or it may have been rerouted. The spring box has obvious seepage from cracks in the infrastructure. The cleanout pipe being cut may have been the main cause if the pipe was cut prior to the system failing. The community members could not remember why the system stopped functioning.

3.0 Data Collection and Analysis

3.1 Surveying

Pluma Inc. was asked to survey the community to determine the layout of the system. The water committee had determined the route of the water line and will provide each household with a "pluma" or tap. The land that was surveyed had steep hills and thick vegetation that needed to be clear-cut so that the area could be accurately surveyed by the engineers. The vice president of the water committee, Balbino, gathered volunteers to clear cut the surveying pathway and to make stakes to mark each survey point.

Pluma Inc. used a digital rangefinder, abney level, tape measure, and a GPS to survey the land. Three surveying posts were made from identical sticks found on site. The posts ensured that the rangefinder remained level and that the measured angle was accurate. The targets were placed on top of three sticks, 5 feet in height. Every forward shot with the rangefinder was matched with a "back shot" to the initial point to ensure that the measurement was accurate and within 0.5 degrees. The accuracy of the first several ground measurements (approximately 40), was verified with the tape measure. The digital rangefinder and tape measure showed a distance discrepancy of 7.5-8 feet each shot, which required a correction to the distance measurement. The digital range finder proved to be inaccurate for distances less than 30 feet. For shorter distances, the abney level was used to measure angles of inclination and declination, and the tape measure was used to measure the length between survey points. A GPS data point was recorded at each point so that a map could be created of the entire system at a later time; however, the GPS points did not transfer correctly and a precise map was not created. The complete survey data was extracted and organized in an Excel file to be used for calculations throughout the project. This raw data can be found in Appendix A.

3.2 Flowrate Analysis

The flowrate at the spring was gathered using the volume-time method. From the existing spring box, a cut pipe jutted out from the box. This pipe was used to gather water to determine the flowrate; however, a higher flowrate may be available since it was difficult to determine the complete flow of the spring. The spring box is cracked and damaged, and water seepage from the box was visible. A Nalgene water bottle with known volume was filled, and the time it took to fill this amount was recorded. The results are shown below in Table 1. The flowrates were averaged to determine a final flowrate of 1.13 gallons per minute. This data was gathered in August 2016. A second spring source is located nearby at a higher elevation but is deemed unreliable during the dry season

(January-May). Therefore, this spring source has been omitted from the final design. Table 1 shows data collected during flowrate tests.

Table 1. Flowrate Data Collected On-Site

Trial	Volume (L)	Time (s)	Flowrate (L/s)
1	0.95	11.8	0.08
2	0.90	12.0	0.075
3	0.875	15.2	0.058
4	0.90	12.2	0.074
5	0.95	13.6	0.070
Average Flow Rate	**0.0714 L/s**	**1.13 gpm**	

3.3 Water Quality Results

Water quality tests are performed at the site of the spring box. Five tests were conducted using 3M petrifilms. For accurate water quality tests, the petrifilms should have been kept refrigerated prior to use. Because these tests were conducted in a remote location without access to refrigeration or electricity, they were kept at room temperature. The films were observed four days after they were taken. Figure 9 shows the results. The average number of coliforms was 11.6. No E-coli colonies were observed per 1 milliliter sample. Based on the results and the absence of E-coli, the water should be sufficiently treated with chlorine tablets. Chlorination is further described in section 5.6 of this report.

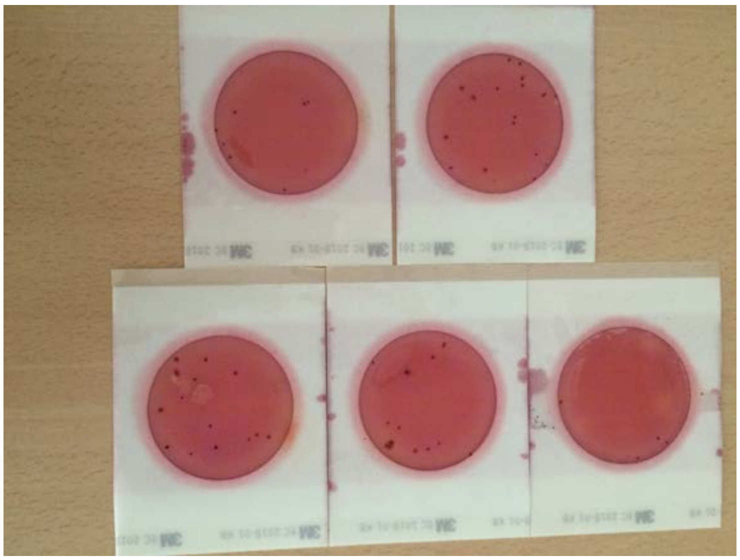


Figure 9. Water Quality Petrifilms (Photo by: Hailey Goupille)

3.4 Water Usage and Recommendations

The water usage in the community was never officially recorded. The system has been designed to provide 20 gallons per person per day. The World Health Organization

(WHO) suggests that 5 gallons per person per day is sufficient for basic water access [1]. This suggests that the system will provide a sufficient amount of water to the community members. The amount allotted (20 gallons per person per day) is the maximum allowable usage to service 78 community members with the measured flowrate of 1.13 gallons per minute. The community does not currently have a working running water system. Due to this new concept, Pluma Inc. is concerned that the community members may overuse the water available, or the usage will be uneven throughout the community. Members are being asked to monitor water usage per family, and not exceed this allowable amount. When new members join the household, or citizen numbers change, the allowable water usage will need to be adjusted.

Table 2. Total Allowable Usage per Household

Household	**Number of Members**	**Total Allowable Usage per Household (gallons/day)**
Louisa	7	140
Nicolas	8	160
Maritza	5	100
Martin	4	80
Petita	6	120
Elena	5	100
Higlihia	11	220
Balbino	2	40
Ovidio	8	160
Florentia	4	80
Monico	8	160
Eugenio	2	40
German	8	160

4.0 Final Design and Recommendations

4.1 EPANET

The pipeline for the water system will be approximately 5,654 feet with a total elevation change of 375 feet. The pipeline will be constructed of 1.5-inch and 1-inch diameter SDR 26 PVC piping. The main line will be 1.5-inch diameter pipe, and the branches will be 1-inch diameter pipe. The pipeline will lead to 13 homes, serving approximately 78 people. It will include a spring box, a rainwater catchment system, a holding tank, air valves, and a pressure reducing system.

An EPANET model was developed to simulate the water demands, pressures throughout the system, and tank water levels over a specified period of time. The EPANET model showed that there are no negative pressures occurring in the system. The 13 tap stands, major survey points that indicated steep up-hills or drastic declines, the tank, the spring box, and the pressure reducing valves are all represented in this model.

At each tap stand, the elevation and base demand were input. All elevations for each element were taken from the rangefinder data collected by Pluma Inc. while in Panama. The base demands were calculated by dividing the flowrate by 78 total people located on the water line. The value was found to be 0.0141 gallons per person per minute. This value was multiplied by the number of people in each household, and this total value was the base demand for each tap. Figure 10 shows the demand pattern for every hour over a 24-hour period. The demand pattern was determined based on estimated water usage rates at peak hours during the day, when the community will likely be drawing water.

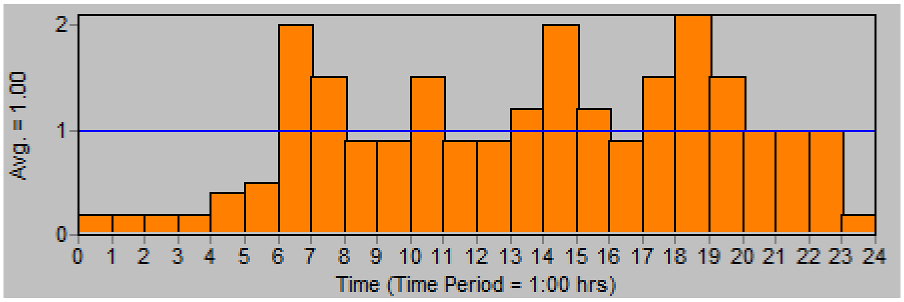


Figure 10. Demand Pattern over 24 Hours

The major survey points that needed to be modeled in the EPANET model were determined based on discretion of the Pluma Inc. engineers. All major points included tap stands, areas where the pipeline split into branches, and drastic and/or sudden incline or declines. The model is meant to accurately depict the terrain of the system, and each node location was chosen to achieve this goal. A total of 41 survey points accurately depicted the system.

The tank and spring box are also included in the model. The spring box was modeled as a source that releases the measured flowrate gathered on site. The tank is set to model the designed 2,000-gallon tank. In EPANET this tank is modeled as a cylindrical tank with the correct diameter to create a 2,000-gallon tank. This diameter was found to be 18.5ft. All of the piping for the mainline is a diameter of 1.5 inches, while each branch is 1.0 inches. The pipe is made out of SDR 26 PVC pipe. The Hazen-Williams roughness coefficient used is 145 for all sections of the pipeline.

A time series model was chosen to represent the varying demand patterns at each point in the day. The theory is that in the morning, around lunch time, and before bedtime water usage will spike. During sleeping hours and late afternoon, less water demand will be needed. The demand pattern multiplying factors that were chosen are shown in Figure 10 and can also be found in Appendix B.

The schematic of the system in EPANET is shown in Appendix C. A sample table of results is shown in Appendix D. This table represents results from one hour during the day. Any hour can be chosen in the model, but hour 6:00 was chosen to be showcased. Figure 11 represents the tank's water level throughout the day. The time series can be modeled for any time period; however, a 48-hour time period was chosen. The bottom of the tank is located at 977 feet, and the tank water level reaches approximately 981 feet at 7:00 A.M. each day. The tank fills each night and never fully empties.

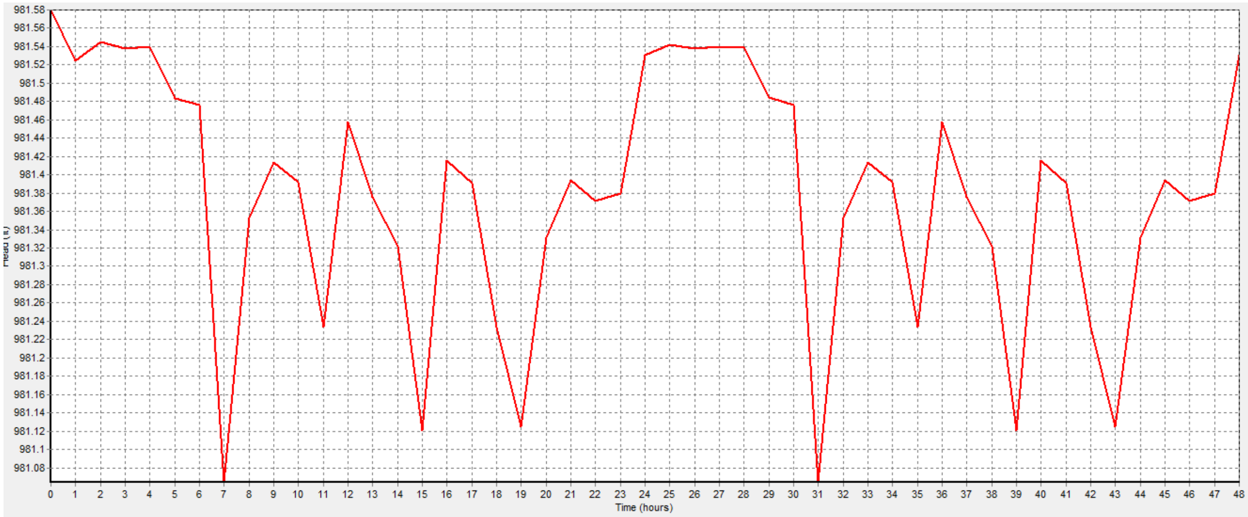


Figure 11. Head in the Holding Tank from EPANET Model Simulation

The EPANET model outputs pressure and head at each node along the system. These values were used to calculate the hydraulic grade lines (HGLs) for the system. Sample calculations can be found in Appendix E. The HGLs were plotted against the elevation of the system to ensure that the pressure was within the safe limits, and that there were no negative pressures. An HGL plot can be seen for each of the branches of the system in Appendix E.

4.2 Spring Box

The water system will start at the spring box which will contain and direct water coming from a natural spring. The box will have a length of 4 feet, a width of 2.5 feet, and a height of 2 feet and will be constructed from reinforced concrete. The walls of the tank will be 6 inches thick and the top will be 4 inches thick. The spring box will only have 3 side walls and a top.

Steel rebar will need to be placed in the top and in the walls of the spring box. Number 5 steel rebar should be used (0.625-inch diameter). The rebar will need to be 2 feet on center for the walls. The front wall will require 1 bar horizontally and 2 bars vertically. The side walls will require 1 bar horizontally and 1 bar vertically. The rebar will need to be 1 foot on center for the top. The top will require 2 bars horizontally and 4 bars vertically. The spring box will not have a back wall or bottom since it will be built into the hillside to collect water from the spring.

One 80-pound bag of Quikrete Ready-To-Use Concrete Mix yields two-thirds of a cubic foot. Thirteen bags of Quikrete will be needed to construct the spring box. Plywood sheets and 2-by-4 boards, 4 feet in length will be used to form the tank. Concrete wall ties will be needed to keep the form in place and can be purchased from a local lumber yard or home improvement store.

A 20-inch diameter manhole will be located on the top of the spring box so the community members can access the inside. The manhole can be placed at any location on the top of the box. A plastic manhole cover will be used to cover the hole and protect the inside of the spring box. The Panamanian Institute of National Aqueducts and Sewer has recently been replacing metal manhole covers near Panama City with plastic ones, so these plastic covers are available in Panama. The community members could also choose to make the manhole cover out of concrete if they are unable to locate a plastic manhole cover.

The spring box will have a 1.5-inch diameter outlet 6 inches from the riverbed on the front wall. An overflow pipe of 1-inch diameter will be located 7 inches from the top of the spring box. This overflow pipe can be placed on any wall of the spring box as long as it is located 6 inches from the top. Spare 1-inch diameter PVC pipes can be used as the overflow pipe. The spring box will also have a clean-out valve located below the outlet. This valve will be lockable, and the head of the water committee will be in control of the key. Figure 12 shows a schematic of the spring box.

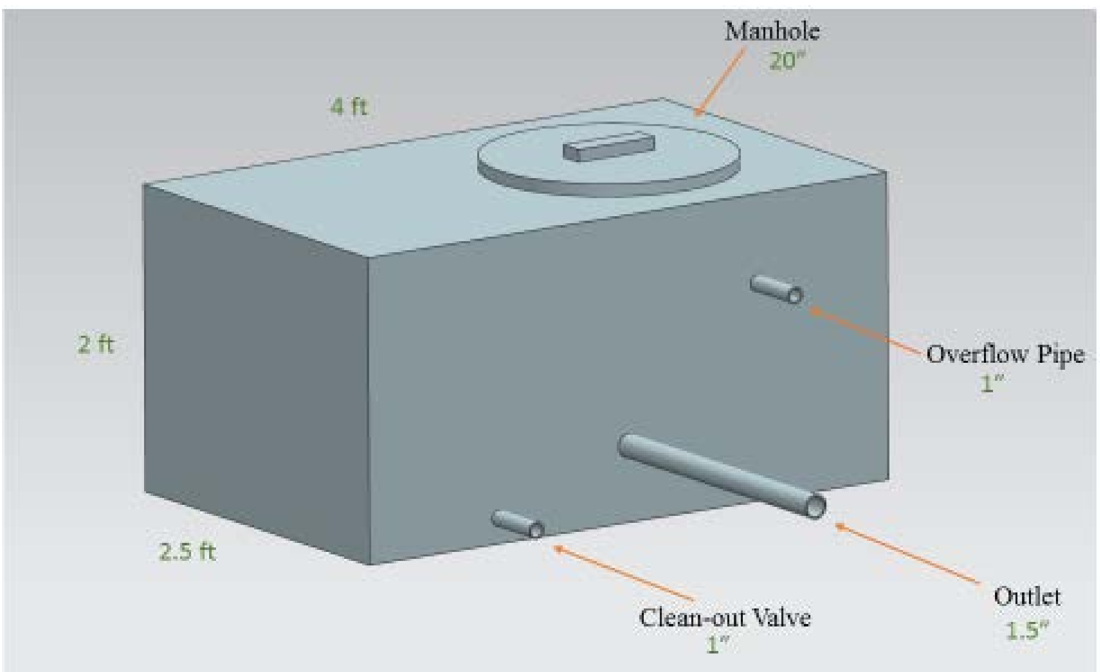


Figure 12. Spring Box Schematic

4.3 Holding Tank

The average flow rate from the spring is approximately 1,630 gallons per day during the wet season. The water system needs to deliver water to 78 individuals in the community. Assuming that each person consumes 20 gallons per day, the water system will be delivering 1,620 gallons per day. The tank will have a length of 7.5 feet, a width of 7.5

feet, and a height of 6 feet, and will be constructed from reinforced concrete. The walls and bottom of the tank will be 6 inches thick, and the top will be 4 inches thick. These dimensions allow for a holding capacity of approximately 270 cubic feet, or just over 2,000 gallons.

Rebar will need to be placed in the top, bottom, and walls of the holding tank. Number 5 steel rebar should be used (0.625-inch diameter). The rebar will need to be 2 feet on center for the walls and bottom. The walls will require 3 bars horizontally and 4 bars vertically. The bottom will require 4 bars in each direction. The rebar will need to be 1 foot on center to construct the top of the tank. The top will require 8 bars in each direction. Waterstop for concrete joints is required to seal the walls to the top and bottom of the tank. One hundred seventy-nine (179) bags of Quikrete will be needed to construct the holding tank. Plywood sheets and 2-by-4 boards 8 feet in length will be used to form the tank. Concrete wall ties will be needed to keep the form in place and can be purchased from a local lumber yard or home improvement store.

A 20-inch diameter manhole will be located on the top of the tank so that community members can access the inside of the tank. The manhole should be built near a corner of the tank at least 2 feet from either side. A plastic manhole cover will be used to cover the hole and protect the inside of the tank. This manhole design is exactly the same as the manhole for the spring box, and the same type of cover can be used for both.

The tank will be built 2.5 feet into the ground with a 1.5-inch diameter inlet located 12 inches from the top of the tank to receive water from the chlorinator. The pipe will come out from the ground and run up the side of the tank. This will allow unrestricted flow at the top of the tank so that the spring does not back up and better mixing of the chlorinated water occurs. The exposed pipe will need to be painted to protect the PVC from UV rays. The opposite wall of the tank will have a 1.5-inch diameter hole located 12 inches from the bottom of the tank to deliver water to the rest of the system. A screen will be placed over the outlet to prevent sediment from traveling into the pipeline. Two overflow pipes of 1-inch diameter will be located 6 inches from the top of the tank. These overflow pipes can be placed on any wall but must be located 6 inches from the top of the tank. Spare 1-inch diameter PVC pipes can be used as the overflow pipes. The overflow pipes should be at least 6 inches in length. Pipes will be sealed using Quikrete Water-Stop Cement. A clean-out valve will be located below the outlet, approximately 8 inches from the bottom of the tank. The valve will be attached to a spare 1-inch diameter PVC pipe. Figure 13 shows a schematic of the holding tank.

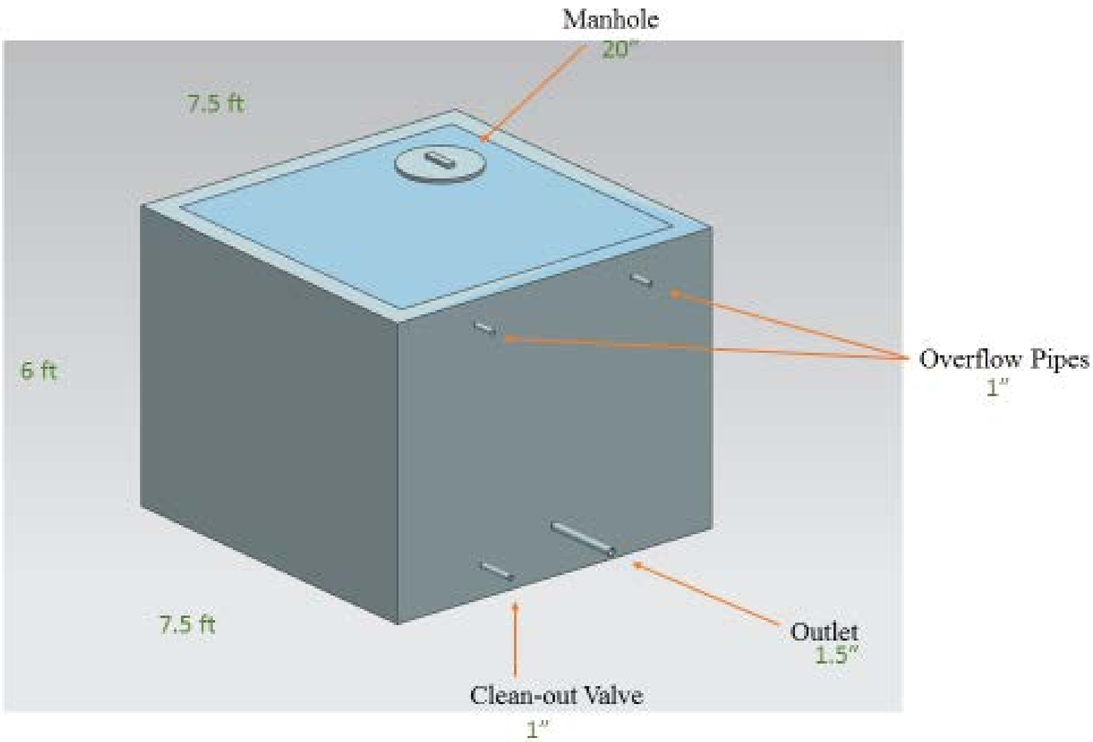


Figure 13. Holding Tank Schematic

Alternatively, the spring box and holding tank can be constructed using locally sourced sand and gravel mixed with cement, instead of buying Quikrete Concrete Mix. Concrete can be made using one-part cement (94 pounds), two-parts sand (160-180 pounds), three-parts gravel (240-300 pounds), and approximately six gallons of water. Six bags of Quikrete Portland Cement yields approximately one cubic yard, so 29 bags of cement will be needed to construct both the spring box and holding tank. This method will add time to the construction schedule because sand and gravel will have to be extracted on site, but will cost less than Quikrete Concrete Mix and will be easier to transport.

4.4 Rainwater Catchment System

A rainwater catchment system will be located above the spring box. The catchment system was designed to provide water to the laundry area. The catchment area needs to be approximately 50 square feet. An artificial dam can also be constructed from materials onsite such as large boulders, gravel, and sand to keep water in the laundry area. The dam can be mortared together to prevent water from leaving this pooled area.

The rainwater catchment roof will be one-sided, as shown in Figure 14. The roof will be made of corrugated PVC and will have an attached gutter and spout to funnel water into the laundry area. The gutter consists of PVC material and has a short PVC spout. There will be four 4-inch by 4-inch posts that will be used to stabilize the structure. The area of the roof was found using Equation 1.1 [2]. The roof area was estimated first, and based on the volume of harvested water was finalized. The 2016 rainfall data was averaged for David, Panama and the average rainfall data for the year was used in Equation 1.2 [3].

With the average rainfall data, the area of the roof will be 5 feet by 5 feet for a total area of 25 square feet. This area will provide on average 170 gallons of rainwater per month. The average rainfall for the dry season (February-April) and the wet season (January-May) was also averaged. Using the square footage of the roof, it was calculated that 145-180 gallons of rainwater per month can be captured by the system.

$$Harvested\ water\ (gal) = catchment\ area\ (ft^2) * rainfall\ depth\ (in) * 0.623\ conversion\ factor \tag{1.1}$$

$$25ft^2 * 10.9in * 0.623 = 170 gallons/month \tag{1.2}$$

The weather station for this region is located in Limon, Costa Rica. This station's data for 2016 is shown in Figure 15. December is averaged from previous years.

Figure 14. Sample Rainwater Catchment Roof [3]

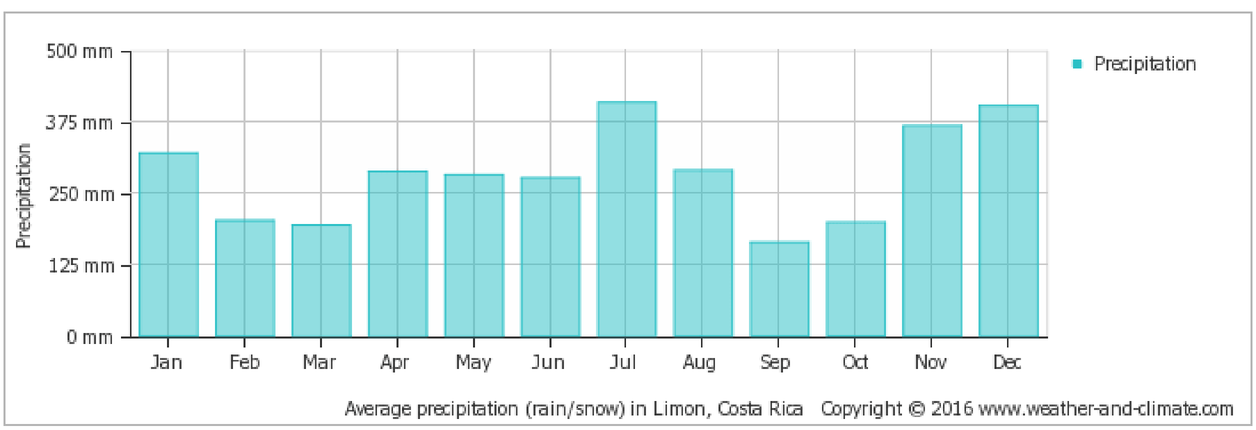


Figure 15. Average Monthly Rainfall Data for David, Panama [3]

4.5 Chlorinator

An exact dose of chlorine and expected free chlorine concentration cannot be determined without doing test in the field. Suggestions based on Yaokum (2013) are provided below [4]. The chlorinator will be moved and located before the storage tank. It is currently located after the storage tank. Moving the location of the chlorinator will allow for a longer contact time for disinfection.

MINSA will provide a chlorinator for $25 to be used in the system. Due to this low cost option, and easy maintenance, this chlorinator has been chosen for Pluma Inc.'s design. The community members can receive up to 15 free chlorinator tablets per visit to MINSA. The number of visits to MINSA is unlimited. A schematic of the chlorinator system provided by MINSA is shown in Figure 16. A photo in Figure 17 shows how the chlorine tablets are inserted into the chlorinator body, which is constructed from PVC. A box should be constructed around the chlorinator to protect the system from damage.

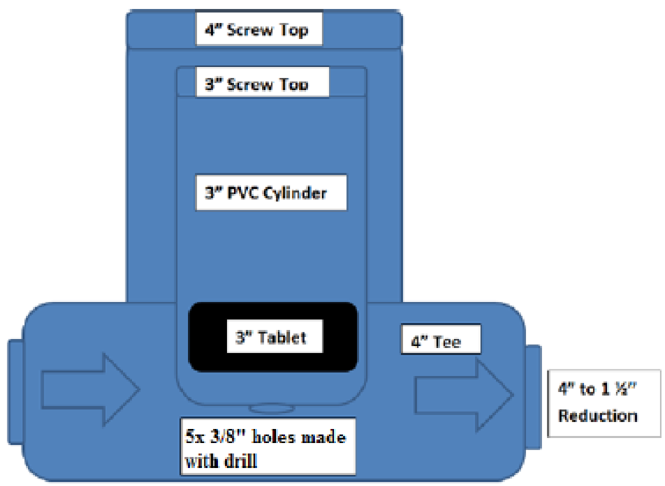
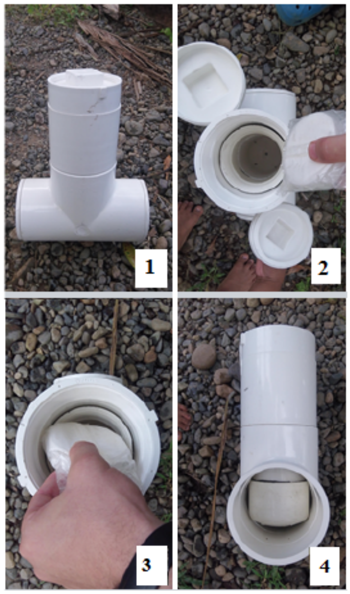


Figure 16. Chlorinator Schematic [4]



1) Front view
2) Top view showing where the chlorine tablets would be inserted (Note: holes in bottom)
3) Top view showing chlorine tablet being inserted into chlorinator
4) Side view showing the 3 inch cylinder sitting all the way down in the 4 inch Tee

Figure 17. Chlorinator [4]

The tablets are 3 inches in diameter and each weigh 200 grams. The article suggests inserting three chlorinator tablets at a time to provide higher surface area for the water to come in contact with [3]. The tablets must be cut in half to properly fit. The cutting should be done over the chlorinator to allow for the dust produced during cutting to fall in the chlorinator.

The decay rate of each tablet was studied using a water system located in rural Panama with the chlorinator provided from MINSA [3]. The study had a flowrate of 12 gallons per minute compared to Pluma's design flowrate of 1.13 gallons per minute. The 12 gallons per minute flowrate allowed for a decay rate of each tablet to be approximately 1 gram per hour. Cerro Ortiga II has a drastically lower flowrate, so the tablets are expected to decay at a much slower rate. This exact rate cannot be calculated without field tests. However, it can be assumed that the same volume of water would be treated, and the volume of water in contact with the tablets is independent of the flowrate. Based on the 12 gallons per minute flowrate, the tablets will decay in 5-7 days. The tablets used in Cerro Ortiga II are expected to last much longer; however, an exact time period cannot be calculated. This was calculated based in the chlorine tablets consisting of 70-90% or 140-180 grams of available chlorine.

The average retention time in the tank was calculated to be 8.8 hours, using a conservative baffling factor of 0.3 in Equation 1.3 below. The retention time is the amount of time a molecule of water will remain in the tank. The concentration of the chlorine needed to eliminate 99.9% of harmful bacteria can be calculated using the Chick-Watson model. The calculations are shown in Equation 1.4. The Chick-Watson rate law constant, k, was chosen based on E. Coli treatment using chlorine. This value was chosen based on the Yoakum article's recommendations. The concentration of disinfectant for 3-log removal of the bacteria is approximately 0.055 milligrams per liter.

$$C = \frac{\ln(\frac{N}{N_0})}{-kt} = \frac{\ln(0.001)}{-0.24 * 528\, minutes} = 0.055\, mg/L \quad (1.3)$$

C= Concentration of disinfection (mg/L)

K= Chick-Watson rate law constant (min^{-1})

N_0= Microorganism concentration at starting time

N= Microorganism concentration at a future time

t= Retention time (minutes)

$$Retention\ Time(hours) = \frac{Flowrate}{Volume} * 0.3\ baffling\ factor = \frac{1.13 gpm}{2{,}000\ gallons} * 0.3 = 8.8\ hours \quad (1.4)$$

4.6 Pipe Crossings

Five pipe crossings will have to be constructed for this system. The bridges span 38 feet, 83 feet, 26 feet, 25 feet, and 35 feet, respectively. Suspension bridges will be constructed for each crossing. A 3-inch diameter PVC sleeve will go over the pipeline to protect it, and a cable and stringers will be used to suspend the pipeline. A diagram of a suspension bridge pipe crossing is shown below in Figure 18.

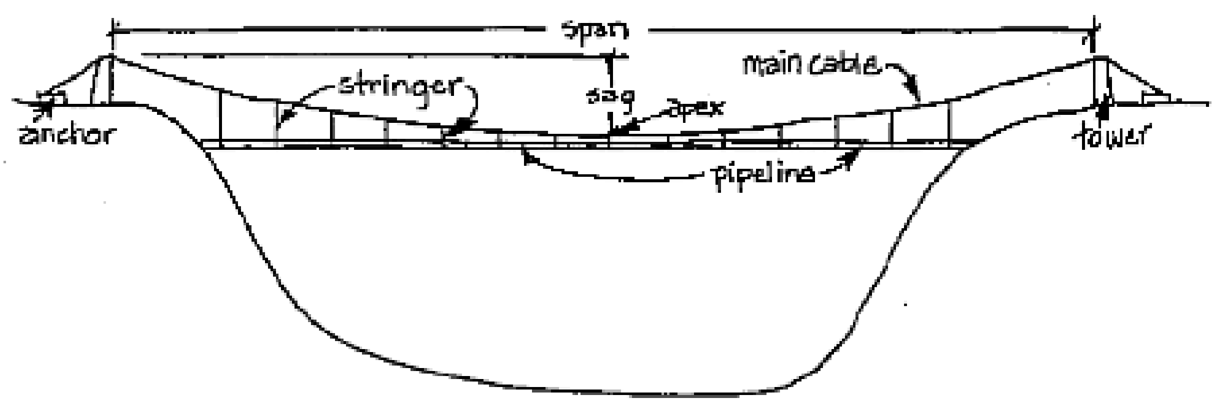


Figure 18. Simple Suspension Crossing [4]

Total tension in the main cable was calculated based on the horizontal tension and the angle of tension for each crossing. The total tension at each crossing was multiplied by a safety factor of 3. The total tension for each crossing is shown in Table 3. Since all tensions are below 1700 pounds, 7x7 1/8-inch diameter steel cable will be used as the main cable to suspend the pipeline. The pipe crossings will require approximately 350 feet of cable. An example calculation can be found in Appendix F.

Table 3. Cable Tension at Each Crossing

Crossing	**Length of Span (ft)**	**Total Tension (lbs)**
1	38	395
2	83	985
3	26	250
4	25	233
5	34	322

Simple block anchor masses constructed from concrete will be used to anchor the crossings. All anchors will have a height of 2.5 feet and a width of 2 feet. The base will be built 1.5 feet below the surface. To ensure that the anchor will not overturn, the length of each anchor was determined by summing the moments around the front bottom edge. A safety factor of 3 was used and the density of concrete is assumed to be 150 pounds per cubic foot. The dimensions of the anchors at each crossing are shown below in Table 4. The horizontal forces were summed to ensure that the safety factor is in the allowable range and to check that the anchor will not slide. A friction angle of 36 degrees was used. All safety factors were checked and solved to be above 3. Sample calculations can be found in Appendix F. Eighteen 94-pound bags of cement, sand, gravel, and water will be needed to construct the anchors. The community members may choose to use Quikrete Pre-Mixed Concrete if they wish.

Table 4. Anchor Dimensions

Crossing	Length (ft)	Width (ft)	Height (ft)	Weight (lbs)
1	1.6	2.0	2.5	1169
2	2.5	2.0	2.5	1864
3	1.2	2.0	2.5	923
4	1.2	2.0	2.5	888
5	1.4	2.0	2.5	1046

Stringers will tie the pipe to the main cable, as shown in Figure 19. 7x7 1/8-inch diameter steel cables will be used as the stringers. Crossings 1, 3, 4, and 5 will have 4 stringers. Crossing 2 will have 8 stringers. The recommended turnback length for a 1/8-inch steel cable is 4 inches. Two turnback lengths were used at the top and two at the bottom. An additional 4 inches was added to go around the eyelet. The stringers will have to be wrapped around the pipe circumference twice, so an additional 6 inches was added. Stringer lengths and sample calculations can be found in Appendix F. Table F3 is the determined sag using tabulated C values [5]. Table F4 lists the stringer locations and respective lengths. These stringer lengths are recommended for the assumed sag, but since these pipe crossing are short, community members can choose to create stringers of their own desired lengths to suspend the pipe. Distances are listed from the apex, and stringers should be placed at the respective distance on both sides of the apex.

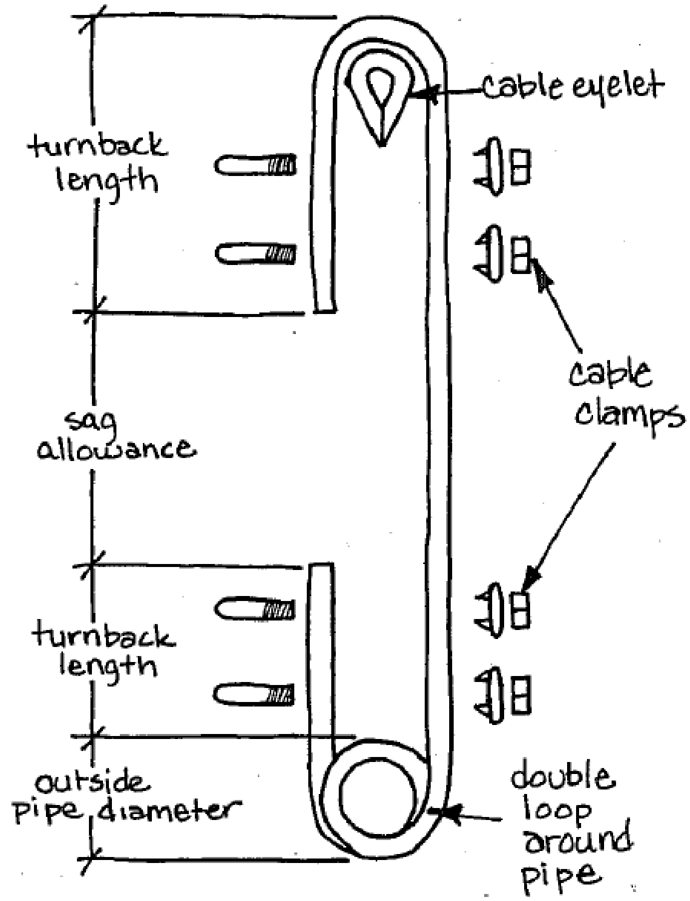


Figure 19. Stringer Design [4]

4.7 Air Valves

Air blockages can occur within a gravity-fed water system and can cause water to be blocked. Air release valves are needed in places where this can occur. An air release valve will need to be installed at point L3 on the system (Appendix C). Sample calculations can be found in Appendix G [6]. The air block will not be eliminated with the flow because the head of the air block is less than the tap elevation. Pluma Inc. researched air valve designs and concluded that it was more cost effective and reliable to buy a pre-assembled thermoplastic air release valve (Figure 20) where L is 4.7 inches, D is 1.9 inches, and D1 is 2.8 inches [7]. The valve is closed when the system is running normally. If an air blockage occurs the air will flow out of the valve, and as the air dissipates the water causes the poppet within the valve to rise and close.

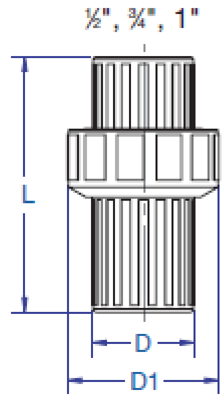


Figure 20. Air Release Valve [7]

4.8 Pressure Reducing System

The overall elevation change from the spring box to the last home on the system is approximately 375 feet, which caused the EPANET model to produce pressures between 100 and 150 pounds per square inch at the lower end of the system. Normal pressure at a water tap is considered to be between 45 and 60 pounds per square inch. SDR 26 pipe has a pressure rating of 160 pounds per square inch, so for safety reasons the pressure must be reduced. A pressure release system will be installed on the main line at survey point 14, which is 1,457 feet downstream from the spring box. There are two options for a pressure release system - a pressure release valve and a pressure break tank.

Pluma Inc. recommends using a pressure reducing valve because transportation of the materials and installation will be easier. The pressure reducing valve can be set to reduce the pressure to a preferred pressure. Two gauges would be installed upstream and downstream of the valve to verify the pressure on each side. The pressure reducing valve has a maximum working pressure of 300 pounds per square inch. It has an adjustable reduced pressure range of 25 to 75 pounds per square inch, and a standard pressure setting of 50 pounds per square inch.

A pressure break tank could be an alternative pressure release system if the materials for the pressure reducing valve are not available to the community. A pressure break tank would open up the system to the atmosphere, reducing the pressure to atmospheric. The tank includes a float valve to eliminate overflow from the tank and a baffle system to reduce the impact of turbulent flow on the float valve [8]. A model of the pressure break tank can be found in Appendix H.

4.9 Taps and Shut-off Valves

There will be a tap-stand at each of the 13 homes on the water system. The tap-stand will be constructed of 4-inch by 4-inch wooden posts that the PVC pipe will be clamped to. Hose clamps will be used to clamp the pipe to the post. The taps will have globe valves to prevent water hammer in the pipeline. Water hammer is a buildup of pressure in the pipeline that occurs when water is shut off abruptly. Globe valves turn the water off more slowly than a gate valve, therefore are the safest option for the taps.

Throughout the water system there will be five valves that can shut off water to certain parts of the system when maintenance is needed. The valves will be placed before the chlorinator, between survey points main 5 and L1, between survey points main 7 and N1, before the pressure release system, and between survey points main 20 and main 27. Figure 21 shows the location of each valve.

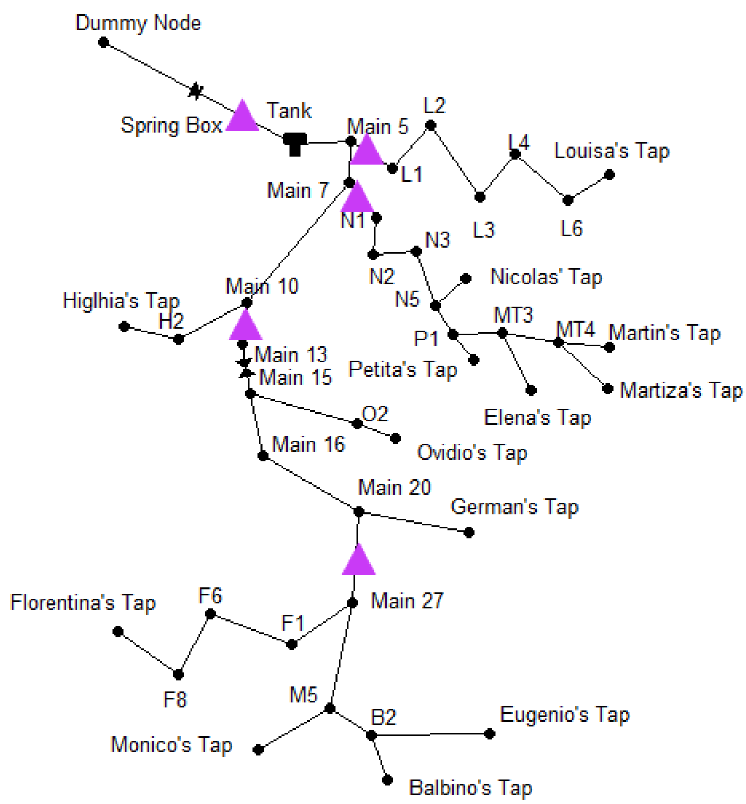


Figure 21. Shut-off Valve Locations

5.0 Cost Estimate and Construction Schedule

5.1 Cost Estimate

The final cost is an estimation based on prices taken from the “Do it Center” in David, Panama, and Home Depot’s online site. Most material was found on the “Do it Center” located in Panama; however, some very specific materials were difficult to find.

The budget for this project was $8,000, and the final cost is estimated to be $7,200. This includes all materials and equipment. Labor costs are not included, since the community members will be constructing the system. When completing the final estimated cost, the remote location of Cerro Ortiga II was taken into consideration. The only way to transport materials onsite is to hike for two hours one way, or use horseback. Each horseback trip costs approximately $8, round trip. Some heavy materials, like cement and Quikrete, were necessary; however, the size of the holding tank and spring box were limited because of this heavy material. The pressure break tank is included in the design as an alternative, if a pressure reducing valve cannot be found. The pressure reducing valve was chosen for the final design because of its ease in transportation and installation.

The cost needed to be kept under the grant cap of $8,000. Pluma Inc. tried to keep the costs low, and the materials light. Some larger materials do have a buffer on the amount needed. The pipeline has a 10% buffer on the total pipe needed. The complete cost estimate, which is broken down by design element, can be found in Appendix I.

This cost estimate includes the use of cement for constructing the tanks instead of using Quikrete. The final cost would increase significantly to $8,600 if the community members choose to use Quikrete. Pluma Inc. recommends the use of cement if gravel and sand can be found on site. The final cost estimate was also calculated using a pressure reducing valve instead of constructing a pressure break tank.

5.2 Construction Schedule

The construction is scheduled to begin on August 1, 2017. The project will last for approximately three months, ending on November 1, 2017. This is during the rainy season, so Pluma Inc. is aware that during certain hours of the day, construction may cease. Pluma Inc. has tried to incorporate this in the final construction schedule. If possible, this schedule should be shifted to an earlier start date to avoid working during the rainy season. This construction schedule represents the alternative designs that will take the longest; it accounts for using cement instead of Quikrete and constructing a pressure break tank instead of installing a pressure reducing valve.

The spring box and holding tank will each take 7 days to construct using cement. The pressure break tank will take 6 days to construct. If community members decide to use Quikrete or to install a pressure reducing valve, the schedule will be completed early. The pressure reducing valve will have to be completed after the pipeline is installed. The pipeline is the most time consuming element which is expected to take 41 days to complete. The laundry area’s rainwater catchment system is the final element and is estimated to take 6 days to construct. These estimates were created using a standard 40-hour work week.

6.0 Conclusions and Recommendations

Pluma Inc. has designed a gravity-fed water system to provide running, clean, and safe water to the community members of Cerro Ortiga II. This report will be presented to the Peace Corps volunteer on site, Marlana Hinkley, along with the water committee members of the Cerro Ortiga II community. The final design outlines all essential elements, including tank designs, water treatment, necessary pressure reduction equipment, and multiple pipe bridges. The route of the system was chosen by the community members, and Pluma Inc. recommends following the final design elements outlined in this report for maximum success.

The community members of Cerro Ortiga II will be presenting this report to the Panamanian government in hopes of granting aid up to $8,000. This report outlines the cost and necessary construction elements, materials, and equipment to successfully construct this water system. Pluma Inc. hopes the community members of Cerro Ortiga II continue to maintain the system, and create proper ownership throughout the community.

6.1 Next Steps

After this report has been completed, the community members, with the assistance of the on-site Peace Corps volunteer, should begin preparing to apply for a grant. The community team will need to apply for the full amount of $8,000 to cover material costs, equipment, and transportation. The community should summarize the findings in this report to aid in making a compelling argument to provide a water system in the Cerro Ortiga II community.

If the request is granted at full, the community members can begin construction. The spring box and holding tank should be constructed first. The walls should be formed using the plywood boards, and then poured. The tank will be buried 2.5 feet below the ground surface to allow for this pipe to remain buried. The pipe system must be dug 18 inches deep throughout the entire system. The pipe bridge anchors will be formed and poured similar to the holding tanks. The stringers must be strung according to the recommendations in this report.

The community members should form a formal water committee and determine regulations for the use of the water system. This may include regulating the amount of water each home is using per day. The water committee is recommended to hold monthly meetings to ensure that residents are taking ownership of their respective lines. The committee must also determine how maintenance costs will be distributed. These decisions are recommended to be determined prior to beginning the water project.

6.2 Operation and Maintenance

Once constructed, the system will require little maintenance. Community members will be able to open their taps and receive water. In the event that water stops flowing, one or more of the following may have occurred:

- The spring box is no longer delivering water to the holding tank. This could happen if the clean out valve is left open, debris is clogging the outlet, or the pipeline has been cut to get more water in the laundry area. A member of the Water Committee should be in charge of the key for the clean-out valve. The only time the clean-out valve should be opened is when the spring tank needs to be entirely emptied. In the event that debris is blocking water flow, the clean-out valve should be opened and someone should enter the spring box and remove any debris. After exiting the box, the clean-out valve should be closed and locked. In the event that the pipeline has been cut, it will need to be replaced.
- The holding tank may not be holding water. This could happen if the clean-out valve is left open or debris is clogging the inlet or outlet. Follow the same procedure for clearing debris from the spring box.
- Air is trapped in the pipe. The design has included multiple air valves to mitigate this risk. In the event that air is trapped in the pipe, more air valves may need to be added.

To maintain proper water quality, please refer to section 4.6 of this report. Multiple shut-off valves should be installed in the pipeline, as dictated by the design. In the event that any part of the pipeline needs to be repaired or replaced, the system must be shut off. It is recommended to close the nearest valve **up-hill** from the spot being worked on. This will allow water to continue flowing to some branches of the system while the system is being repaired.

Pluma Inc. recommends that the water committee completely cleans and disinfects the spring box and holding tank at least twice a year. This will ensure that the water remains at a proper drinking quality standard.

7.0 References

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7. "Series ARV Thermoplastic Air Release Valves" *Plast-O-Matic Valves.* n.d. Web. 6 Oct. 2016

8. Narkevic, J., "An Improved Break- Pressure Tank for Rural Water Supply" (1992). *Waterlines*, 11(2) pp. 12- 13

List of Appendices

Appendix A: Raw Survey Data

Main Line				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77.00	7.30	990.22
2	3	153.00	2.60	986.77
3	4	230.00	7.60	976.58
4	5	281.00	10.15	967.60
5	6	376.00	21.85	932.24
6	7	465.50	9.40	917.62
7	8	566.00	3.85	910.87
8	9	730.00	9.50	883.81
9	10	899.00	4.80	869.67
10	11	1025.00	6.00	856.49
11	12	1144.50	7.60	840.69
12	13	1240.50	6.20	830.32
13	14	1360.50	9.00	811.55
14	15	1457.00	9.80	795.12
15	16	1590.00	5.25	782.95
16	17	1656.50	14.55	766.25
17	18	1728.00	8.10	776.32
18	19	1829.50	4.20	783.76
19	20	1949.50	2.80	777.89
20	21	2037.50	1.50	780.20
21	22	2102.50	2.40	777.48
22	23	2178.50	5.80	769.80
23	24	2254.00	8.90	758.12
24	25	2334.50	2.90	754.04
25	26	2425.50	9.30	739.34
26	27	2526.50	0.75	738.01

Louisa				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77.00	7.30	990.216
2	3	153.00	2.60	986.7684
3	4	230.00	7.60	976.5847
4	5	281.00	10.15	967.5972

5	LL2	321.00	0.55	967.9811
LL2	LL3	355.00	14.70	959.3534
LL3	LL4	395.50	13.50	968.8079
LL4	LL5	480.50	16.65	944.4533
LL5	LL6	533.50	7.80	951.6463
LL6	LL7	621.50	6.70	941.3792
LL7	LL8	672.50	2.65	939.0213
LL8	LL9	745.50	6.30	947.0319
LL9	LL10	817.50	0.15	946.8434
Nicolas				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	N1	531	8.6	907.828
N1	N2	615	2.7	911.785
N2	N3	678.5	4.2	907.1344
N3	N4	776	1.5	909.6866
N4	N5	859	7.7	898.5658
N5	N6	943.5	3.2	893.8488
Petita				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	N1	531	8.6	907.828
N1	N2	615	2.7	911.785
N2	N3	678.5	4.2	907.1344
N3	N4	776	1.5	909.6866

N4	N5	859	7.7	898.5658
P1	P2	992	11.1	872.9603
P2	P3	1082	5.7	864.0216
Elena				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	N1	531	8.6	907.828
N1	N2	615	2.7	911.785
N2	N3	678.5	4.2	907.1344
N3	N4	776	1.5	909.6866
N4	N5	859	7.7	898.5658
P1	P2	992	11.1	872.9603
P2	MT2	1089	5.75	863.2421
MT2	MT3	1150	13.35	849.1573
MT3	EM2	1236	6.35	839.6455
EM2	EM3	1295	5.9	833.5808
EM3	EM4	1342	2.75	835.8357
Martin				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	N1	531	8.6	907.828
N1	N2	615	2.7	911.785
N2	N3	678.5	4.2	907.1344
N3	N4	776	1.5	909.6866
N4	N5	859	7.7	898.5658

P1	P2	992	11.1	872.9603
P2	MT2	1089	5.75	863.2421
MT2	MT3	1150	13.35	849.1573
MT3	MT4	1257	1.5	846.3563
Maritza				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	N1	531	8.6	907.828
N1	N2	615	2.7	911.785
N2	N3	678.5	4.2	907.1344
N3	N4	776	1.5	909.6866
N4	N5	859	7.7	898.5658
P1	P2	992	11.1	872.9603
P2	MT2	1089	5.75	863.2421
MT2	MT3	1150	13.35	849.1573
MT3	MT4	1257	1.5	846.3563
MT4	MB1	1335	2.15	843.4301
Higihia				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	H1	981.5	7.4	859.0396
H1	H2	1097.5	5.4	848.123

H2	H3	1122.85	2.2	847.1499
H3	H4	1186.85	7.6	855.6143
Ovidio				
Beginning Point	End Point	Total Distance	Avg. Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322
13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	OV2	1590	13.1	764.9801
OV2	OV3	1649	13.6	751.1067
OV3	OV4	1750	2.25	755.0719
German				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322

13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	16	1590	5.25	782.955
16	17	1656.5	14.55	766.2485
17	18	1728	8.1	776.323
18	19	1829.5	4.2	783.7566
19	20	1949.5	2.8	777.8947
20	G1	2037	5.2	769.9643
G1	G2	2132.5	10.15	753.1348
G2	G3	2215.5	7	743.0196
G3	G4	2291.5	11.5	727.8676
G4	G5	2367	7.9	717.4906
G5	G6	2468	4	710.4452
G6	G7	2546	3.6	705.5475
G7	G8	2620	13.95	687.708
G8	G9	2658	21.95	673.5037
G9	G10	2724	3.65	669.302
G10	G11	2793.5	5.95	662.0976
G11	G12	2907.5	7.8	646.626
G12	G13	3007.5	7.1	634.2659
G13	G14	3092	4.7	627.3421

Monico

Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322
13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	16	1590	5.25	782.955

16	17	1656.5	14.55	766.2485
17	18	1728	8.1	776.323
18	19	1829.5	4.2	783.7566
19	20	1949.5	2.8	777.8947
20	21	2037.5	1.5	780.1982
21	22	2102.5	2.4	777.4763
22	23	2178.5	5.8	769.796
23	24	2254	8.9	758.1154
24	25	2334.5	2.9	754.0427
25	26	2425.5	9.3	739.3367
26	27	2526.5	0.75	738.0147
27	M1	2642.75	6.1	725.6615
M1	M2	2678.2	2.95	723.8371
M2	M3	2723	21.55	707.3814
M3	M4	2789.5	30	674.1314
M4	M5	2861.5	12.9	658.0574

Balbino				
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322
13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	16	1590	5.25	782.955
16	17	1656.5	14.55	766.2485
17	18	1728	8.1	776.323
18	19	1829.5	4.2	783.7566
19	20	1949.5	2.8	777.8947
20	21	2037.5	1.5	780.1982

21	22	2102.5	2.4	777.4763
22	23	2178.5	5.8	769.796
23	24	2254	8.9	758.1154
24	25	2334.5	2.9	754.0427
25	26	2425.5	9.3	739.3367
26	27	2526.5	0.75	738.0147
27	M1	2642.75	6.1	725.6615
M1	M2	2678.2	2.95	723.8371
M2	M3	2723	21.55	707.3814
M3	M4	2789.5	30	674.1314
M4	M5	2861.5	12.9	658.0574
M5	B1	2949.5	5.4	649.7759
B1	B2	3068	4.85	639.757

Eugenio

Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322
13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	16	1590	5.25	782.955
16	17	1656.5	14.55	766.2485
17	18	1728	8.1	776.323
18	19	1829.5	4.2	783.7566
19	20	1949.5	2.8	777.8947
20	21	2037.5	1.5	780.1982
21	22	2102.5	2.4	777.4763
22	23	2178.5	5.8	769.796
23	24	2254	8.9	758.1154

24	25	2334.5	2.9	754.0427
25	26	2425.5	9.3	739.3367
26	27	2526.5	0.75	738.0147
27	M1	2642.75	6.1	725.6615
M1	M2	2678.2	2.95	723.8371
M2	M3	2723	21.55	707.3814
M3	M4	2789.5	30	674.1314
M4	M5	2861.5	12.9	658.0574
M5	B1	2949.5	5.4	649.7759
B1	B2	3068	4.85	639.757
B2	E1	3118.75	6.95	633.6161
E1	E2	3276.25	1.05	636.5023
E2	E3	3408.75	1.9	632.1092
E3	E4	3572.5	3.95	643.3893
E4	E5	3685	2.75	637.9918

Florentina

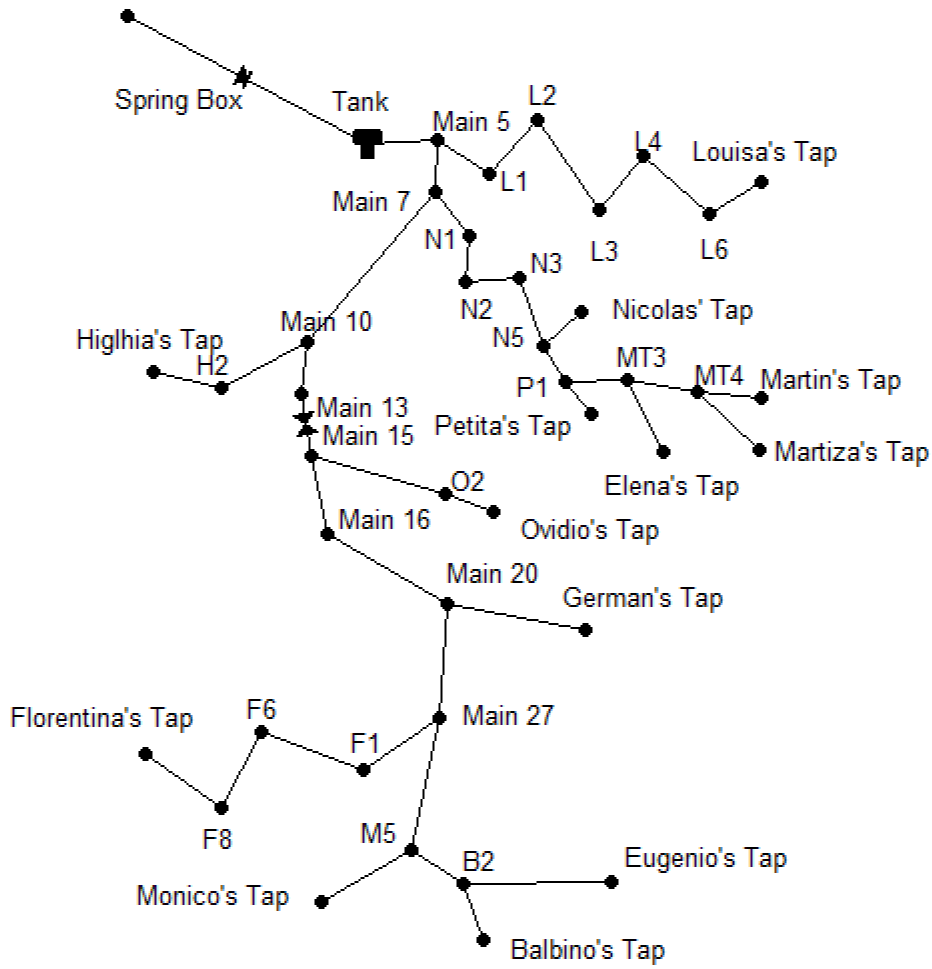
Beginning Point	End Point	Total Distance	Average Angle	Total Elevation
0	1	0	0	1000
1	2	77	7.3	990.216
2	3	153	2.6	986.7684
3	4	230	7.6	976.5847
4	5	281	10.15	967.5972
5	6	376	21.85	932.2403
6	7	465.5	9.4	917.6226
7	8	566	3.85	910.8746
8	9	730	9.5	883.8068
9	10	899	4.8	869.6652
10	11	1025	6	856.4946
11	12	1144.5	7.6	840.69
12	13	1240.5	6.2	830.322
13	14	1360.5	9	811.5499
14	15	1457	9.8	795.1247
15	16	1590	5.25	782.955
16	17	1656.5	14.55	766.2485
17	18	1728	8.1	776.323
18	19	1829.5	4.2	783.7566
19	20	1949.5	2.8	777.8947
20	21	2037.5	1.5	780.1982
21	22	2102.5	2.4	777.4763

22	23	2178.5	5.8	769.796
23	24	2254	8.9	758.1154
24	25	2334.5	2.9	754.0427
25	26	2425.5	9.3	739.3367
26	27	2526.5	0.75	738.0147
27	F1	2690.25	6.3	720.0457
F1	F2	2774.25	13	701.1498
F3	F4	2827.25	25.2	723.7161
F4	F5	2866.25	2.75	725.5872
F5	F6	2918.25	10.4	734.9742
F6	F7	2967.25	5.8	739.926
F7	F8	3049	11.8	756.6436
F8	F9	3113	1.9	754.5216
F9	F10	3169	1.1	753.4466
F10	F11	3297.5	0.7	751.8767
F11	F12	3348.5	15.6	738.1618
F12	F13	3398.5	24.85	717.1496
F13	F14	3424.5	0	717.1496
F14	F15	3479.5	28.2	743.1399
F15	F16	3526	9.05	750.4541

Appendix B: Demand Pattern Multiplying Factors

Time Period	Multiplier	Time Period	Multiplier
1	0.2	13	1.2
2	0.2	14	2.0
3	0.2	15	1.2
4	0.2	16	0.9
5	0.5	17	1.5
6	2.00	18	2.1
7	1.5	19	1.5
8	0.9	20	1.0
9	0.9	21	1.0
10	1.5	22	1.0
11	0.9	23	1.0
12	0.9	24	0.2

Appendix C: EPANET Schematic


Spring Box
Tank
Main 5
L2
L4
Louisa's Tap
L1
Main 7
L3
L6
N1
N3
Nicolas' Tap
N2
N5
Main 10
Higlhia's Tap
H2
MT3
MT4
Martin's Tap
P1
Main 13
Main 15
Petita's Tap
Martiza's Tap
O2
Elena's Tap
Main 16
Ovidio's Tap
Main 20
German's Tap
Florentina's Tap
F6
F1
Main 27
F8
M5
B2
Eugenio's Tap
Monico's Tap
Balbino's Tap

Appendix D: EPANET Results

Table D1. EPANET results at hour 06:00

Node ID	Demand (gpm)	Head (ft)	Pressure (psi)
Main 5	0	981.58	21.38
L1	0	981.58	5.89
L2	0	981.58	9.63
L3	0	981.58	5.53
L4	0	981.58	16.09
L6	0	981.58	17.42
L tap	0.02	981.58	15.05
Main7	0	981.58	30.86
N1	0	981.58	31.95
N2	0	981.58	32.26
N3	0	981.58	32.26
N5	0	981.57	35.97
P1	0	981.57	47.06
N tap	0.02	981.57	38.01
P tap	0.02	981.57	50.94
MT 3	0	981.57	57.37
MT4	0	981.57	58.59
MT tap	0.01	981.57	58.59
E tap	0.01	981.57	63.15
MZ tap	0.01	981.57	59.86
Main 10	0	981.58	48.49
H2	0	981.58	57.83
H tap	0.03	981.58	54.58
PBT	0	795.12	0

O2	0	795.12	19.07
O tap	0.02	795.12	17.35
Main 15	0	795.12	5.27
Main 16	0	795.12	6.46
G tap	0.02	795.12	72.7
Main 20	0.05	795.12	24.74
Main 27	0	795.12	32.53
F1	0	795.12	26.06
F6	0	795.12	16.67
F8	0.01	795.12	19.35
F tap	0.04	795.12	52.42
M tap	0.02	795.12	59.39
B2	0	795.12	67.32
B tap	0.01	795.12	67.32
E tap	0.01	795.12	68.08

Appendix E: Hydraulic Grade Lines

Figure E1. Branch 1: Louisa

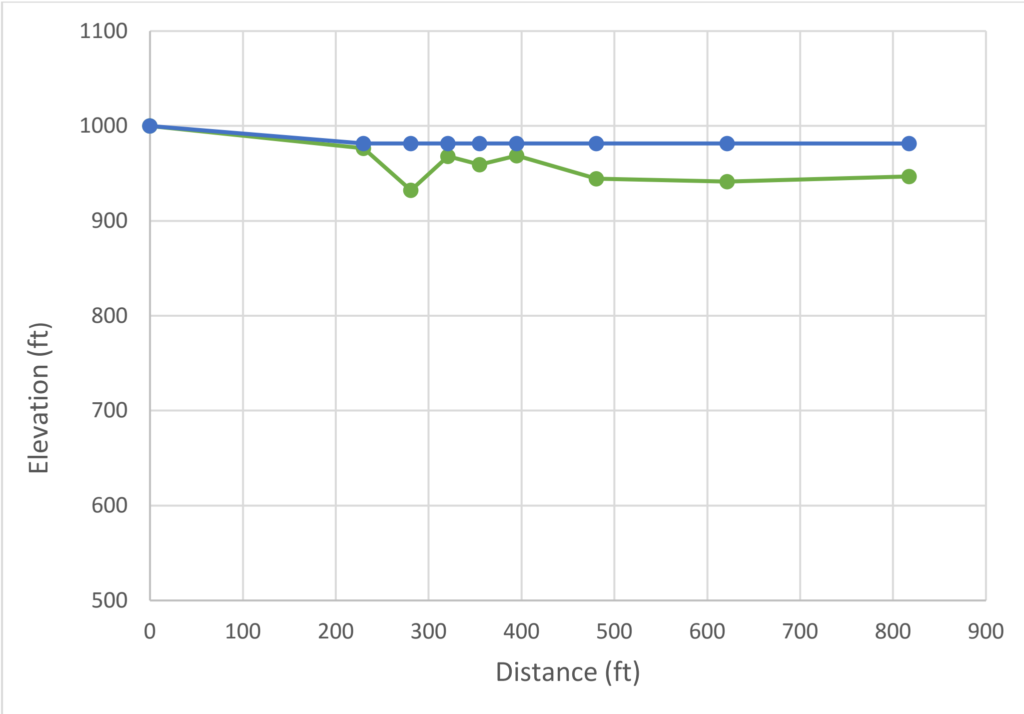


Figure E2. Branch 2: Nicholas, Petita, Elena, Martin, Maritza

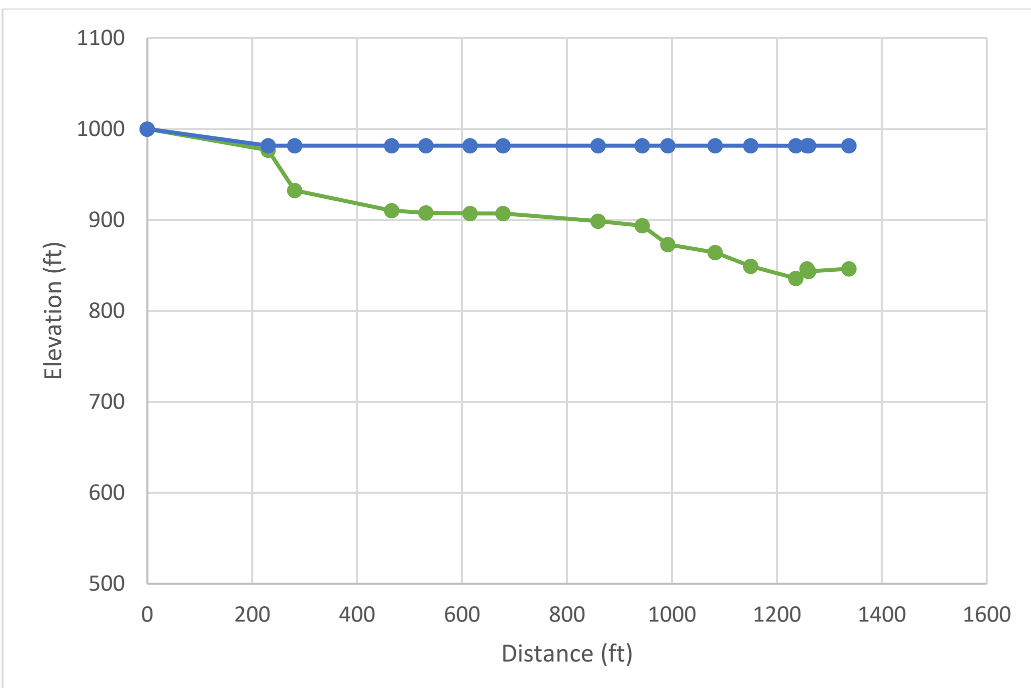


Figure E3. Branch 3: Highlia

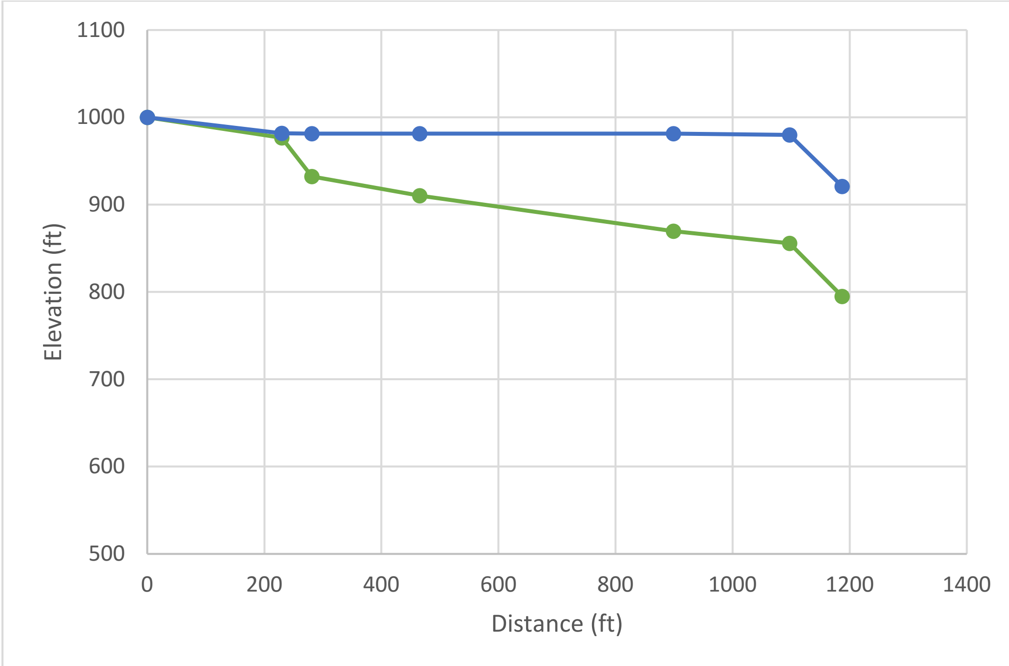


Figure E4. Branch 4: Ovidio

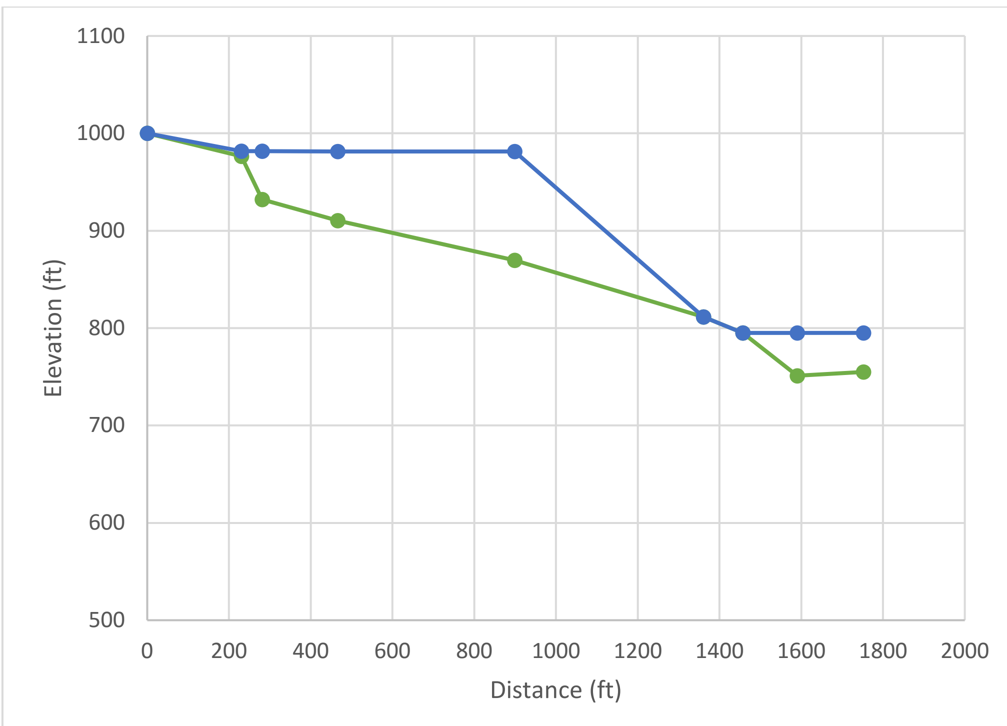


Figure E5. Branch 5: German

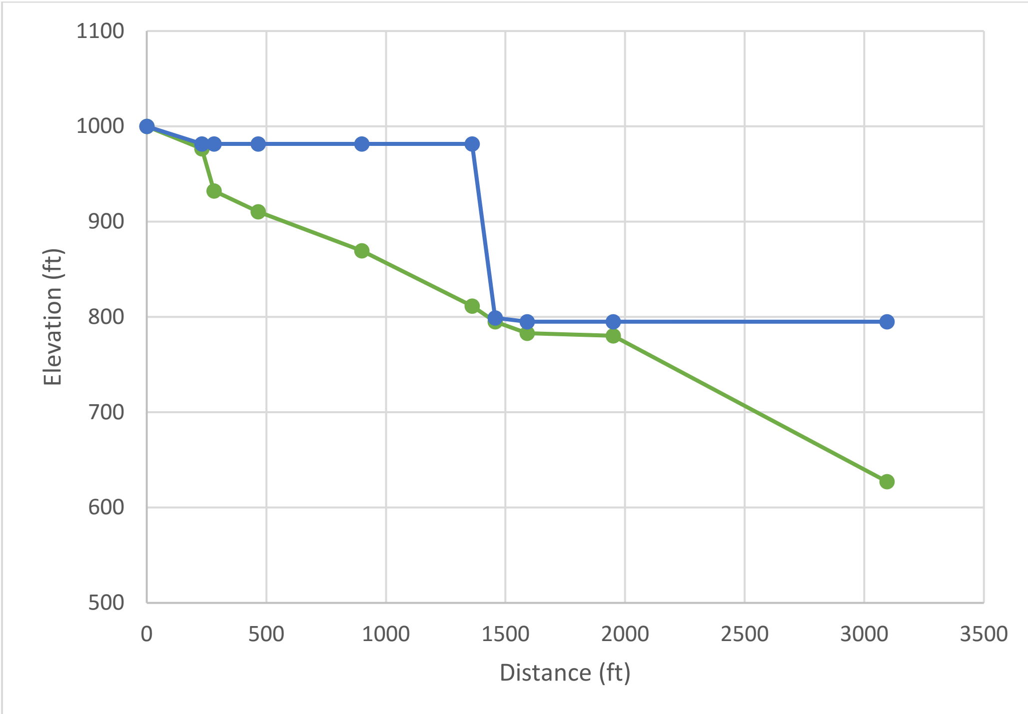


Figure E6. Branch 6: Florentina

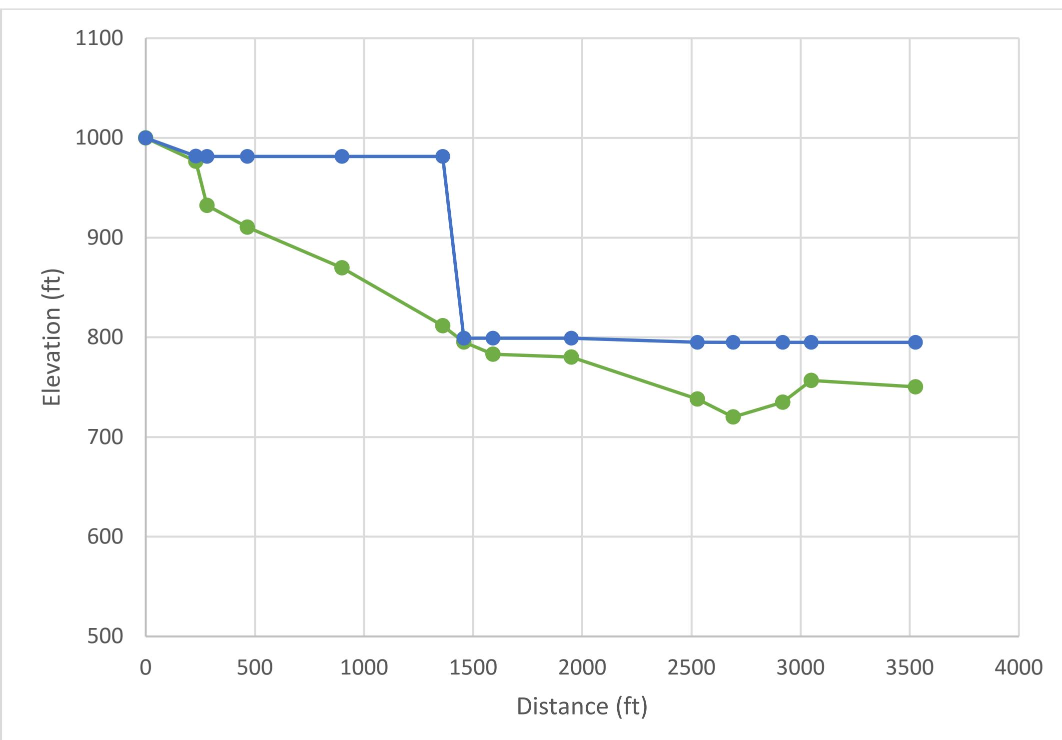
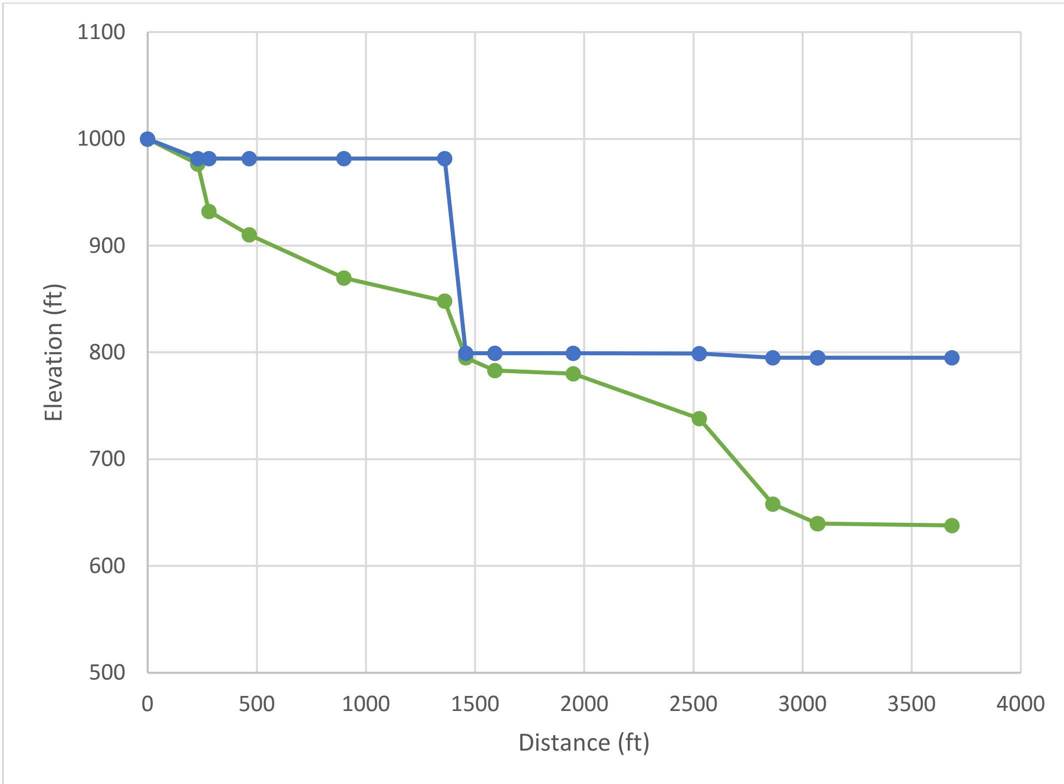


Figure E7. Branch 7: Monico, Balbino, Eugenio



Appendix F: Pipe Crossing Data and Calculations

Cable Design:

Table F1. Cable Tensions

Crossing	Length of Span	Weight per unit Length	Sag	Horizontal Tension	Angle of Tension	Total Tension	Safety Factor	Total Tension (SF)
1	38	2.69	4.0	121.39	22.83	131.71	3.00	395.12
2	83	2.69	7.5	308.86	19.87	328.41	3.00	985.24
3	26	2.69	3.0	75.77	24.78	83.45	3.00	250.35
4	25	2.69	3.0	70.05	25.64	77.70	3.00	233.11
5	34	2.69	4.0	97.18	25.20	107.40	3.00	322.20

$$Horizontal\ Tension = \frac{(weight\ pipe\ per\ unit\ length) x\ (length\ of\ span)^2}{8\ x\ sag}$$

$$Angle\ of\ Tension = arctan\left(\frac{4\ x\ sag}{length\ of\ span}\right)$$

$$Total\ Tension = \frac{horizontal\ tension}{\cos(angle\ of\ tension)}$$

$$Horizontal\ tension = \frac{\left(2.69\ \frac{lb}{ft}\right)\ x\ (38\ ft)^2}{8\ x\ 4\ ft} = 121.4\ lb$$

$$Angle\ of\ Tension = arctan\left(\frac{4\ x\ 4\ ft}{38\ ft}\right) = 22.8\ degrees$$

$$Total\ Tension = \frac{121.4\ lb}{\cos(22.8)} = 131.7\ lb$$

$$131.7\ lb\ x\ 3 = \mathbf{395\ lb}$$

Anchor Design:

Table F2. Anchor Dimensions

Crossing	Horizontal Force (lb)	Vertical Force (lb)	Height (ft)	Overturning Safety Factor	Width (ft)	Density of Masonry (lb/ft^3)	Length (ft)	Friction Angle	Sliding Safety Factor
1	121.39	51.11	2.5	3	2	150	1.56	36	7.42
2	308.86	111.64	2.5	3	2	150	2.49	36	4.75
3	75.77	34.97	2.5	3	2	150	1.23	36	9.31
4	70.05	33.63	2.5	3	2	150	1.18	36	9.69
5	97.18	45.73	2.5	3	2	150	1.39	36	8.29

$$\sum M = 0 = [(horizontal\ foce)\ x\ (height)\ x\ (safety\ factor)] - \left[length\ x\ width\ x\ height\ x\ (weight\ of\ mass\ per\ ft^3) x\ \frac{length}{2}\right]$$

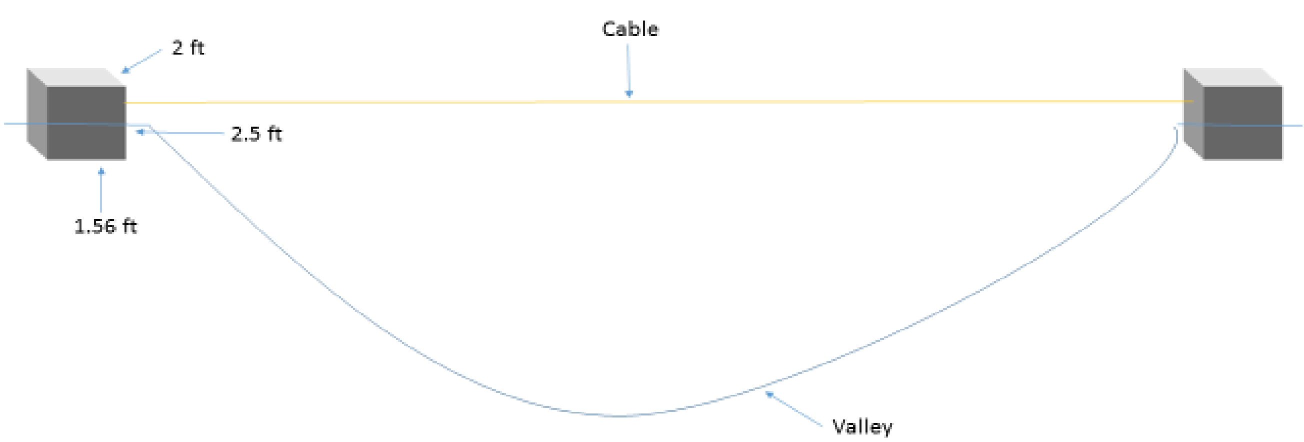
$$\sum M = 0 = [(121.39\ lb)\ x\ (2.5\ ft)\ x\ (3)] - \left[(length)\ x\ (2\ ft) x\ (2.5\ ft) x\ \left(150\ \frac{lb}{ft^3}\right) x\ \frac{length}{2}\right]$$

$$length = \mathbf{1.56\ ft}$$

$$\sum F_x = 0 = [(safety\ factor) x\ (horizontal\ force)] - [(length) x\ (width) x\ (height) x\ (weight\ per\ ft^3)\ x \tan(friction\ angle)] - [(vertical\ force)]$$

$$\sum F_x = 0 = [(safety\ factor) x\ (121.39\ lb)] - \left[(1.56\ ft) x\ (2\ ft) x\ (2.5\ ft) x\ \left(150\ \frac{lb}{ft^3}\right)\ x \tan(36)\right] - [(51.11\ lb)]$$

$$safety\ factor = \mathbf{7.42}$$



Stringer Design:

Table F3. Determining Sag Using Sag Ratio and Tabulated C Values

Crossing	Sag Ratio	c	X1	L	C	Sag (y)
1	0.11	1.22	0.5	1.03	46.32	3.95
2	0.09	1.40	0.5	1.02	116.50	7.47
3	0.12	1.11	0.5	1.03	28.99	2.96
4	0.12	1.06	0.5	1.04	26.53	3.00
5	0.12	1.10	0.5	1.04	37.28	3.94

$$sag\ ratio = \frac{sag}{length\ of\ span}$$

$$sag\ ratio = \frac{4\ ft}{38\ ft} = \mathbf{0.11}$$

Table F4. Stringer Locations and Lengths

Distance (ft)	Sag Allowance (ft)	Normalized (ft)	Final Length (in)
Crossing 1			
5	0.27	0.00	30.00
15	2.45	2.18	32.18
Crossing 2			
5	0.11	0.00	33.50
15	0.97	0.86	34.36
25	2.69	2.59	36.95
35	5.30	5.19	42.13
Crossing 3			
2	0.07	0.00	29.00
10	1.74	1.67	30.67
Crossing 4			
2	0.08	0.00	29.00
10	1.91	1.83	30.83
Crossing 5			
4	0.21	0.00	30.00
14	2.66	2.45	32.45

$$y_n = (\,C)\,x\left(\cosh\frac{distance}{C}\right) - (C)$$

$$y = 46.32\,cosh\left(\frac{5\,ft}{46.32}\right) - 46.32 = \mathbf{0.27}$$

Appendix G: Air Valve Calculations

Air pressure of air block

$$P_b = P_{atm} + Z$$

$$P_b = 406.8\ in\ H_2O + 11625.72\ in = 559.87\ in\ H_2O$$

Volume of compressed air

$$V_{a1} = L\left(\frac{\pi D^2}{4}\right)$$

$$V_{a1} = 1020\ in\ \left(\frac{\pi 1\ in^2}{4}\right) = 801.12\ in^3$$

$$V_{a2} = V_{a1}\left(\frac{P_{atm}}{P_{atm} + Z}\right)$$

$$V_{a2} = 801.12\ in^3\left(\frac{406.8\ in}{406.8\ in + 11625.72\ in}\right) = 582.09\ in^3$$

Elevation of the air block

$$Z_b = L\left(\frac{V_{a2}}{V_{a1}}\right)$$

$$Z_b = 1020\ in\ \left(\frac{582.09\ in^3}{801.12\ in^3}\right) = 741.14\ in$$

Equivalent head

$$H_e = P_b - P_{atm}$$

$$H_e = 559.87\ in\ H_2O - 406.8\ in\ H_2O = 153.07\ in\ H_2O$$

Final head

$$H_f = H_e - h_L$$

$$H_f = 153.07\ in\ H_2O - 0 = 153.07\ in\ H_2O$$

Check

$$C = Z_t - (Z_b + Z)$$

$$C = 11362.08\ in - (741.14\ in + 11625.72\ in) = -1004.78\ in$$

Appendix H: Pressure Break Tank Model

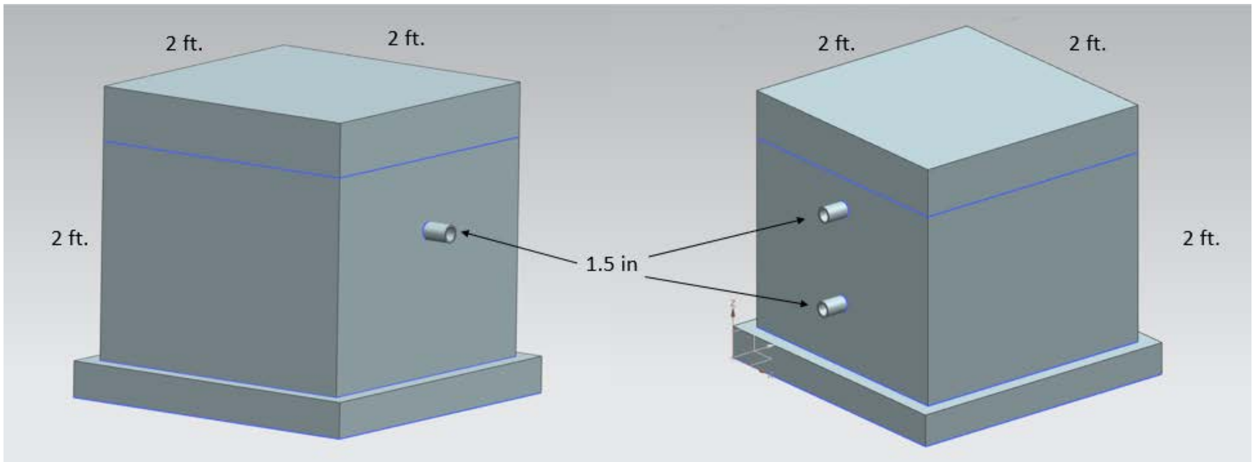


Figure H1. Pressure Break Tank Model

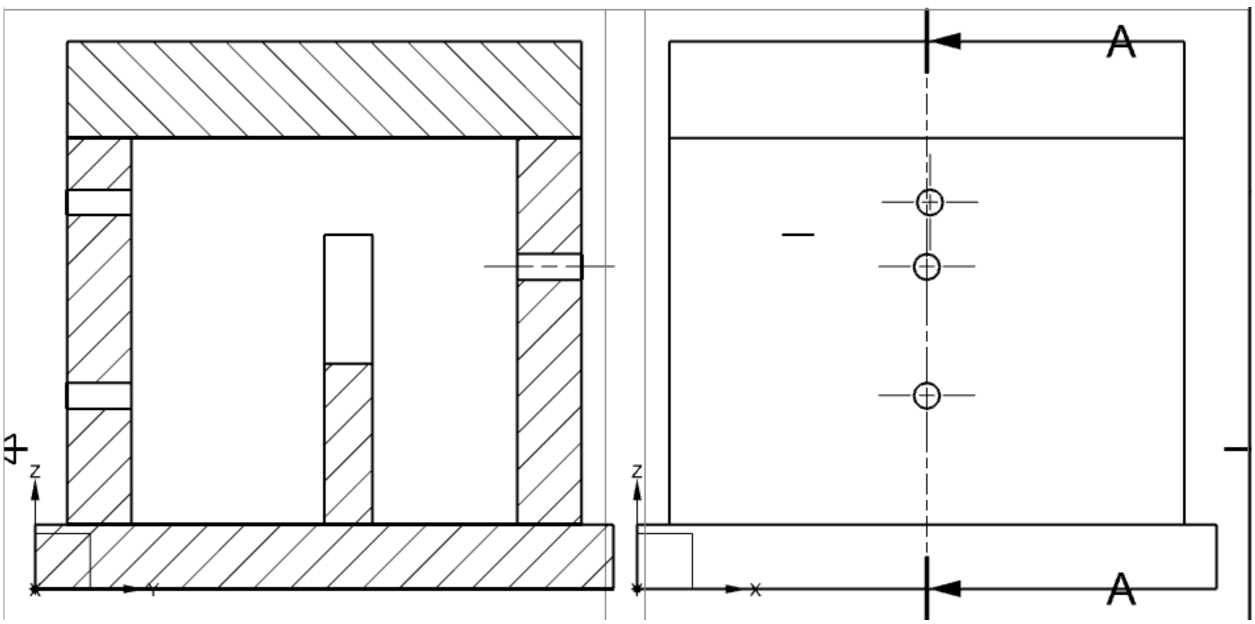


Figure H2. Pressure Break Tank Cross Section

Appendix I: Cost Estimate

	Item	Quantity	Price per Unit	Total
Material				
Pipeline	1" 20 ft PVC	297	5.99	1778.1315
	1" Coupling	297	0.49	145.53
	1.5" 20 ft PVC	133	9.99	1328.67
	1.5" Coupling	133	0.69	91.77
	1.5" PVC T's	9	1.39	12.51
	1" PVC T's	9	2.99	26.91
	Shut-off Valves	7	4.82	33.74
	Tap valve	14	4.82	67.48
	PVC Adapter (1-1/2")	1	1.4	1.4
	90 PVC Elbows	42	0.59	24.78
	Reducers	9	0.69	6.21
	PVC Glue (16 oz.)	5	7.99	39.95
Pressure Reducing	Pressure Reducing Valve	1	84.92	84.92
	Pressure Test Gauge	2	9.98	19.96
	Brass to PVC Conversion	4	11.24	44.96
	1 1/2" to 3/4" Reducer	2	1.81	3.62
	3/4 PVC T	2	0.5	1
	3/4 PVC Pipe	1	1.92	1.92
	Quikrete for Box	3	6.99	20.97
Air Valve	Air Valve	1	9.1	9.1
	Concrete Box	3	6.99	20.97
Tanks	2" x 4"x12ft Boards	12	7.27	87.24
	2" x 4"x12ft Boards	9	2.57	23.13
	94lb Bag Cement	29	9.97	289.13
	#5 Rebar	67	8.47	567.49
	Quikrete Water Stop	1	12.97	12.97
	Vinyl Waterstop	1	48.99	48.99
	Concrete Wall Ties	1	24.99	24.99
	Plywood (3/4"x4"x8")	22	28.85	634.7
	Valve	2	13.25	26.5
	Man Hole Covers	2	30	60
	Gate Valve Lock	1	28.5	28.5
Rainwater Catchment	Gutter	1	13.99	13.99
	PVC Corrugated Roofing	2	14.97	29.94
	4" x 4" Posts	4	7.27	29.08

	Gutter Spout	1	6.99	6.99
Bridges	7x7 Galvanized Cable (1/8"x50ft)	7	16.9	118.3
	Clamps (3/16)	60	0.75	45
	94lb Bag Cement	15	9.97	149.55
	3" 20ft PVC Sleeve	12	31.99	383.88
	3" PVC Coupling	12	1.37	16.44
Chlorinator	Chlorinator	1	25	25
Taps	Metal Ties	32	0.98	31.36
	4" x 4" Posts	6	7.27	43.62
	Spray Paint	5	6.99	34.95
Equipment	Shovel	9	12.99	116.91
	Saw	4	13.99	55.96
	Hammer	5	4.99	24.95
	Cable Cutter	1	78.15	78.15
	Pickax	3	31.66	94.98
	Level	1	4.47	4.47
	Post Hole Digger	1	24.97	24.97
Transportation	Horse/Donkey Rental	40	8	320
TOTAL				**$7,217**

Do it Center, David, Panama:

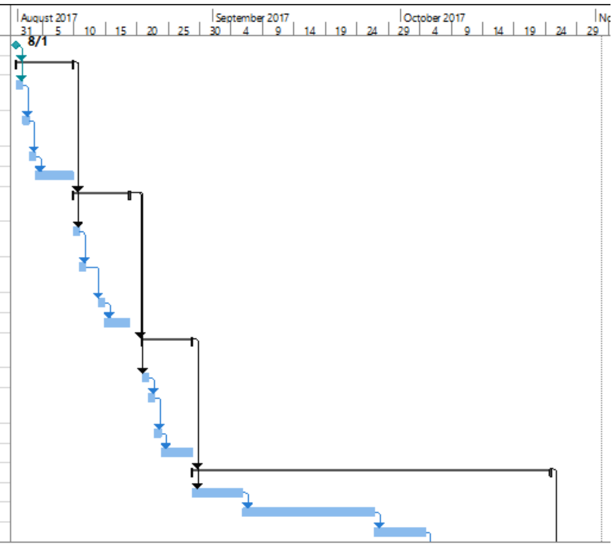
http://www.doitcenter.com.pa/tienda/

Home Depot, United States:

http://www.homedepot.com/

Appendix J: Construction Schedule

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Project Start	0 days	Tue 8/1/17	Tue 8/1/17	
2		**Construct Spring Box**	**7 days**	**Tue 8/1/17**	**Wed 8/9/17**	**1**
3		Clear Spring Box Area	1 day	Tue 8/1/17	Tue 8/1/17	1
4		Dig Tank Area & Level Ground	1 day	Wed 8/2/17	Wed 8/2/17	3
5		Form Spring Box	1 day	Thu 8/3/17	Thu 8/3/17	4
6		Mix & Pour Concret	4 days	Fri 8/4/17	Wed 8/9/17	5
7		**Construct Holding Tank**	**7 days**	**Thu 8/10/17**	**Fri 8/18/17**	**2**
8		Clear Holding Tank Area	1 day	Thu 8/10/17	Thu 8/10/17	2
9		Dig Tank Area & Level Ground	1 day	Fri 8/11/17	Fri 8/11/17	8
10		Form Tank	1 day	Mon 8/14/17	Mon 8/14/17	9
11		Mix & Pour Concret	4 days	Tue 8/15/17	Fri 8/18/17	10
12		**Construct Pressure Break Tank**	**6 days**	**Mon 8/21/17**	**Mon 8/28/17**	**7**
13		Clear Tank Area	1 day	Mon 8/21/17	Mon 8/21/17	7
14		Dig Tank Area & Level Ground	1 day	Tue 8/22/17	Tue 8/22/17	13
15		Form Tank	1 day	Wed 8/23/17	Wed 8/23/17	14
16		Mix & Pour Concret	3 days	Thu 8/24/17	Mon 8/28/17	15
17		**Construct Pipeline**	**41 days**	**Tue 8/29/17**	**Tue 10/24/1**	**12**
18		Clear Pipeline	6 days	Tue 8/29/17	Tue 9/5/17	12
19		Dig Trench	15 days	Wed 9/6/17	Tue 9/26/17	18
20		String Pipe	6 days	Wed 9/27/17	Wed 10/4/17	19



Project: Construction Estimate
Date: Wed 12/7/16

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

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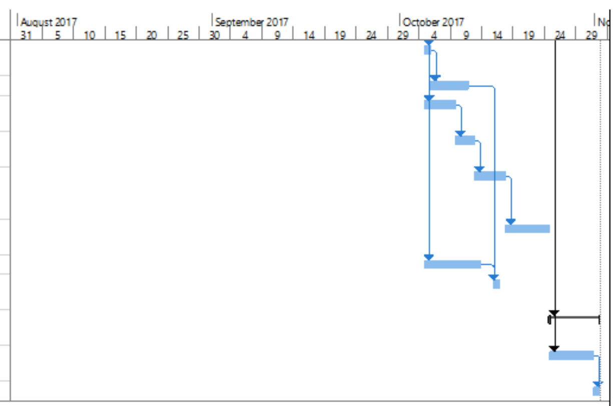
ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
21		Install Air Release Valve	1 day	Thu 10/5/17	Thu 10/5/17	20
22		Fill Trench	4 days	Fri 10/6/17	Wed 10/11/1	21
23		Dig Area for Pipe Crossing Anchors	3 days	Thu 10/5/17	Mon 10/9/17	20
24		Form Pipe Crossing Anchors	3 days	Tue 10/10/17	Thu 10/12/17	23
25		Mix & Pour Concrete for Anchors	3 days	Fri 10/13/17	Tue 10/17/17	24
26		Construct Pipe Crossings	5 days	Wed 10/18/17	Tue 10/24/17	25
27		Build Tap Stands	7 days	Thu 10/5/17	Fri 10/13/17	20
28		Connect Pipe to Spring Box	1 day	Mon 10/16/17	Mon 10/16/17	27,22
29		**Construct Laundry Area**	**6 days**	**Wed 10/25/17**	**Wed 11/1/17**	**17**
30		Build Rainwater Catchment	5 days	Wed 10/25/17	Tue 10/31/17	17
31		Construct Dam	1 day	Wed 11/1/17	Wed 11/1/17	30



Project: Construction Estimate
Date: Wed 12/7/16

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

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