Michigan Technological University

Gravity-Fed Water Distribution System

Bucori, Panama

iDesign
CE 4916
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LETTER OF TRANSMITTAL

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Description:

Mesele's mission was to create a pipe network that will distribute water from three natural springs to the neighborhood of Central Bucori. Water will be treated individually at home.

The water from the springs will be fed to a holding tank with PVC piping; from the holding tank the water will be distributed directly to the community homes and buildings. The water piping network will cross seven streams, one river, and one valley.

Mesele created a water distribution design, performed a cost analysis, and developed a construction schedule and manual.

The system will cost 15,300 dollars and take 40 work days to complete. The water will be treated in home using chlorine.

Mesele would like to thank instructors Mike Drewyor and David Watkins for their support on the project. Mesele would like to also thank Taylor Domagalla for her support in the community and providing information in the United States. Mesele would also like to thank Kiko de Melo e Silva and the Community of Bucori for all the support in collecting the necessary data.

This report, titled "Gravity-Fed Water Distribution System; Bucori, Panama", represents the efforts of undergraduate students in the Environmental and Geological Engineering Departments 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.

By **Team Mesele**:

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Executive Summary

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<u>**Introduction**</u>

Community Background

The village of Bucori is located on the Valiente peninsula in the Ngabe-Bugle region of Panama (Figure 1). Currently, the community has no access to potable water for drinking and cooking. The mission of Mesele was to “Create a pipe network that will distribute water from 3 natural springs to the neighborhood of Central Bucori. Water will be treated individually at home”.

Figure 1 Location of Bucori, Panama [6]

The history of Bucori stems back to many years ago when a Ngabe man moved to Bucori to work for a German banana farmer. After some time, the farmer stopped paying the workers so the man sued the farmer. The man won the lawsuit and all of the farmer’s land, including Bucori. The man’s grandson, Faustino, is now the chief and landowner of the community.

Throughout Bucori there are seven neighborhoods. To travel between most of the neighborhoods, it is necessary to take a canoe. The terrain is too treacherous, and no trail has been created to connect the neighborhoods by land, although there are currently a few community members working on creating trails, especially for children to commute by land to school in inclement weather conditions. The school is located in Central Bucori, which requires students to have to row themselves in a canoe for up to an hour and a half. In bad weather it becomes dangerous to travel between the neighborhoods.

The houses in the community are all made from wood with thatched roofs. All of the houses are raised about one meter off the ground on stilts. Raising up the houses is done so the houses will not be affected by the heavy rains that occur often. Some of the houses are located on docks over the water, while others are inland. The neighborhood of Central Bucori is mostly connected by a sidewalk that was constructed in the 1980's. Areas where the sidewalk does not run are often muddy and rougher terrain. There are also many docks used to connect houses to the community. There are streams that run through some areas of the community. Bridges of concrete or wood planks are used to cross the streams, although the conditions of these crossings are often poor. There is also a large river through the community that is only crossable by boat.

The community currently obtains fresh water from harvesting rainwater in large plastic drums. Chlorine is then used to sanitize the water. An outdated 5,000-gallon capacity concrete tank exists near one of the older spring boxes and is not functional. There are remnants of disconnected PVC pipes, throughout the community, that once transported water from the holding tank to the buildings. There is also a water distribution system already in place from a local creek, and this water is used for laundry and bathing.

Project Information

According to the United States Geological Survey, a spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table, below which the subsurface material is saturated with water [13]. A spring is the result of an aquifer being filled to the point that the water overflows onto the land surface. The water system being designed will run from three natural springs in the jungle of Bucori to a large holding tank. The water will be piped to the community from the holding tank. Each house willing to pay a dollar per month for system maintenance will have water delivered to their faucet.

The community has three stores, a school, a health center, a community kitchen, a church and 31 homes that will be receiving water. Most of the faucets will be located one to three meters off the ground to reach the kitchens of each home.

Seven stream crossings and one river crossing have been designed throughout the system. All crossings will be independent of the bridges and/or have their own suspension system associated with them. The largest river crossing is 39.5 meters across. The stream crossings in the community averaged from two to eight meters.

The rest of this report explains how information on the project was gathered, the design of different components in the system, a recommended construction schedule for the system, and a cost estimate for the project.

Methodology

On Site Data Gathering

Design for the water network is based on data collected on-site and research conducted at Michigan Technological University. Data collected during the on-site survey includes; flowrates of springs, water quality of springs, elevation changes throughout the network, and distances from the springs.

The volume-time method was used to calculate the flowrates of the springs. A stopwatch was used to determine how long it takes to fill a gallon bucket. The flowrates were then calculated using the volume of the container divided by time.

Water quality tests were performed at each spring using 3M Petri-films [19]. These Petri-films displayed the amount of coliform and E. coli colonies present in the water sample. To use the Petri-films, 1 mL of the water was extracted from the spring source and placed on the Petri-film plate. Light pressure was applied across the water sample using the plastic 3M Petri-film spreader to distribute the sample equally throughout the plate. Three samples were taken at each spring. The plates were then incubated, lying flat, for 48 hours. After incubation, the coliforms present were counted. Blue colonies represent E. coli colonies and red colonies represent coliform colonies. Colonies on the ring or foam are not counted.

Multiple points were surveyed along the network. Elevations of the points from the springs to the proposed water tank were measured using a water level. The water level is a simple apparatus prepared by using water and a tube. The tube can be attached to a meter stick for elevation reference. Since water equalizes its level, the difference in elevation can then be measured from both ends of the tube that are attached to the meter sticks, making sure there are no air bubbles in the tube [17]. Water level data for the network was measured by Peace Corps Volunteer Taylor Domagalla and community members.

All data points following the proposed water holding tank were collected using a Nikon Rangefinder, measuring tape, and Garmin GPS. GPS points were recorded along the route from the springs to the holding tank, at significant elevation changes, and observed water crossings. The distance between points was measured with measuring tape. A Nikon Rangefinder was utilized to measure the angle of elevation between two points. Sticks of equal length were placed at each point. A foresight angle was measured by placing the Range Finder on the first stick and aiming towards the top of the second stick. The back sight angle was recorded by measuring from the top of the second stick to the top of the first stick. During this process, it was important to keep the sticks vertical. The process was then repeated along the proposed water route, measuring points at any significant elevation change or water crossing.

Other Project Information

Further research has been conducted at Michigan Tech University to create an optimal design for the water network. Improvements in Sustainability in Gravity-Fed Water Systems [9] paper has been utilized as guidance for spring box construction. For design of the holding tank, recommendations from the Handbook of Gravity-Flow Water Systems [10] have been incorporated. Stream and river crossing designs have been designed based on technical guidance from Standard dimensions and weight of PVC - Polyvinyl Chloride [14]. Anchor calculations for stream and river crossings were researched referencing Pipeline Crossings [18].

Additional data about functionality of the network has been obtained from EPANet model analyses. This software models the water distribution within the network over a 24-hour period. Team Mesele chose to use the Hazen-Williams approximation for estimation of head loss in the network (Eq.1) [11].

$$h_L = 4.727C^{-1.852}d^{-4.871}L$$

$$h_L = Head\ Loss\ (m)$$

$$C = Hazen - Williams\ Roughness\ Coefficient$$

$$d = Pipe\ Diameter\ (mm)$$

$$L = Pipe\ Length\ (m)$$

Eq. 1 Hazen-Williams Head Loss Equation

The pipe roughness coefficient, C, was assigned a value of 140. Two-inch (50.8 mm) pipe diameter was used for the main network. There are three springs in the network. EPANET does not provide an input for springs. Due to this limitation, springs were simulated based on Arnalich's book, EPANET and Development. Springs were designated with a node and were assigned a demand value that represented the observed spring flow rate [20]. An overflow tank was connected to the spring(s) to assist in pressurized flow from springs to the holding tank. Lastly a check valve was attached to the pipes connected to the overflow tanks. Check-valves helped ensure that water flowed only from the springs and that any excess water would be diverted to the overflow tank.

Two scenarios were modeled in EPANET. One scenario used the yearly average spring flow rates in the simulation. The second scenario used the rainiest month spring flow rates in the simulation. Pressure profile plots for each case show how the elevation head varies over a 24-hour period in the holding tank. Water consumption is based on average, yearly spring flow rates, and is very conservative. The conservative water consumption scenario shows less variance in the water level of the tank over a 24-hour period (Appendix 1). In the second scenario, water consumption is based on the rainiest season of the year where spring flowrates are highest. The water elevation of the holding tank varies a lot more because consumption rises due to increased availability of resources (Appendix 1). Additionally, a system flow balance profile was created in EPANET to show the relation between water supplied by springs and water consumption rates. For both cases, there is sufficient water to supply community needs. Lastly, a hydraulic head profile was created displaying the relation between head in the holding tank and head in selected nodes within the network. This profile was produced for both scenarios. Results can be found in Appendix 1.

Spring Boxes

There are three spring captures within the network, located at Springs A, B, and C. The spring captures will serve to capture and protect freshwater flowing from the natural geologic source until it reaches the storage tank. Spring A is a concentrated spring located at an elevation of 5 meters above the storage tank. Spring B is a seepage spring elevated at 16 meters above the storage tank; it requires excavation to expose more eyes (inlets) of the spring. Spring C is also a seepage spring elevated at 10 meters above the storage tank. This spring has been excavated to discover more eyes, but it typically dries up in the summer months. Underneath this spring are two smaller inlets that will need to be exposed to yield more water.

Spring capture dimensions should be determined from a proper topographic survey of the spring capture area. This is done by determining the cross sectional dimensions of the eyes of the spring and the depth to the impermeable layer [9]. Current dimensions of the spring capture areas in Bucori are unknown because the eyes have not been fully exposed.
The inlets should be clearly exposed, after the excavation of the spring areas, so the depth to the impermeable layer can be measured. Next adequate spring capture dimensions can be determined.

Dimensions for the spring boxes were determined based on World Health Organization (WHO) data. Length, width, and height of the spring box were chosen using engineering judgement and should not be regarded as a final decision until the eyes of the spring and impermeable layers are clearly exposed, after excavation has taken place. Thickness of base, cover, and walls of the spring box were determined per recommendation of WHO [12]. Thickness dimensions for the cover, base, and walls of the spring boxes will be 50mm, 100mm, and 100mm respectively. Spring box A will have length, width, and height dimensions of 1m x 1m x 0.6m. The base will be 1m x 1m with rebar spaced in 0.33m across the width and 0.33m spacing across the length of the base. The dimensions for the side walls of spring box A will be 1m x 0.6m. Rebar will be spaced 0.15m across the height of the wall and 0.15m across the length of the wall. The front wall will have dimensions of 1m x 0.6m with rebar spaced in 0.15m intervals across the width and height. The cover of the spring box will be 1m x 1m with rebar spaced 0.4m across the length of the cover and 0.4m across the width of the cover [9].

The base dimensions for spring boxes B and C will have length, width, and height dimensions of 0.5m x 1m x 0.4m. The base of spring boxes B and C will have length and width dimensions of 0.5m x 1m. Rebar will be spaced in 0.33m across the width of the base and in 0.33m across the length of the base. The side walls of spring boxes B and C will have dimensions of 0.5m x 0.4m with rebar spaced in 0.15m intervals across the length and width. The front walls of both spring boxes will have dimensions of 1m x 0.4m with rebar spaced in 0.15m across the width and height of the box. Calculations for spring box dimensions, concrete mix ratios, and rebar can be found in Appendix 2.

The spring boxes will be designed with reinforced concrete with 3/8" rebar. The eye(s) of the spring will flow directly into the spring box. The spring box will be enclosed on five sides with reinforced concrete walls and the back of the box open to collect water from the spring inlets. The top of the spring box will be covered to prevent contamination from runoff, mosquitos, and other debris. An access lid/cap will be designed in the cover to allow for cleanout of the spring box (Figure 2). Lastly overflow and cleanout pipes will be screened with mesh to prevent contamination from entering the pipes.

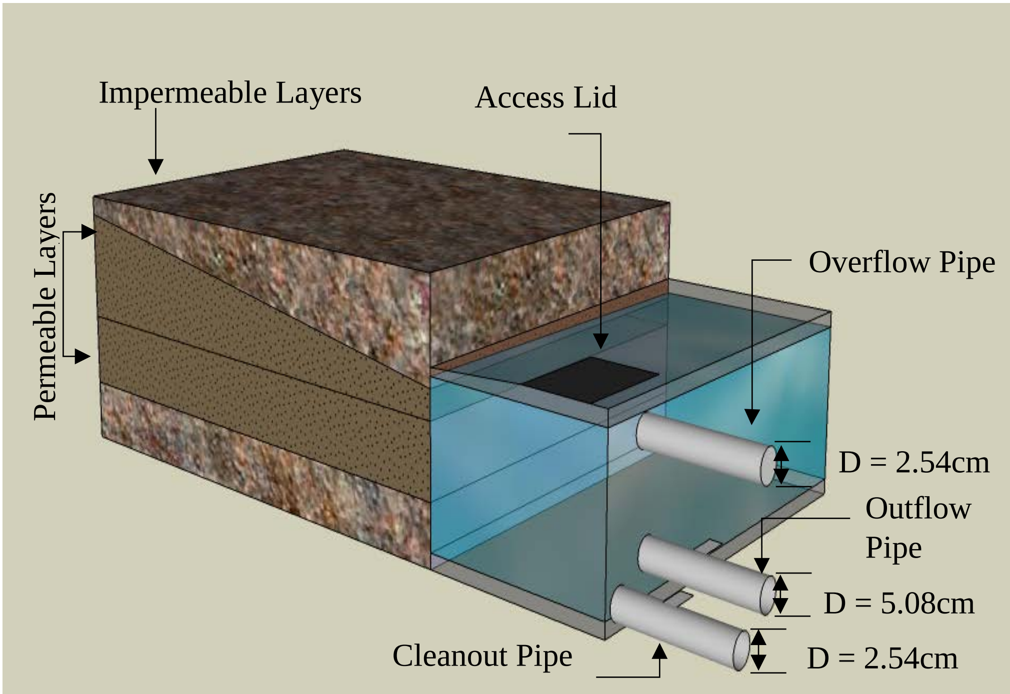

Figure 2 Spring Box A Schematic Highlighting Major Components

Holding Tank

The holding tank will be built to hold 22m^3 (5810 gallons) of water. This was determined to be a satisfactory volume of water by Mesele for multiple reasons. The first reason was this amount of water would meet the current demand of the community for 4 days based on the water census. This seems to be plenty of backup and will be helpful in the dry season when water use will have to be reduced. The second reason was this would provide the villagers with 109 L of water per person when the tank is full. The United Nations (UN) says every person has the right to access 50 – 100 L of water a day [6]. The UN number includes; cooking, dishes, laundry and bathing. The system being designed is for drinking, cooking and dishes alone, so 109 L far exceeds UN recommendations. The third reason was physical size of the tank. The group did not want the tank to be too tall for structural reasons. Also the group did not want the tank to be too large to make the building of the tank difficult or too expensive. After the volume was chosen, a reasonable height was selected. Mesele determined the inside height of the tank should be 2m so the community member cleaning the tank will be able to stand. This height will also make building the tank easier because tall ladders will not be necessary to reach the top. Also, it will make accessing the manhole easier when cleaning is necessary.

Next, the thickness for different parts of the tank had to be determined. These values were chosen using information from the Handbook of Gravity-Flow Water Systems by Thomas Jordan [10]. The thickness of the floor was determined to be 0.10m for reinforced concrete. For the walls of the tank, the thickness was determined to be 0.30m. There will also be concrete footings for the walls which will be 0.20m thick. The roof will be 0.10m thick [10]. Using the water volume, maximum height and thickness of different aspects of the tank, the rest of the measurements were determined. All measurements can be found in Appendix 3, along with the Engineering Drawing in Appendix 4 and the model in Figure 3.

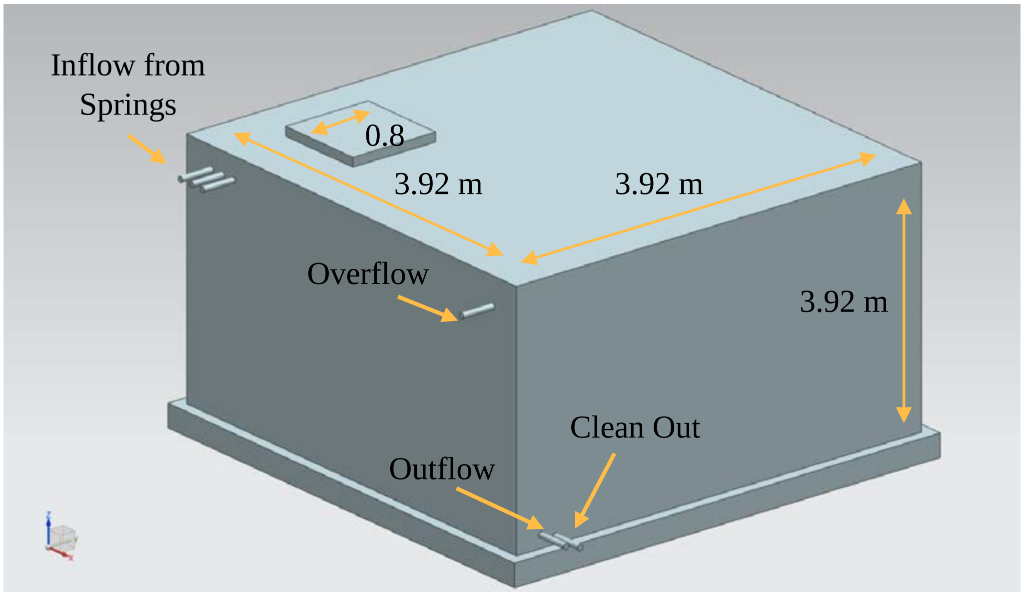

Figure 3 Model of Water Holding Tank

There are three inlets to the tank from the three natural springs. Each of the inlets will have a valve on them so inflow can be stopped when the tank needs to be cleaned. There will be one outlet to the community from the tank. This outlet will also have a valve on it in case any piping needs to be repaired. There will also be a fifth opening that will act both as a pressure release and an overflow pipe. As water flows into the tank this overflow will allow air to escape and water to escape when the tank is full. A sixth opening will be located near the outlet and will be used as a cleanout valve to flush sediment as needed.

Also on the tank will be a manhole access to allow the tank to be cleaned regularly. The manhole will be 0.6m by 0.6m, as suggested in the Handbook of Gravity-Flow Water Systems by Thomas Jordan [10]. The cover for the hole will be 0.8 m by 0.8 m by 0.08 m, which will allow the cover to overlap the edges of the hole. The cover will have two handles, made of rebar, for easily moving the cover. The cover will need to be reinforced with wire mesh, and the handles will be able to attach to this.

Ladders will be constructed of ⅜" rebar on the outside of the wall and inside of the wall near the manhole. The rungs will be 0.15 m by 0.20 m, and for the depth of 0.20 m, 0.10 m will be set into the concrete. The shape of the rungs can be seen in Figure 4. The rungs will need to be spaced 0.30 m apart, making for a total of 7 rungs per ladder [10].

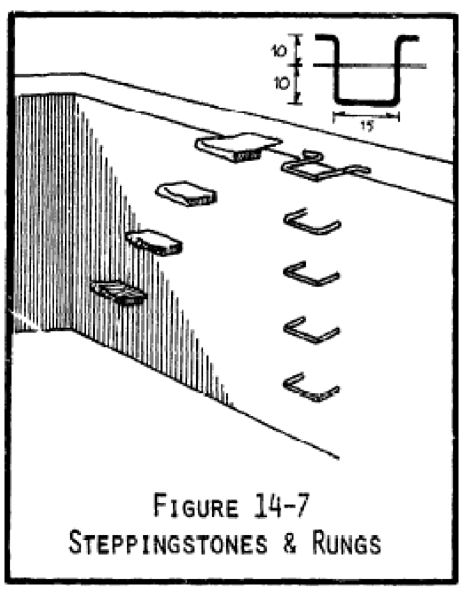

Figure 4 Image to Show Ladder Rungs Shape and Placement [10]

Rebar (⅜”) will be used in the floor, walls and roof to support the concrete. Rebar of 3.32 m lengths will be placed every 0.40 m, for the floor [10]. A total of 17 rebar lengths will be required for the floor. Rebar in the walls will be spaced every 0.40 m. In total, there will be 34 lengths of rebar 2.08 m long and 20 lengths of rebar 3.32 m long needed for the walls. The roof will use lengths of rebar of 4.22 m, which will run through the roof slab and extend into the walls on either side 0.30 m (Figure 5). The roof rebar will be spaced 0.33 m apart [10], requiring 24 lengths for the roof. The total length of rebar required will be 333 m.

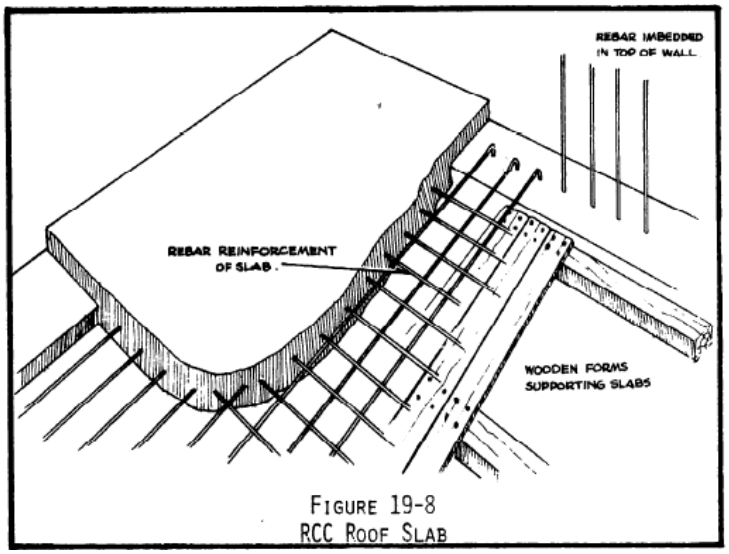

Figure 5 Image of Roof Slab Reinforced with Rebar [10]

Piping Network

The piping within the network will consist of SDR 26 PVC pipe with 2-inch and 1.5-inch diameters. There is a total of 1600 m of 2-inch pipe, and approximately 800 m of 1.5-inch pipe. Pipe will be in 6 m sections plus coupling for the pipe joints that will join both plain ends of the pipe by solvent welding the ends using PVC cement. Pressure standards for the pipe within the network were taken into consideration. SDR 26 has a pressure rating of 160 psi, which is a much higher pressure value than what is expected from the entire network; the highest pressure is expected to reach a maximum value of

9 psi. There will also be a number of fittings, including three cleanout valves that occur at local low points in the network, two air valves at local high points, 135 elbows, 400 unions, and 35 Y/T fittings. The total number of fittings includes a 10% overestimate for error and breakage. Although there will be some locations along the pipeline where a slight bend will be necessary, the PVC pipe and couplings are expected to allow a 10% bend. These locations occur at points V43 and V55 at distances of 850m and 974m along the network.

Counting the number of pipes and fittings, the entire network was broken into zones, as seen in Figure 6 below. This data division was done to create organization and reference when installing the network, allowing for easier tracking of inventory and a better estimation for manpower required to install certain parts of the network. Located in the appendices is a breakdown of the zones, highlighting the 1.5in pipe that should be installed at each location.

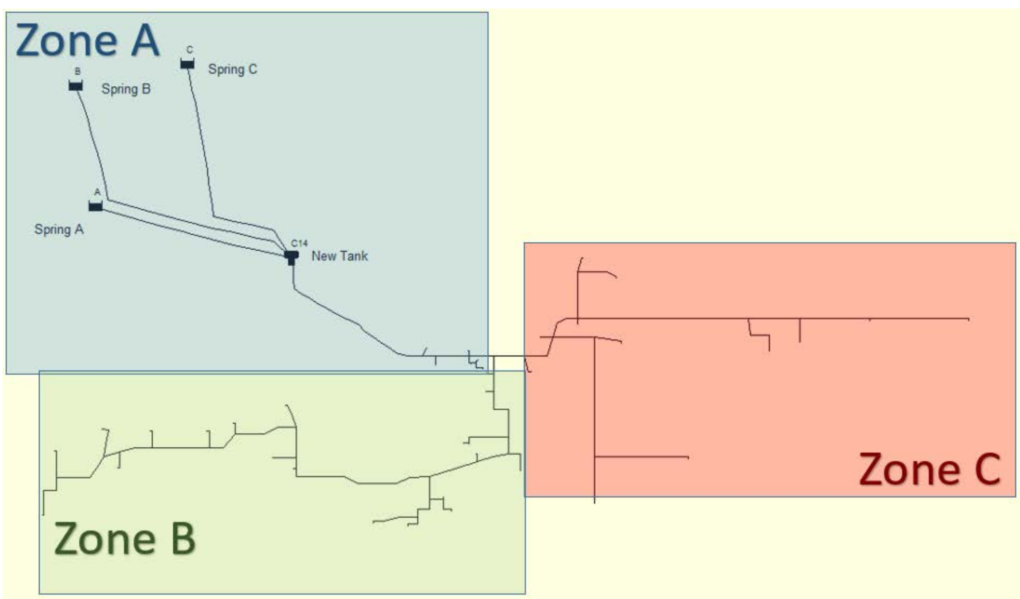

Figure 6 Layout of Network Zones

Protection and maintenance within the pipe network will include UV spray paint coating for the pipes that are exposed to sunlight. Maintenance along the network will include scheduled upkeep at the cleanout valves, starting every four weeks and adjusting in frequency if needed based on the amount of sediment buildup. The cleanout valves will be located at 247m, 394m and 680m along the network and will consist of a Y-fitting placed for easy access (Figure 7). These distances along the network are based on the HGL plot in Figure 8. The length of the stem on the Y-fitting will be dependent on the accessibility and location of each valve. The air valves will be located at two local high points to release air blocks. These points are located at 196m and 550m along the network. The community's goal is to bury as much of the piping as possible due to the harsh weather conditions, so a network test for water flow will need to be conducted before burying the pipe.

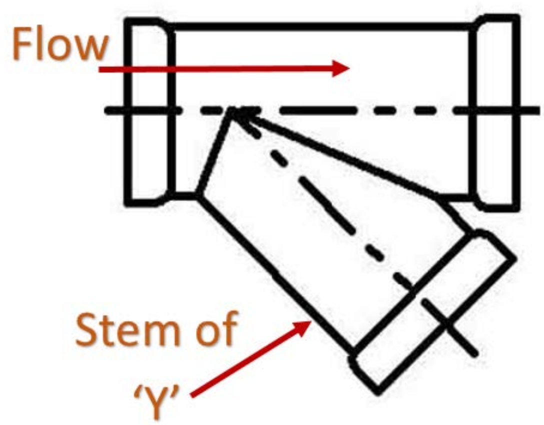

Figure 7 Cleanout Valve Fitting

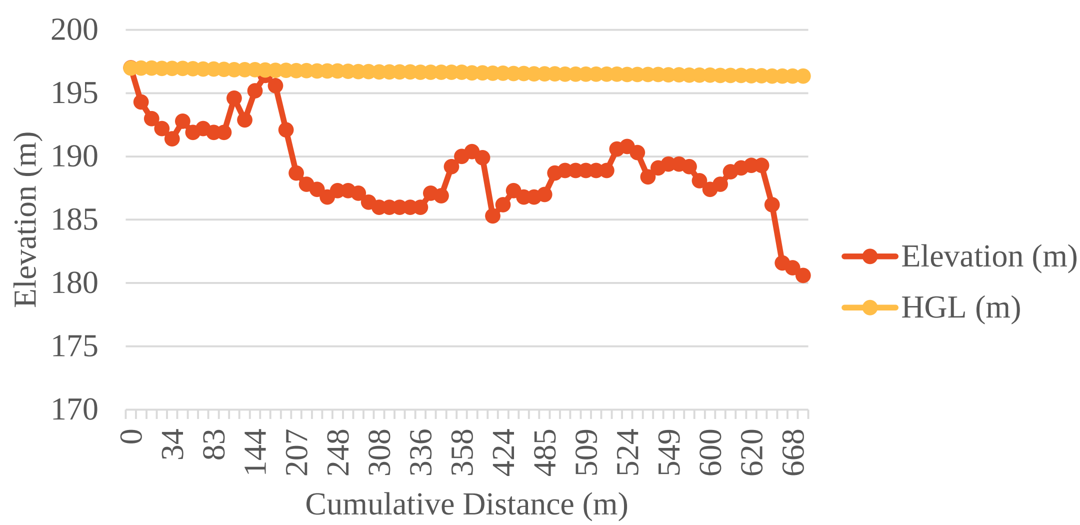

Figure 8 HGL and Elevation of Pipeline

River Crossing

There will be a pipeline crossing over the 40-meter-wide river in the community (Figure 9). The suspension over the river will consist of galvanized wire rope with stringers to hold the pipe. The 2” PVC pipe will be covered with a 4” PVC pipe to protect it from the natural elements. Additionally, the 4” PVC pipe will be sprayed with a UV protection spray. The pipe is run through the ground to a knot in the tree on the other side of the river. A cable will support the pipe with multiple stringers. The cable will be held on one side by a concrete anchor buried in the ground. The cable will be wrapped around the tree with cable clamps on the other side of the river.

Tl Anchor xisting pipe through one of the knots on the tree Tree
M Block ves the tree will be sturdy enough to support the pipe. Starting from the knot in the tree, the pipe will have a 90-degree elbow to run it parallel to the tree with extra cable and cable clamps for support. Once the pipe reaches the ground, there will be another 90-degree elbow to run the piping to the last houses in the system.

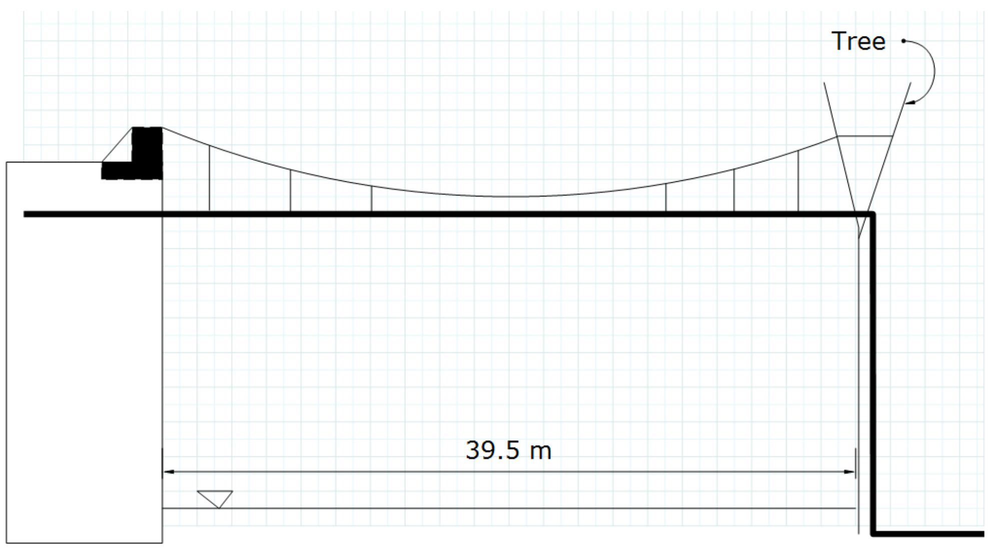

Figure 9 Conceptual Sketch of River Crossing

Cable Calculations

The diameter of cable supporting the pipe was determined by the total weight it must support. The total weight was calculated by adding the weight of the 2” PVC pipe, the 4” PVC pipe, and the weight of water in the 2” pipe.

The weight of 2” PVC pipe and weight of 4” PVC pipe is 2.23 lb/m and 6.59 lb/m respectively; this was then multiplied by the pipe length to get the total weight of piping [14]. The density was multiplied by the volume of the pipe to calculate the weight of water in the pipe.

The allowable sag of the cable was chosen to be 2 m. The horizontal tension was calculated using Eq. 5 (Appendix 7). The total tension was then calculated using the angle of tension and horizontal tension. The total tension on the cable is 1,317 lb.; therefore, the cable diameter needed is ¼” of galvanized wire rope. The minimum breaking strength of ¼” wire rope is 5,480lb of force, and dividing the minimum breaking strength by the safety of factor of 3 gives a force of 1,827 lb. Since breaking strength with a safety factor of 3 is greater than the total tension in the cable, the ¼” diameter is sufficient for this design.

Anchor Calculations

The anchor design Mesele chose was a tower and slab anchor mass constructed out of concrete (Figure 10). The size of the anchor was based on the volume of concrete needed to withstand the total horizontal force, including the safety factor. Once the dimensions were chosen and volume was calculated, the anchor was checked for sliding. The friction angle from Table 2 is 33° based on the soil type of well-graded sand [18]. To check for sliding, the safety factor was calculated by balancing forces. The safety factor was calculated to be 3.0, which is a sufficient safety factor for the anchor to not slide.

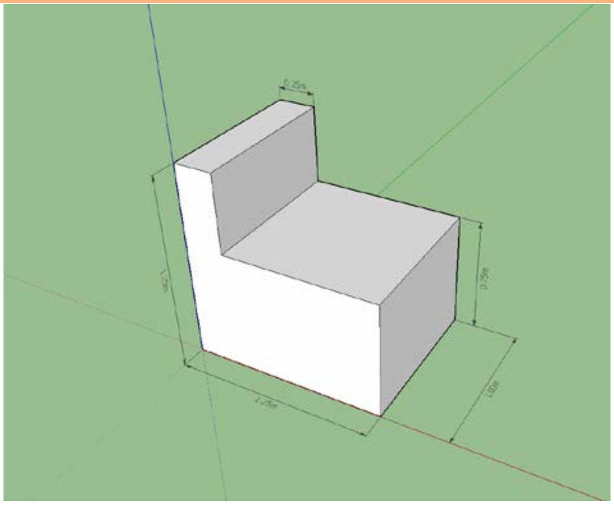

Figure 10 Model of Concrete Anchor

Table 1 Anchor Slab Dimensions

Length1	0.25	m
Length 2	1	m
Width 1	1	m
Width 2	1	m
Height 1	1.25	m
Height 2	0.75	m
Volume Tower	0.313	m^3
Volume Slab	0.750	m^3
Total Volume	1.06	m^3

The anchor will be supported with a rebar cage (Figure 11). There will be a jaw and eye turnbuckle to connect the cable to the rebar hook within the anchor.

The anchor for the river crossing was checked for turnover by calculating the moment about the point (Appendix 7). The safety factor for the river crossing was calculated to be 3.2 which is a sufficient safety to ensure the anchor will not turn over.

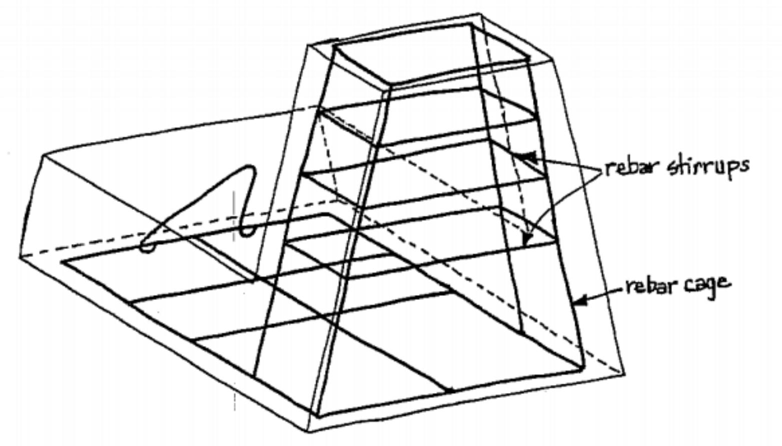

Figure 11 Rebar Cage and Stirrups for Concrete Support

Stringer Lengths

The stringer lengths (Table 2) were calculated by using the equations below. The cable used will have a diameter of ¼-inch. The C value is the value that represents the curve of the cable and can be determined from a table with the corresponding sag ratio. The C value was determined to be 2.51 using a sag ratio of 0.05 and an elevation difference of 0 [18]. The stringers will be placed every 5 meters along the main cable. There will also be a turn back length needed to wrap around the cable eyelet and the pipe itself (Figure 12). To estimate how much cable would be needed for the turn back length, 2/3 of the sag allowance was calculated. The calculated turn back length was then added to the sag allowance to calculate the total amount of cable needed for each stringer.

Table 2 Stringer Lengths and Location

Distance from Apex (m)	Sag Allowance (m)	Turn Back Length (m)	Total (m)
20	2.025	1.35	3.38
15	1.138	0.76	1.90
10	0.505	0.34	0.84
5	0.126	0.08	0.21
Apex (0)	0.000	0.00	0.00
5	0.126	0.08	0.21
10	0.505	0.34	0.84
15	1.138	0.76	1.90
20	2.025	1.35	3.38
Grand Total			12.65

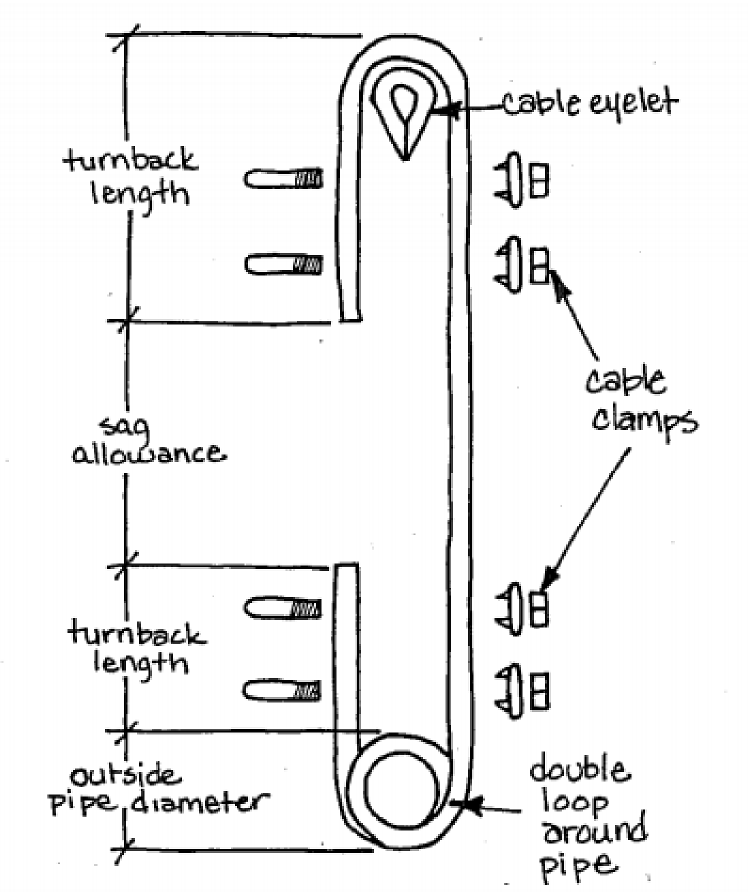

Figure 12 Stringer Connections

The final length of the cable can be calculated by using a designated C value representing the curve of the cable. How much the cable stretches is calculated in Eq.11 (Appendix 7). Because the stretch of the cable is less than 1 cm, it can be ignored. The final length of the cable is based on the curve of the cable, and is expected to be 39.76 m.

Stream Crossings

Mesele came up with three different designs for river, stream, and valley crossings. Mesele did not analyze the wash-out risk; therefore, the design decisions for each stream will be based on the Peace Corps Volunteer's judgement. Design 1 (Figure 13) is for streams that are narrow enough not to need additional support, and have no risk of being. The piping will run through the streambed with no extra support. Design 2 should be implemented if the Peace Corps Volunteer or community feels there is a risk of the pipe washing out.

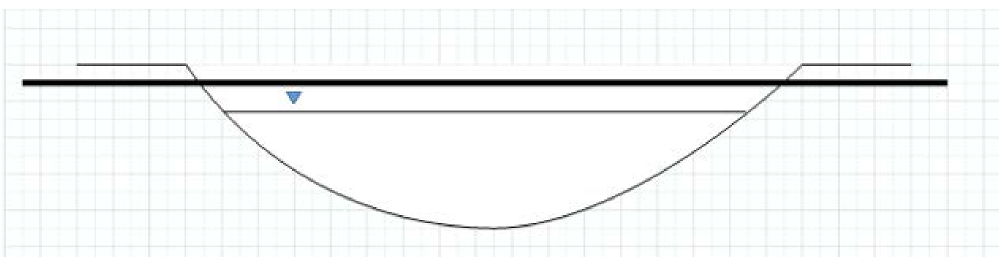

Figure 13 Design 1: Narrow Stream with No Wash-Out Risk

Design 2 (Figure 14) is for streams that have a wash-our risk or are wide. Mesele discovered one stream before the holding tank that is very shallow and had a high-water table; therefore, each of the three pipes from the spring boxes to the holding tank must cross a one-meter stream. The pipe will be elbowed vertically from 0.5 m from the ground and supported with two steel columns. The steel columns will be supported by a concrete platform beneath the ground.

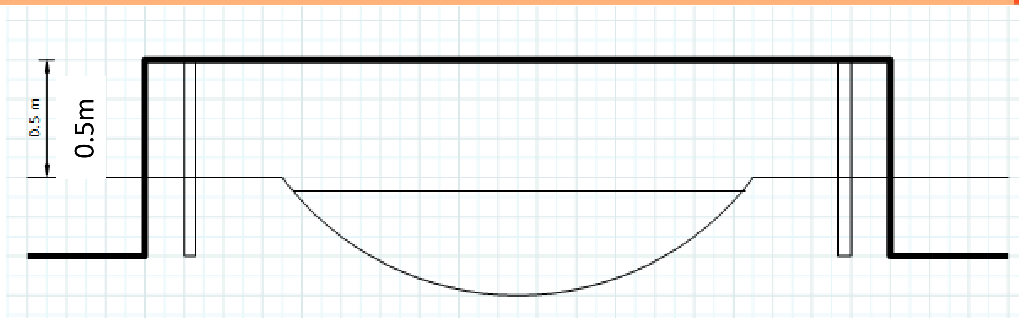

Figure 14 Design 2: Stream Crossings with a Wash Out Risk

Design 3 (Figure 15) is for a valley crossing. Rather than go down and back up the hills, the pipe will have the same type of suspension system as the river crossing (¼” galvanized wire rope and concrete anchors). The concrete anchor dimensions are given in Table 3.

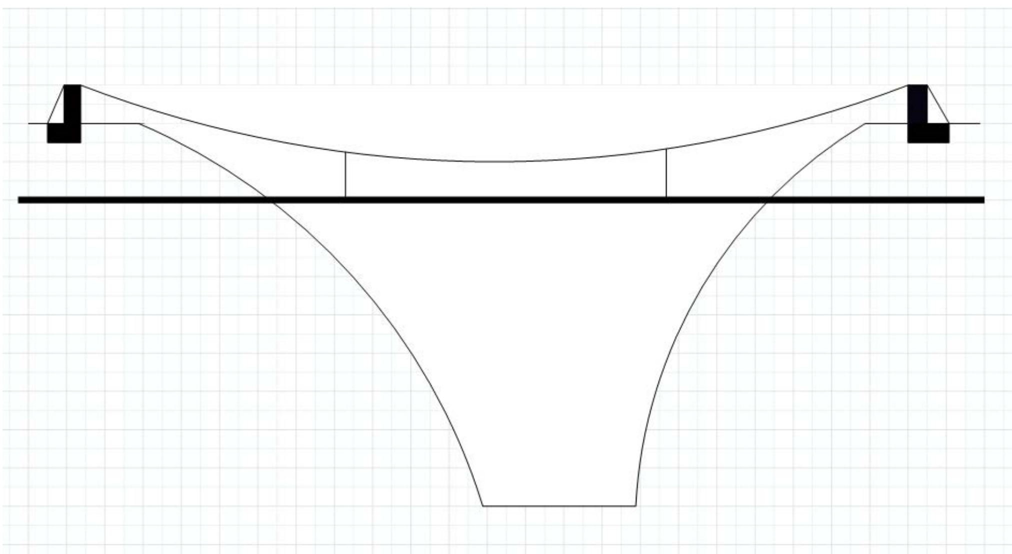

Figure 15 Design 3: Wide Valley Crossing

Table 3 Concrete Anchor Dimensions for Valley Anchor

Length1	0.25	m
Length 2	0.5	m
Width 1	0.5	m
Width 2	0.5	m
Height 1	0.5	m
Height 2	0.5	m

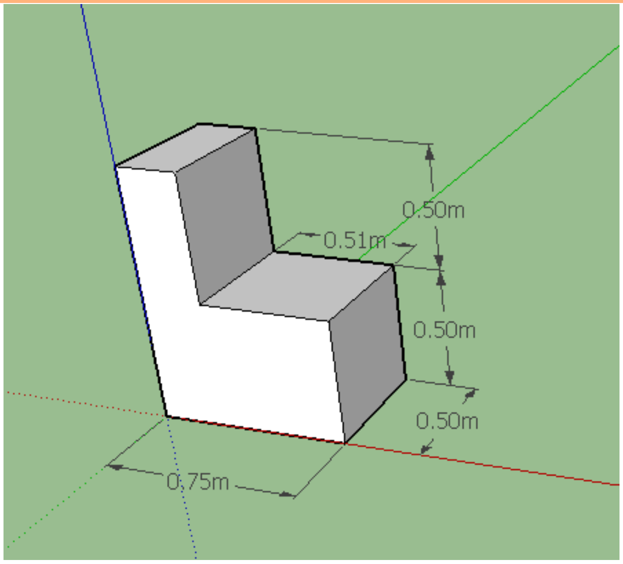

Figure 16 Valley Concrete Anchor

The valley crossing was checked for turnover by calculating the moment about the point (Appendices 5). The safety factor for the river crossing was calculated to be 2.6 which is a sufficient safety factor to ensure the anchor will not turn over.

Water Treatment

Mesele looked at two different options for water treatment either household chlorination or community chlorination within the holding tank. The amount of chlorine needed for proper disinfection would be based on the spring flow rates and water usage. This can be calculated by performing field tests.

During the community visit, Mesele learned that there are only four members on the water committee when the country regulations require seven, showing a lack of commitment to bettering the community water quality. There was also a lack of enthusiasm and commitment in regard to the water distribution project from the community as a whole. However, the PCV is working on educating and gathering support from community. In addition to the lack of commitment, the holding tank and springs are not easily accessible. The whole community would suffer if the person responsible failed to treat the holding tank water. Because of these factors, Mesele concluded the best option for water treatment would be personal, in-home treatment. The recommended chlorine for treatment is 1 mL/L [2]. The ideal water usage per day per person is 50 L which would need 50 mL to be properly treated. For a family of 5 this will require 250 mL of chlorine a day. In home chlorination will require training from the PCV so families will know how to properly treat their water.

Construction Schedule

A schedule was developed for completion of a water distribution network in Bucori, Panama. The major components of the network are the spring captures, holding tank, and piping. This schedule details the construction phase for each component. Tasks and descriptions for work are included in addition to duration, manpower, and man hours estimated to complete the project. Tasks can be found in Appendix 8, with descriptions and a Gantt Chart enclosed.

Total labor estimated to complete the system is 3624 person-hours. Labor rates for Panama are currently estimated at $5 for 8 hours of hard labor, which yields a total labor cost of $2,265 for constructing this system. This number is an estimate, but the community members are expected to help with the building of the system for free.

Cost Estimate

Mesele created a cost estimate for the materials, tools and transportation of tools for the construction of the water distribution system. The total cost estimate was determined to be $15,300 for materials, equipment and transportation. Information on the cost of materials can be found in Appendix 9. The quantity of materials was determined from the design of each component holding tank, spring boxes, piping network, and pipeline water crossings, with a 10% safety factor added for all materials. The unit cost was determined from the Do It Center website, Home Depot website and "Improvements in Sustainability of Gravity-Fed Water Systems in The Comarca Ngäbe-Buglé, Panama: Spring Captures and Circuit Rider Model" by Jones (2014).

Also calculated was the price of equipment needed to build the system. All information on equipment costs can be found in Appendix 9. Equipment needs were based on number of people estimated per task, prices for the equipment was found on the Do It Center website. Transportation of material will be by boat from Chiriquí Grande to Bucori. The cost of one round trip is $125. A conservative estimate of the number of trips needed is 25, which leads to a total transportation cost of $3125. A breakdown of all cost components can be found in Figure 17.

Water treatment will be done in home with the addition of 1 mL of chlorine to liter of water. The cost of chlorine will be covered by the families for their use. The cost of a bottle of 237 mL of chlorine is $0.50. For a family of 5 people each using 50 L of water a day, 1750 mL of chlorine will be needed a week. This means a family of 5 will need to spend $3.70 a week on chlorine.

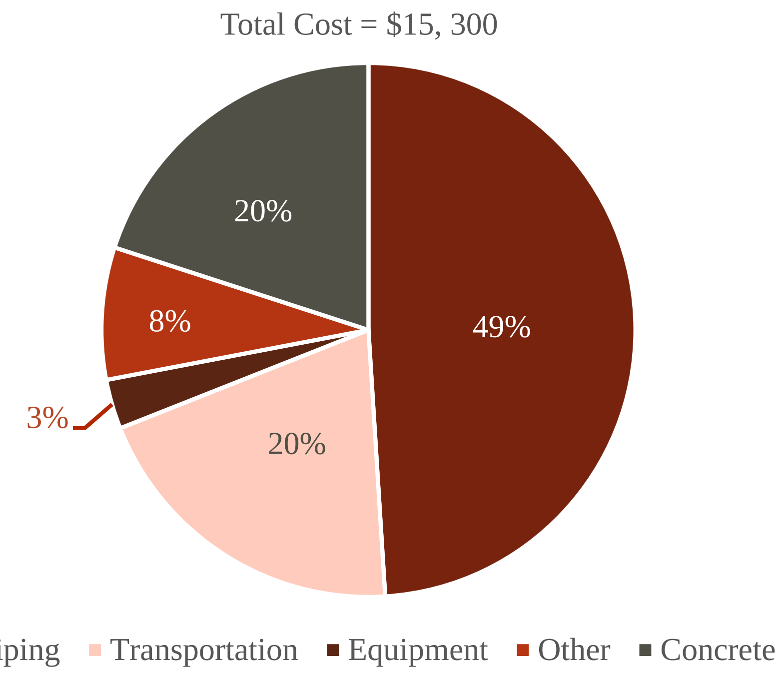

Figure 17 Breakdown of Project Costs

Conclusion

Mesele will provide water directly to 31 homes and 7 other community buildings within Bucori. The water will run from three springs to a holding tank, and from the holding tank it will be distributed throughout the community. The system will cross seven streams, one valley, and one river. The water will be treated in-home using chlorine. The total material and equipment cost is $12,200, with transportation costing an additional $3,125. The construction of the project will take 40, 6-8 hour work days with varying man-hours at different points in the project, dependent on zone requirements. The project schedule does not include rain-out days and weekends. The Peace Corps Volunteer will be applying for a grant to implement this system. If the grant does not cover the entire project, the Peace Corps Volunteer with have to look into further funding or make edits to the system. Instead of the piping running to individual homes there could be community faucets. This would cut down on piping cost. The Peace Corps Volunteer and community should develop a strong water committee upon finishing the project to maintain the system.

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Appendices

1. EPANet Results
2. Spring Box Dimension Calculations
3. Measurements of the Water Holding Tank
4. Engineering Drawing of the Water Holding Tank
5. Maps of Pipe Network
6. Data for River Crossing Calculations
7. River Crossing Equations
8. Schedule: Table and Descriptions
9. Cost Estimate Tables

Appendix 1. EPANet Results

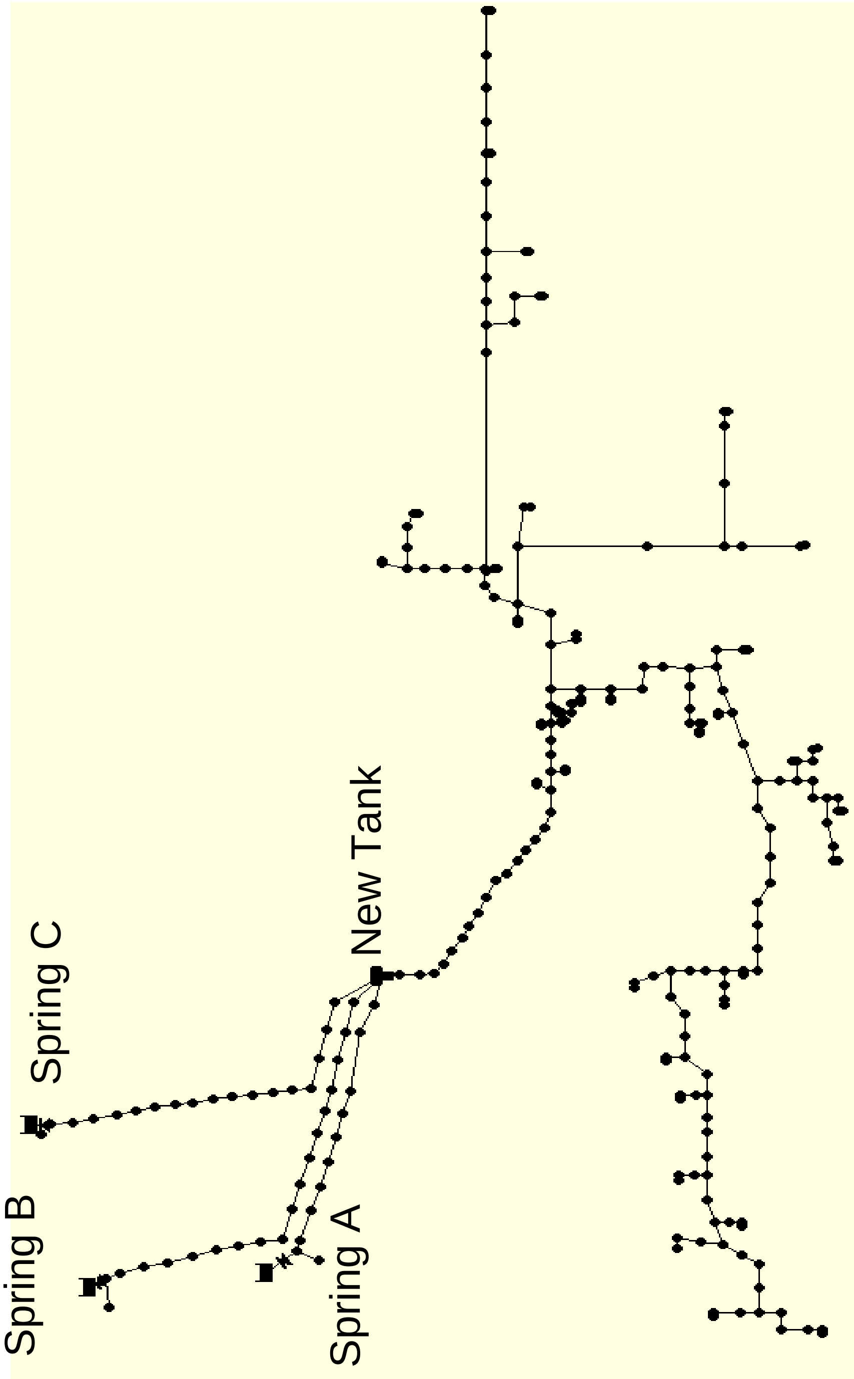

Figure 18. EPANet Model

Springs are treated as nodes. Overflow tank creates pressurized flow. Check valve ensures flow comes from springs and that excess flow is diverted to the overflow tank.

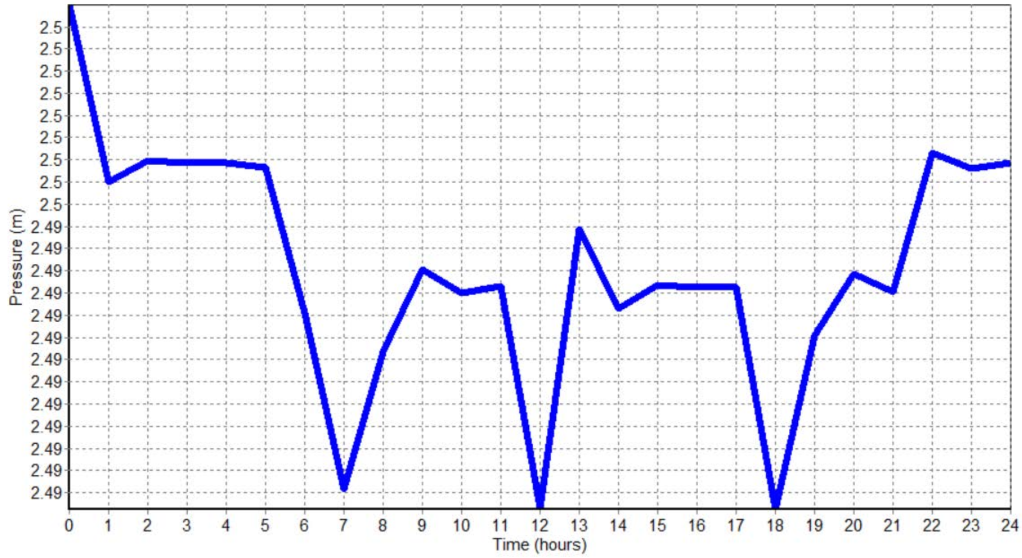

Figure 19. Pressure Profile

Pressure profile created in EPANET for holding tank over 24-hour period based on average, yearly spring flow rates. Pressure ranges from 2.49m to 2.5m. Profile created in EPANET

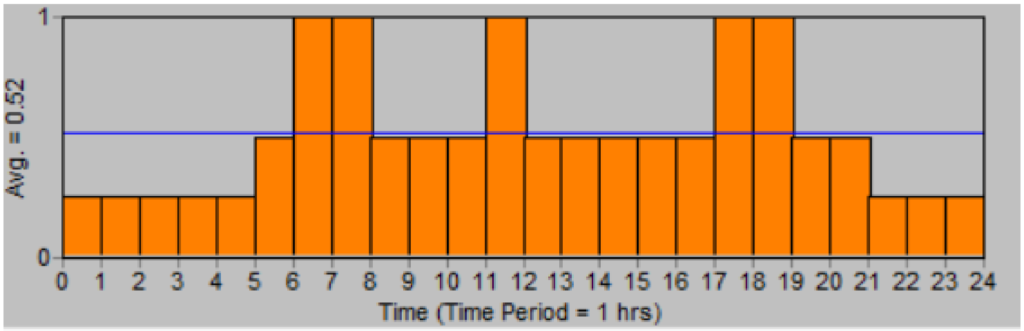

Figure 20. Demand Pattern

Demand pattern created in EPANET over a 24-hour period where water usage values were arbitrarily assigned. Demand values are adjusted for average, yearly spring flow rates. Peak water usage times are 6-8am, 11-12pm, and 5-7pm.

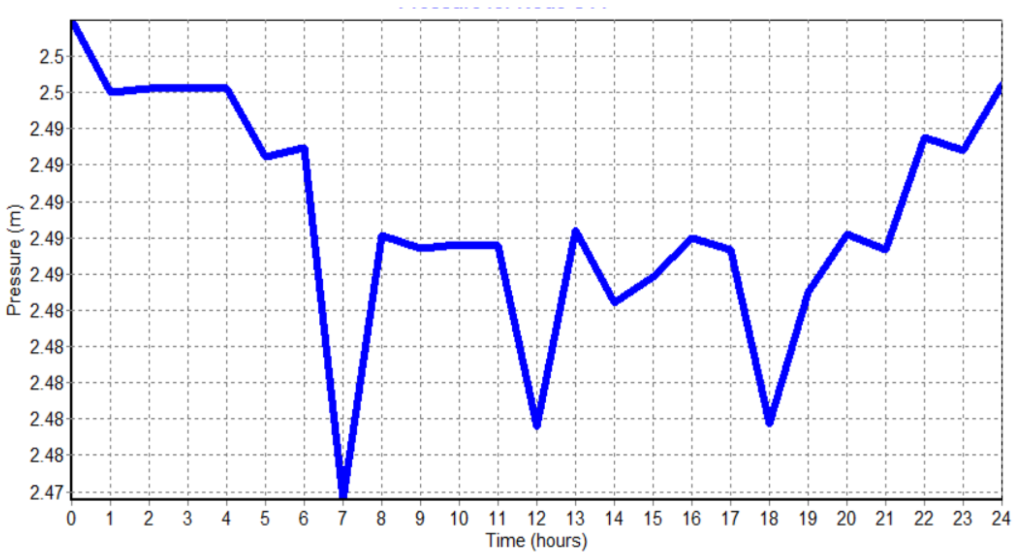

Figure 21. Pressure profile

Pressure profile created in EPANET for holding tank over 24-hour period based on rainiest season spring flow rates. Pressure ranges from 2.47m to 2.5m. Profile created in EPANET

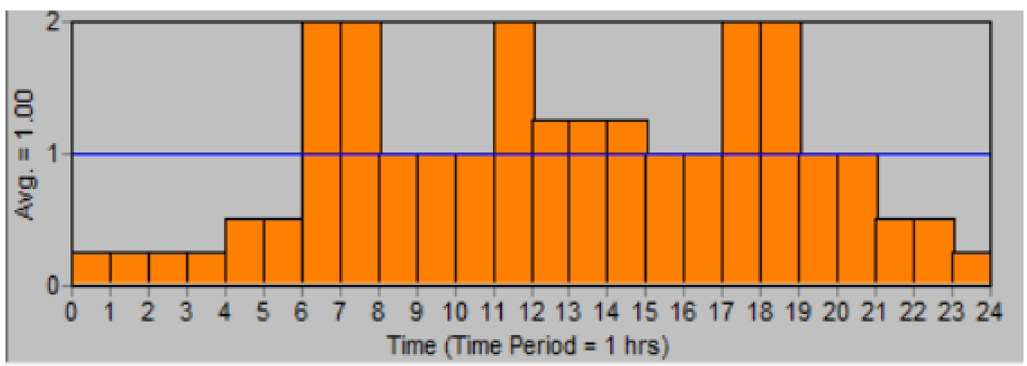

Figure 22. Demand Pattern

Demand pattern created in EPANET over a 24-hour period where water usage values were arbitrarily assigned. Demand values adjusted for rainiest season. Peak water usage times are 6-8am, 11-12pm, and 5-7pm.

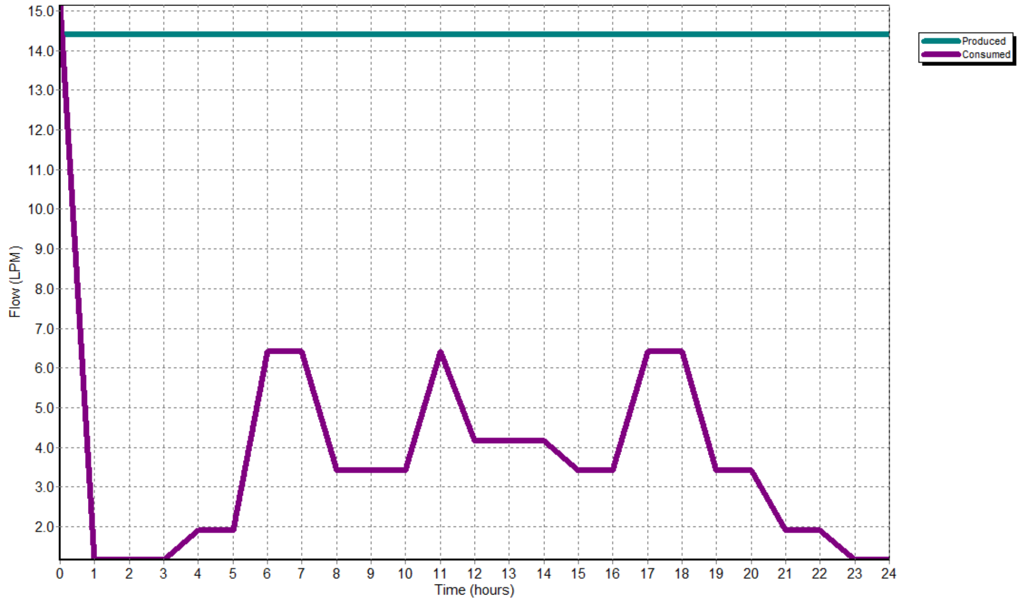

Figure 23. System Flow Balance

System flow balance for the rainy season show water produced by springs and water consumed by the community. Created in EPANET.

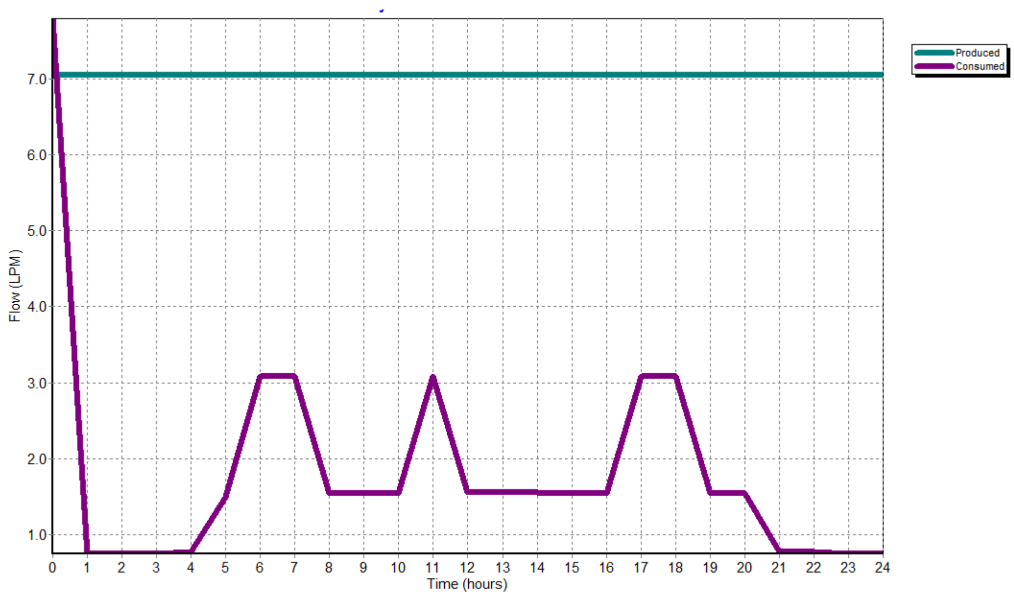

Figure 24. System Flow Balance

System flow balance based average yearly spring flow rates. This figure shows water produced by springs and water consumed by the community. Created in EPANET.

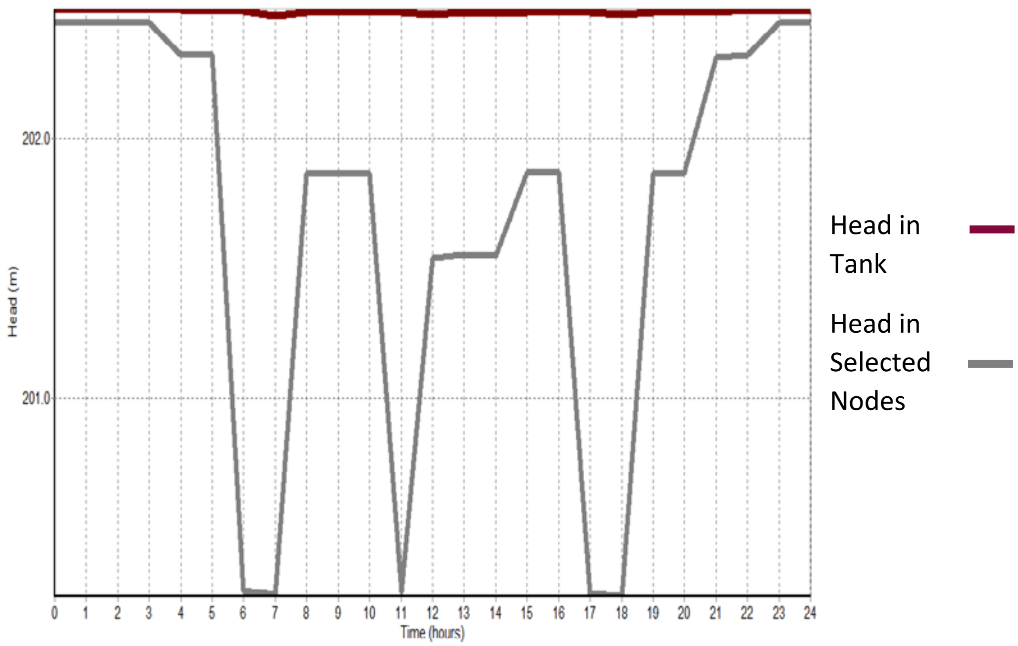

Figure 25. Head Throughout Network

Head throughout network over a 24-hour period during the rainy season. Created in EPANET

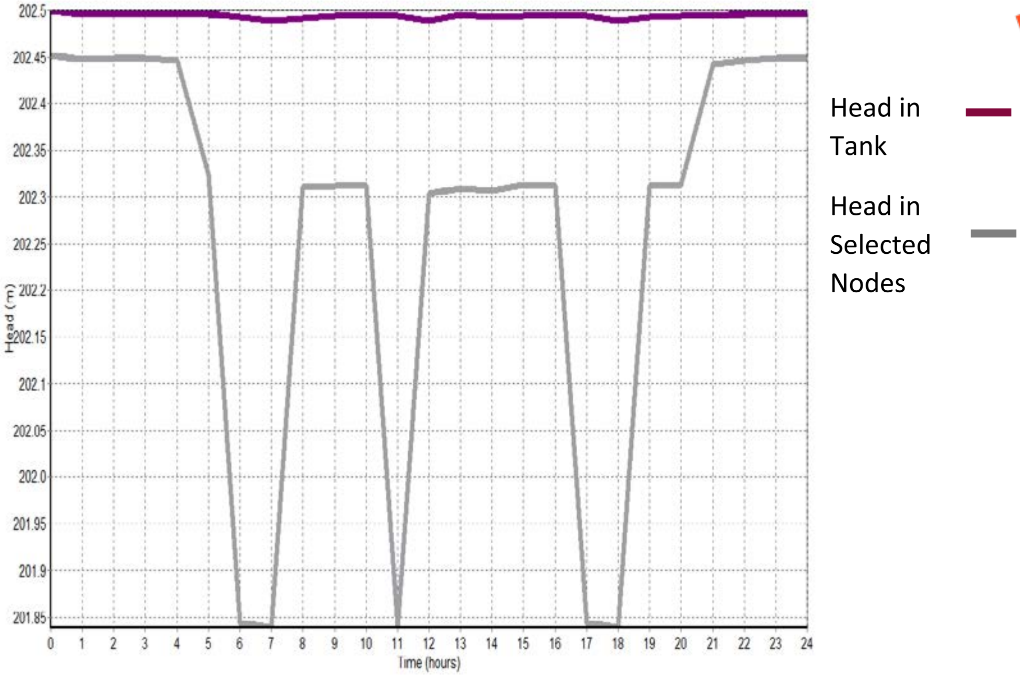

Figure 26. Head Throughout Network

Head throughout network over a 24-hour period using average yearly spring flow rates. Created in EPANET

Appendix 2. Spring Box Dimension Calculations

Table 4. Spring Box Dimensions

Springs	Length (m)	Width (m)	Height (m)
A	1	1	0.6
B	0.5	1	0.4
C	0.5	1	0.4

Spring box dimensions are chosen arbitrarily. After excavation has occurred, dimensions for box should be adequately chosen.

Table 5. Spring Volumes (m^3)

Springs	Base (m)	Side Walls (m)	Front Wall (m)	Cover (m)
	L*W*tb	2(L*H*tw)	W*H*tw	L*W*tc
A	0.1	0.12	0.06	0.05
B	0.05	0.04	0.04	0.025
C	0.05	0.04	0.04	0.025
Where tb=100mm, tw=100mm, tc=50mm				

Table 6. Spring Volumes (ft^3)

Springs	Base (ft)	Side Walls (ft)	Front Wall (ft)	Cover (ft)
	L*W*tb	2(L*H*tw)	W*H*tw	L*W*tc
A	3.53	4.23	2.12	1.77
B	1.77	1.41	1.41	0.88
C	1.77	1.41	1.41	0.88
Where tb=100mm, tw=100mm, tc=50mm				

Table 7. Concrete Mix Ratios for Spring Boxes

Base (1:4:8)	Walls (1:2:4)	Cover (1:2:4)
Cement	Cement	Cement
Sand	Sand	Sand
Gravel	Gravel	Gravel

Table 8. Spring A Concrete Volumes (ft^3)

Base	Walls	Cover	Totals ft^3
Cement	Cement	Cement	Cement
0.27	0.91	0.35	1.53
Sand	Sand	Sand	Sand
1.09	1.81	0.51	3.41
Gravel	Gravel	Gravel	Gravel
2.17	3.63	1.01	6.81

$$Base_{Sand} = \frac{4}{13} * Base_{Volume}$$

Table 9. Springs B & C Concrete Volumes (ft^3)

Base	Walls	Cover	Totals ft^3	B & C Totals ft^3
Cement	Cement	Cement	Cement	Cement
0.14	0.81	0.13	1.07	2.14
Sand	Sand	Sand	Sand	Sand
0.54	0.81	0.25	1.60	3.20
Gravel	Gravel	Gravel	Gravel	Gravel
1.09	0.81	0.50	2.40	4.80

Volume of concrete materials are combined for Springs B and C since they have the same dimension.

Table 10. Concrete for Spring A, B, & C

Cement (lbs.)	Sand (ft^3)	Gravel (ft^3)
3.67	6.61	11.61

Table 11. Rebar for Springs A, B & C

	A	B	C
Cover Length (m)	2.5	0.63	0.63
Cover Width (m)	2.5	2.5	2.5
Base Length (m)	3.03	1.67	1.67
Base Width (m)	3.03	6.67	6.67
Wall Lengths (m)	6.67	1.67	1.67
Wall Heights (m)	2.4	1.07	1.07
Wall Width (m)	6.67	6.67	6.67
Wall Height (m)	2.4	1.07	1.07
Sum (m)	29.2	21.95	21.95
Sum (ft)	95.8	72.0	72.0
Total Rebar	239.8	ft	

$$\frac{Length}{Spacing} * Length$$

Where recommended spacing's for cover, base, and walls are 0.4m, 0.33 m and 0.15m respectively.

Appendix 3. Measurements of the Water Holding Tank

Table 12 Measurements of the Water Holding Tank

Description	**Value**	**Units**	**Walls 2,4**		
Volume of Water	22	m3	**Description**	**Value**	**Units**
Volume of Water	22,000	L	Height	2.08	m
Volume of Concrete	12.73	m3	Width	3.92	m
Volume of Concrete	66,978	lb.	Thickness	0.3	m
Number of Pipe Openings	6	#	**Wall Footings 2,4**		
Diameter of Pipe Openings	0.0508	m	**Description**	**Value**	**Units**
Floor			Length	4.12	m
Description	**Value**	**Units**	Width	0.5	m
Length	3.32	m	Thickness	0.2	m
Width	3.32	m	**Roof**		
Thickness	0.1	m	**Description**	**Value**	**Units**
Walls 1,3			Length	3.92	m
Description	**Value**	**Units**	Width	3.92	m
Height	2.08	m	Thickness	0.1	m
Width	3.32	m	**Manhole**		
Thickness	0.3	m	**Description**	**Value**	**Units**
Wall Footings 1,3			Length	0.6	m
Description	**Value**	**Units**	Width	0.6	m
Length	3.52	m	**Manhole Cover**		
Width	0.5	m	**Description**	**Value**	**Units**
Thickness	0.2	m	Length	0.8	m
			Width	0.8	m
			Thickness	0.08	m

Appendix 4. Engineering Drawing of the Water Holding Tank

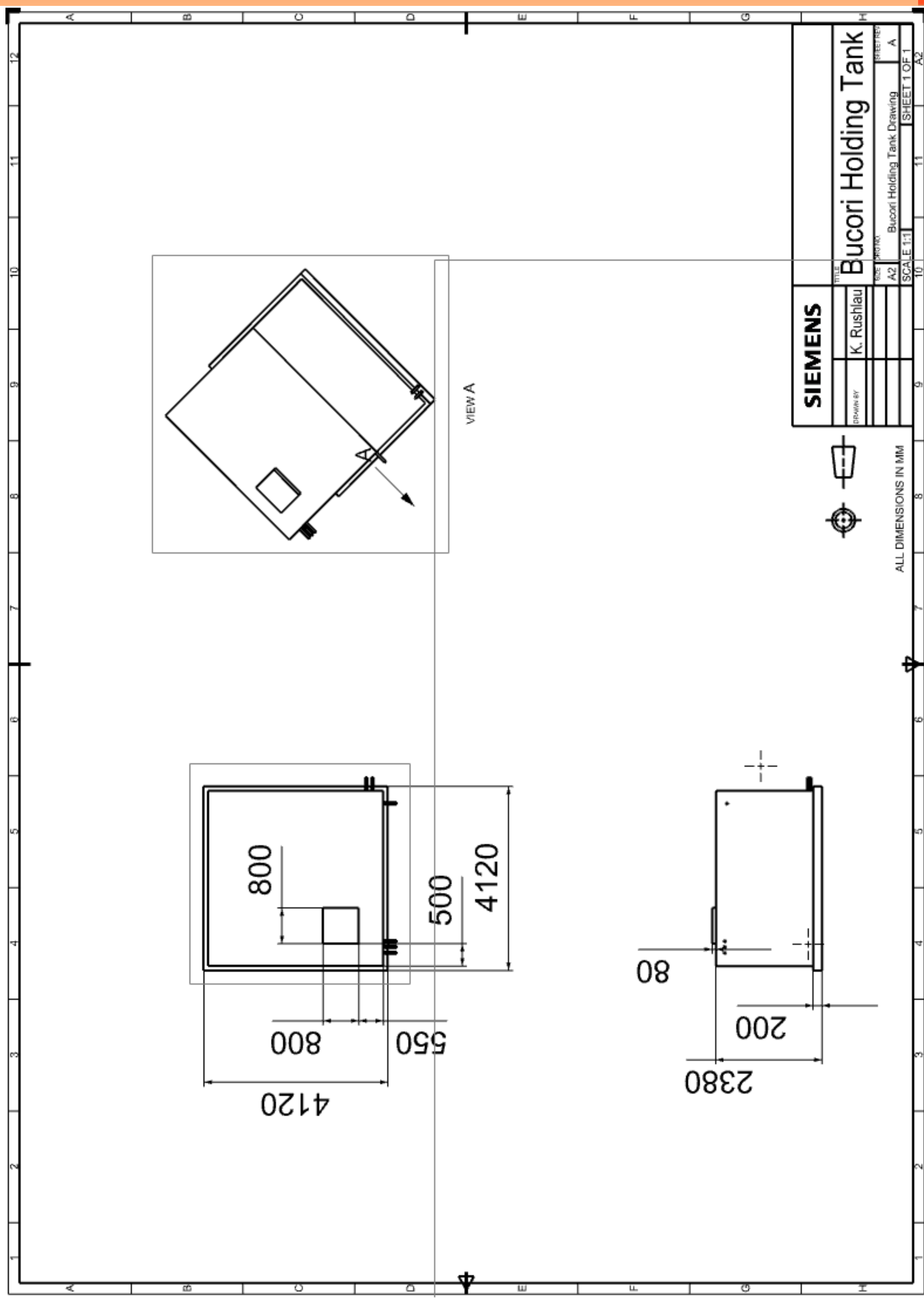

Figure 27 Engineering Drawing of the Water Holding Tank

Appendix 5. Maps of Pipe Network

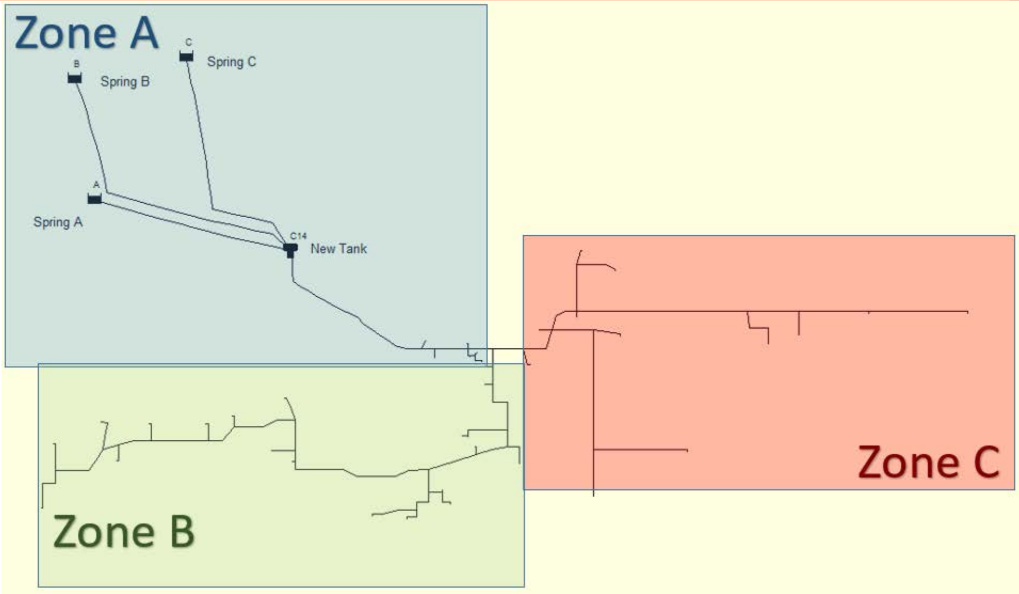

Figure 28 Layout of Network Zones

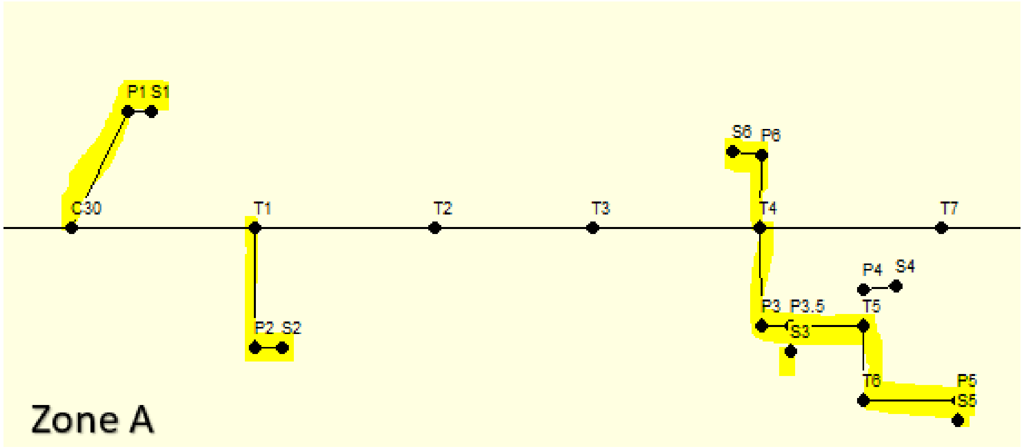

Figure 29 Zone A1 Map (Yellow Highlights are 1.5-inch pipe)

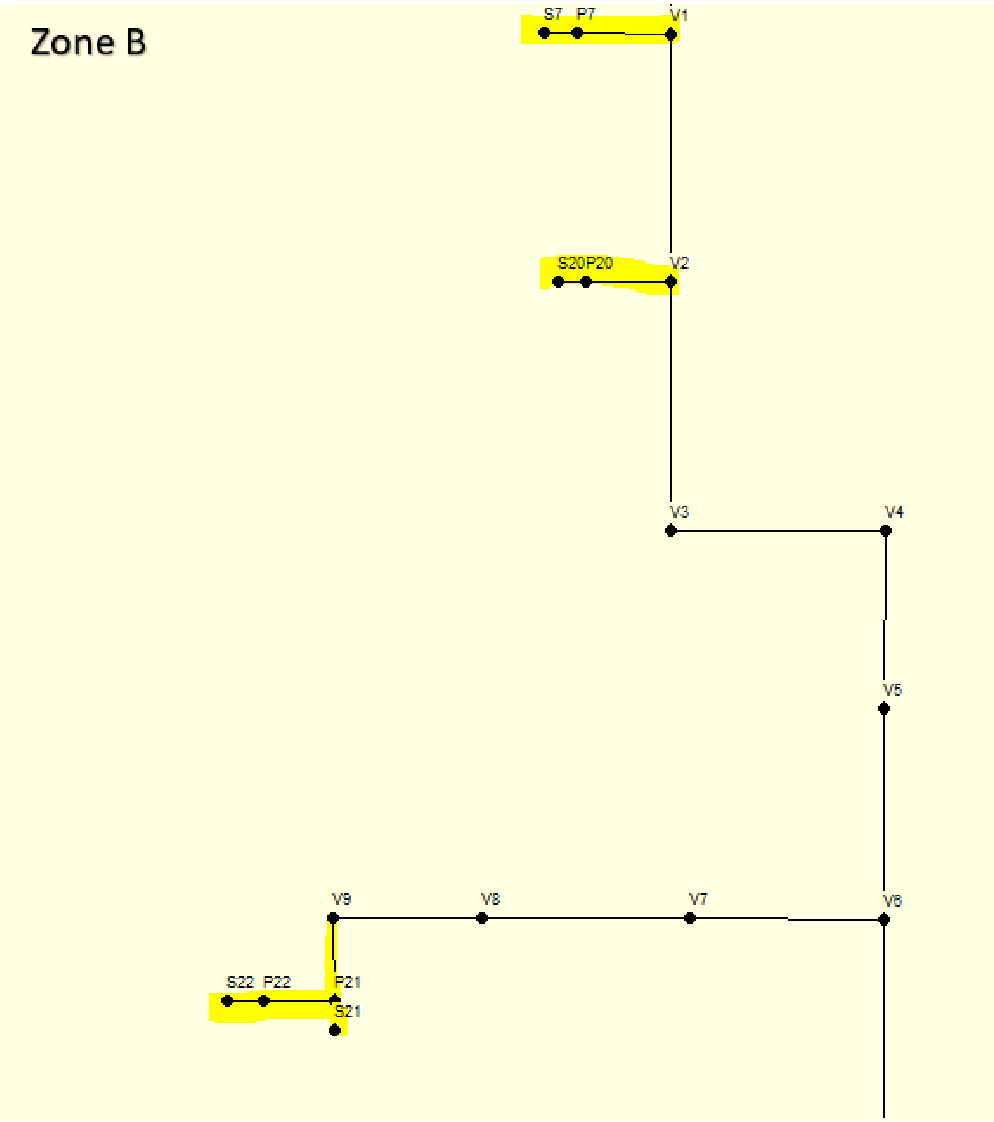

Figure 30 Zone B1 Map (Yellow Highlights are 1.5-inch pipe)

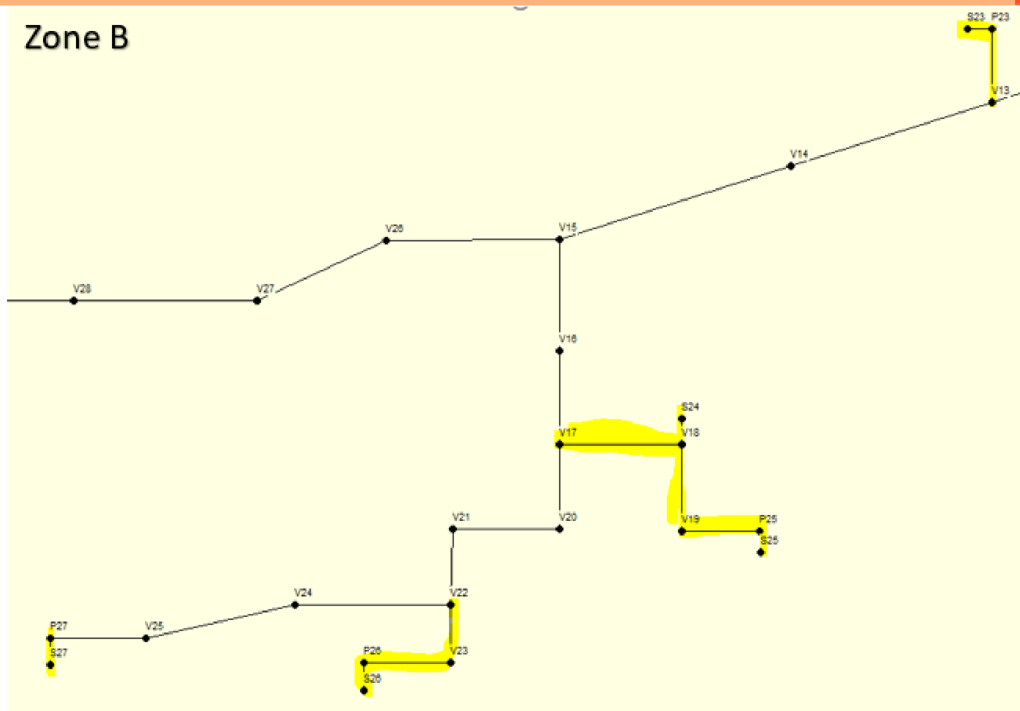

Figure 31 Zone B2 Map (Yellow Highlights are 1.5-inch pipe)

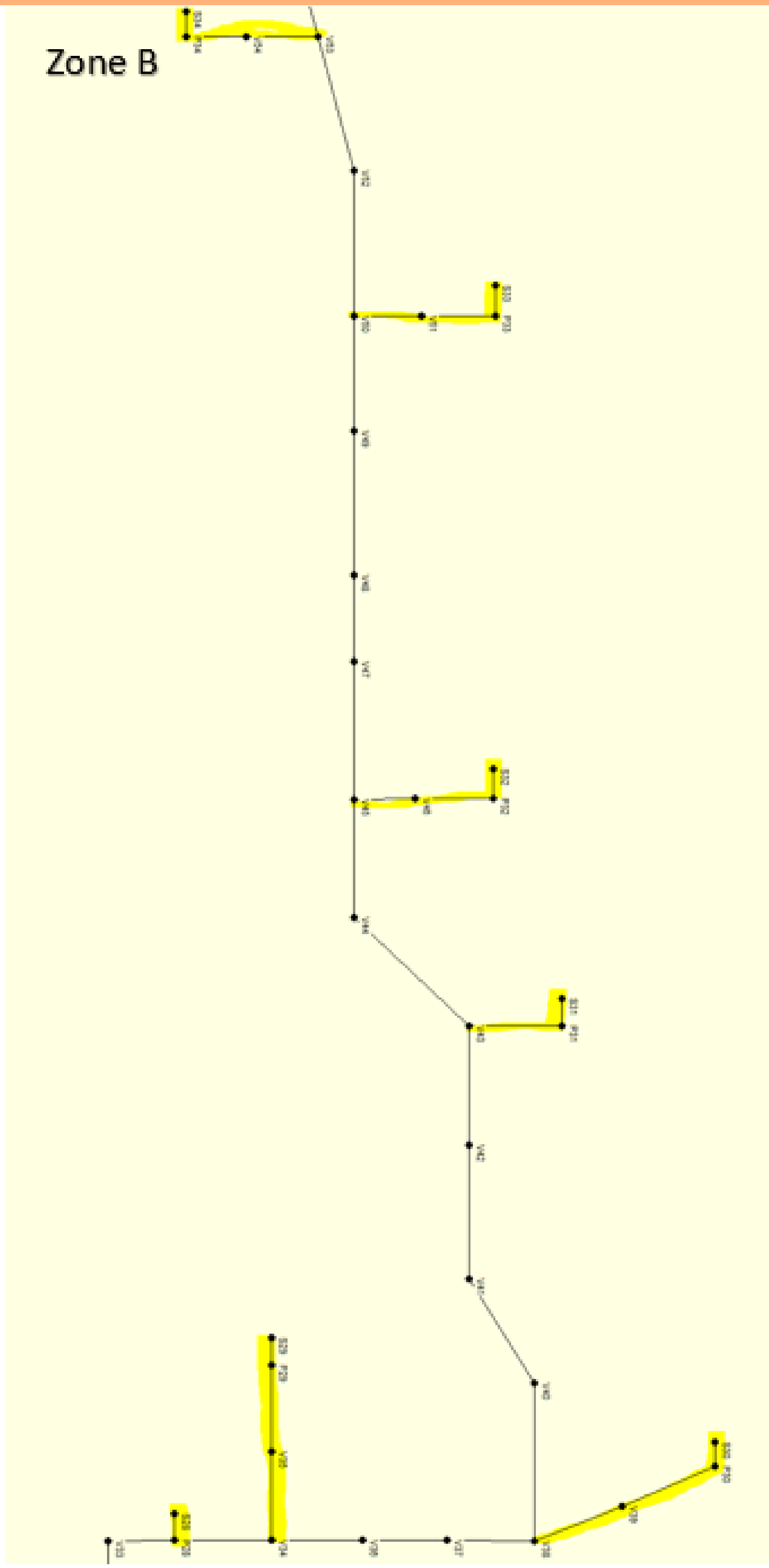

Figure 32 Zone B3 Map (Yellow Highlights are 1.5-inch pipe)

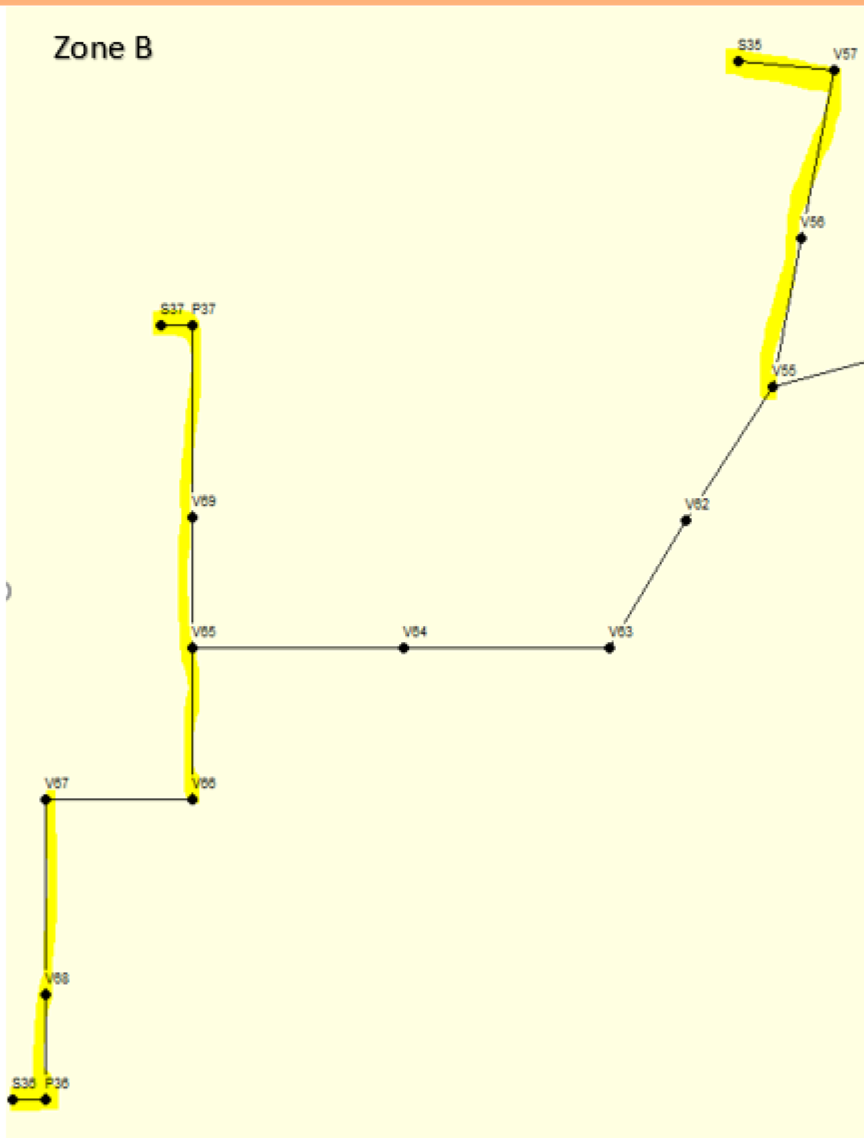

Figure 33 Zone B4 Map (Yellow Highlights are 1.5-inch pipe)

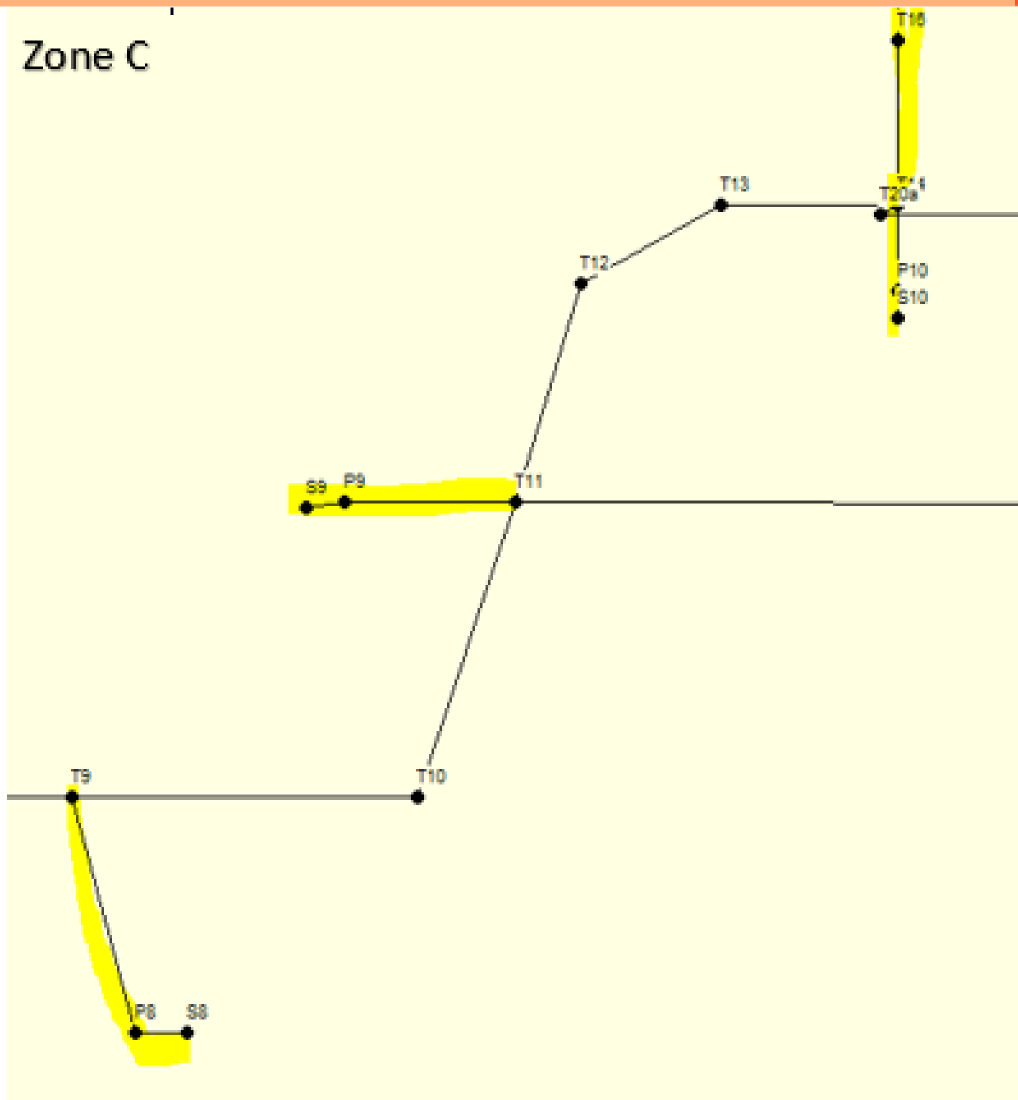

Figure 34 Zone C1 Map (Yellow Highlights are 1.5-inch pipe)

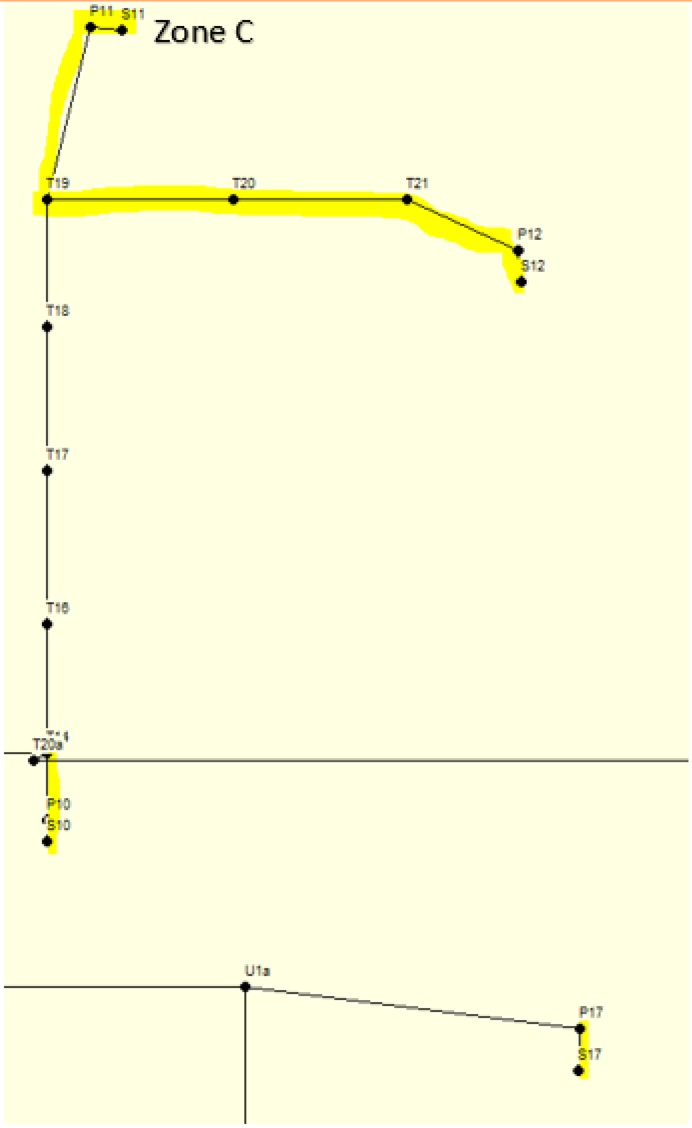

Figure 35 Zone C2 Map (Yellow Highlights are 1.5-inch pipe)

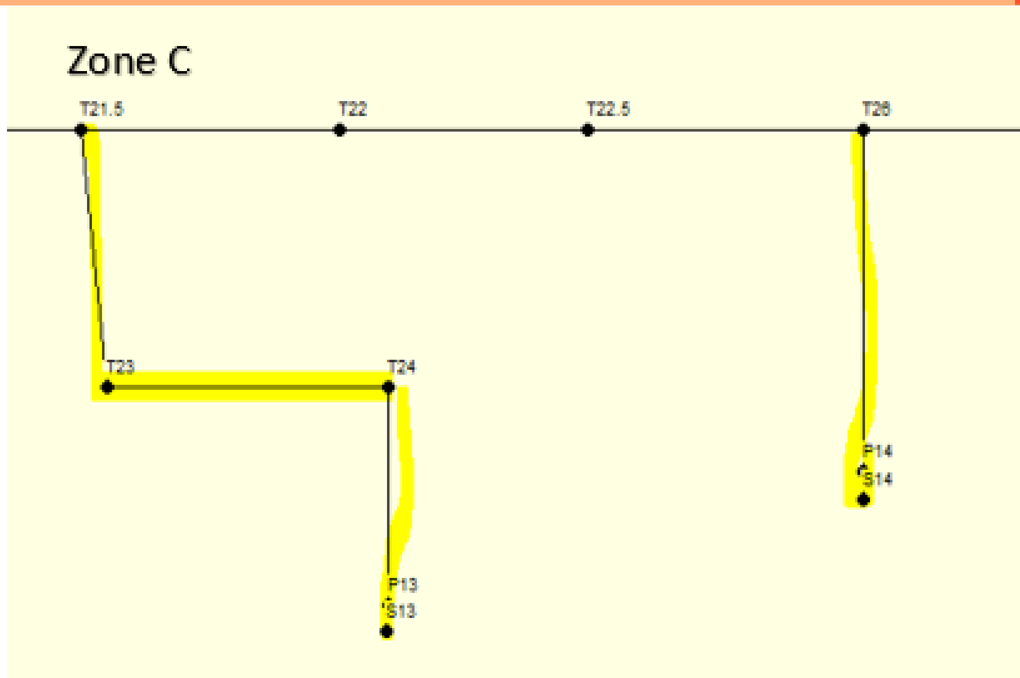

Figure 36 Zone C3 Map (Yellow Highlights are 1.5-inch pipe)

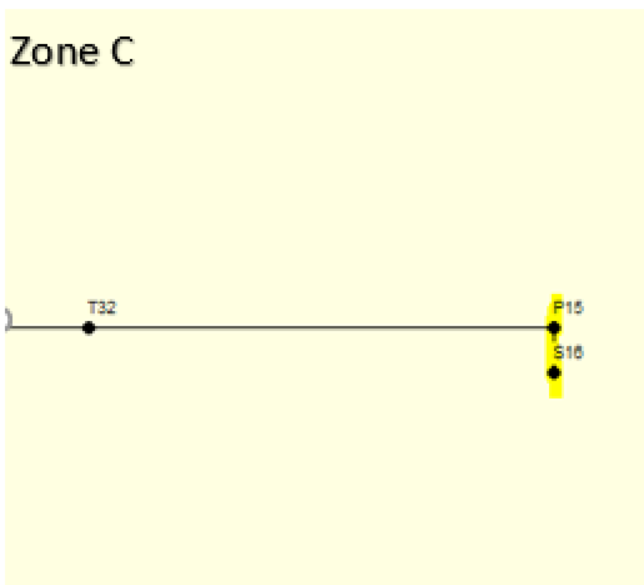

Figure 37 Zone C6 Map (Yellow Highlights are 1.5-inch pipe)

Appendix 6. Data for River Crossing

Table 13 Data for the Cable Calculations for the River Crossing

Pipe Weight / ft.	0.68	lb./ft.
Pipe Weight / m	2.23	lb./m
Pipe weight	88.12	lb.
Weight of Water in Pipe	4.41	lb./m
Weight of Water in Pipe	176	lb.
Outer Pipe weight/ft.	2.01	lb./ft.
Outer Pipe weight/m	6.59	lb./m
Outer Pipe Weight lb.	260.5	lb.
Total Weight	525.0	lb.
Sag allowed	2	m
Horizontal Tension	1291	lb.
Angle of Tension	0.20	radians
Total Tension	1317	lb.
SF	3	
Total Tension w/SF	3951	lb.
Min Breaking Strength (1/4)	1827	
Rope Diameter	1/4	in
Sag Calc.	2	

Table 14 Concrete Anchor Data for River Crossing

Length1	0.25	m
Length 2	1	m
Width 1	1	m
Width 2	1	m
Height 1	1.25	m
Height 2	0.75	m
Volume Tower	0.313	m^3
Volume Slab	0.750	m^3
Total Volume	1.06	m^3
Check for Sliding	3783	
Solved SF	3.0	

Table 15 Stringer Data for River Crossing

Length	39.5
X1	20
Sag Ratio	0.05
C	2.51
Determining Sag	1.97
C Value	99.08

Table 16 Stringer Calculations and Total Cable Required

Distance from Apex (m)	Sag Allowance (m)	Connections (m)	Total (m)
20	2.025	1.35	3.38
15	1.138	0.76	1.90
10	0.505	0.34	0.84
5	0.126	0.08	0.21
Apex (0)	0.000	0.00	0.00
5	0.126	0.08	0.21
10	0.505	0.34	0.84
15	1.138	0.76	1.90
20	2.025	1.35	3.38
Grand Total			12.65

Table 17 Final Cable Length for River Crossing

Final Cable		
y	20	m
ΔL	1.4E-03	m
Total Length	39.76	m

Table 18 Data for the Cable Calculations for the Stream Crossing

Pipe Weight / ft.	0.68	lb./ft.
Pipe Weight / m	2.23	lb./m
Pipe weight	30.11	lb.
Weight of Water in Pipe	1.50	lb./m
Weight of Water in Pipe	60.30	lb.
Outer Pipe weight/ft.	2.01	lb./ft.
Outer Pipe weight/m	6.59	lb./m
Outer Pipe Weight lb.	89.02	lb.
Total Weight	179.44	lb.
Sag allowed	1	m
Horizontal Tension	235.39	lb.
Angle of Tension	0.28	radians
Total Tension	245.51	lb.
SF	3	
Total Tension w/SF	736.54	lb.
Min Breaking Strength (1/4)	1826.66	
Rope Diameter	¼	in
Sag Calc.	1	

Table 19 Concrete Anchor data for Stream Crossing

Length1	0.25	m
Length 2	0.5	m
Width 1	0.5	m
Width 2	0.5	m
Height 1	0.5	m
Height 2	0.5	m
Volume Tower	0.0625	m^3
Volume Slab	0.125	m^3
Total Volume	0.1875	m^3
Check for Sliding	714.01	
Solved SF	3.03	

Table 20 Stringer Data for Stream Crossing

Length	13.5	m
X1	6.75	m
Sag Ratio	0.074	
C	1.79	
Determining Sag	0.93	
C Value	24.26	

Table 21 Stringer Calculations and Total Cable Required

Distance from Apex (m)	Sag Allowance (m)	Connections (m)	Total (m)
3.5	0.25	0.17	0.42
Apex (0)	0.00	0.00	0.00
3.5	0.25	0.17	0.42
Grand Total			0.84

Table 22 Final Cable Length for River Crossing

Final Cable		
y	6.83	m
ΔL	0.0013	m
Total Length	13.67	m

Appendix 7. River Crossing Equations

$$weight = \frac{weight}{length} * total\ length$$

$$2.23\frac{lb}{m} * 40.m = 88.1\ lb$$

Eq. 2 Calculating Weight of 2” PVC Pipe

$$weight = \frac{weight}{length} * total\ length$$

$$6.59\ \frac{lb}{m} * 40.m = 250.5\ lb$$

Eq. 3 Calculating Weight of 4” PVC Pipe

$$weight = \rho * V$$

$$1000\frac{kg}{m^3} * 40m * \pi * (0.0254\ m)^2 * \frac{2.205\ lb}{1\ kg} 176\ lb$$

Eq. 4 Calculating Weight of Water

$$T_{horizontal} = \frac{\frac{total\ weight}{length} * length^2}{8 * sag}$$

$$T_{horizontal} = \frac{\frac{(2.23 + 260.5 + 176)\ lb}{m} * 40m^2}{8 * 2} = 1{,}291\ lb$$

Eq. 5 Calculating the Horizontal Tensions

$$Angle\ of\ tension = \frac{\arctan(4 * sag)}{length\ of\ span}$$

$$Angle\ of\ tension = \frac{\arctan(4 * 2m)}{40m} = 0.20\ radians$$

Eq. 6 Calculating Angle of Tension

$$T_T = \frac{T_H}{Cos(\phi)}$$

$$T_T = \frac{1{,}291\ lb}{Cos(0.20)} = 1{,}317$$

Eq. 7 Calculating the Total Tension

$$vertical\ force = horizontal\ force * \tan(angle\ of\ tension)$$

$$vertical\ force = 1{,}291\ lb * \tan(0.20) = 261\ lb$$

Eq. 8 Calculating the Vertical Force

$$0 = (SF * T_{Horizontal}) - [(V_{Tower} * V_{slab} * \ \rho_{concrete}) * \tan(\phi)] - (T_{Vertical})$$

$$0 = (SF * 1{,}291\ lb) - [0.525\ m^3 * 0.5\ m^3 * 5{,}291 \frac{lb}{m^3} * \tan(0.576)] - 261\ lb$$

$$SF = 2.9$$

Eq. 9 Calculating the Safety Factor to Check for Sliding

$$y = C * \cosh\left(\frac{x}{c}\right) - C$$

$$y = 99.08 * \cosh\left(\frac{5m}{99.08}\right) - 99.08 = 0.13\ m$$

Eq. 10 Calculating the Length at Each Stringer

$$\Delta L_{cable} = \left[\frac{20\%\ of\ min.breaking\ strength}{Area\ x\ 13{,}500{,}000\ lb.in^2}\right] + \left[\frac{Total\ load - 20\%\ \min breaking\ strength}{Area\ x \frac{15{,}000{,}000 lb}{in^2}}\right]$$

$$\Delta L_{cable} = \left[\frac{20\% * 16540\ lb}{3.9 * 10^{-4} m^2 * 20{,}925{,}041{,}850 \frac{lb}{m^2}}\right] + \left[\frac{3{,}059 - 20\% * 16540\ lb}{3.9 * 10^{-4} * \frac{15{,}000{,}000 lb}{in^2}}\right] = 3.8 * 10^{-4} m$$

Eq. 11 Calculating the Cable Stretch

$$y = C * \sinh\left(\frac{x}{c}\right)$$

$$y = 99.08 * \sinh\left(\frac{20\ m}{99.08}\right) = 39.76\ m$$

Eq. 12. Calculating Final Cable Length

$$W_1 = V_1 * \rho_{concrete}$$

$$W_1 = (0.25 * 1.25 * 1)m^3 * \frac{5291 lb}{m^3} = 1653$$

Eq. 13

$$W_2 = V_2 * \rho_{concrete}$$

$$W_2 = (1 * 1 * 0.75)m^3 * \frac{5291\ lb}{m^3} = 3968$$

Eq. 14

$$\sum M = F_c L_c - (W_1 L_1 - W_2 L_2) * SF = 0\ lb * m$$

$$\sum M = 0.5 * (1317\ lb * 1.25\ m) = \left[\left(1653\ lb * \left(\frac{0.25\ m}{2}\right)\right) + \left(3968\ lb * \left(\frac{1.25\ m}{2}\right)\right)\right] SF$$

$$SF = 3.2$$

Eq. 15. Check for Overturning in River Crossing Anchor

$$W_1 = V_1 * \rho_{concrete}$$

$$W_1 = (0.25 * 1 * 0.5)m^3 * \frac{5291 lb}{m^3} = 661\ lb$$

Eq. 16

$$W_2 = V_2 * \rho_{concrete}$$

$$W_2 = (0.5 * 0.5 * 0.5)m^3 * \frac{5291\ lb}{m^3} = 661 lb$$

Eq. 17

$$\sum M = F_c L_c - (W_1 L_1 - W_2 L_2) * SF = 0\ lb * m$$

$$\sum M = 0.5 * (246\ lb * 1\ m) = \left[\left(661\ lb * \left(\frac{0.25\ m}{2}\right)\right) + \left(661 lb * \left(\frac{0.75\ m}{2}\right)\right)\right] SF$$

$$SF = 2.6$$

Eq. 18. Check for Overturning in Valley Crossing Anchor

Appendix 8. Schedule: Table and Descriptions

Table 23 Tasks, Man-hours, and Schedule for Construction

#	Task	Duration (Hours)	Manpower	Man Hours	Work Day
H1	Excavation of Site	8	3	24	1
H2a	Place Gravel and Pour Concrete Base	8	3	24	2
H2b	Allow Concrete Base to Set	72	0	0	3-6
P3a	Dig Anchors for Valley Crossing	1	2	2	4
P3b	Prepare for Concrete	2	2	4	4
P3c	Pour Concrete On Base	2	2	4	4
P3d	Set Concrete Base	72	0	0	4-7
P4	UV Spray All Exposed Piping	5	3	15	5
S1	Drainage Channel	12	4	48	5-6
S2	Water Reserve	4	4	16	7
P5a	Excavate	0.5	2	1	7
P5b	Prepare for concrete	1	2	2	7
P5c	Anchor base	0.5	1	0.5	7
P5d	Set concrete	72	0	0	7-10
P3e	Pour Concrete Tower w/Rebar	3	2	6	8
P3f	Set Concrete Tower	72	0	0	8-11
P3g	Prepare Stringers	2	2	4	8
S3	Excavation Springs	9	4	36	9-10
S4a	SB Base Construction	8	3	24	10
S4b	SB Set Concrete	72	0	0	10-13
H3a	Ladder Rungs	4	1	4	11
H3b	Create Wall Forms	6	2	12	12
H3c	Pour Concrete Wall	8	3	24	13
H3d	Allow Concrete to Set	72	0	0	13-16
P5e	Concrete Tower	6	2	12	14
P5f	Set Concrete	72	0	0	14-17
P6	Prepare Stringers	6	4	24	15
P8	Tree Anchor	1	3	3	15
S5a	Wall Construction	12	4	48	16-17
S5b	Pour Concrete	4	5	20	17
S5c	Set Concrete	72	0	0	17-20
S6	Form & Pour Cover	9	3	27	18
S6a	Set Concrete	72	0	0	18-21

H3e	Remove Base Forms	3	2	6	19
H4a	Create Forms	6	2	12	19
H4b	Pour Concrete	8	3	24	20
H4c	Allow Concrete to Set	72	0	0	20-23
P1	Dig Trenches	168	6	1008	23-30
H5a	Lay Gravel	4	2	8	31
H5b	Place Rebar	4	2	8	31
H5c	Pour Concrete	8	3	24	32
H5d	Allow Concrete to Set	72	0	0	32-35
P7	Stringing Pipe for River Crossing	2	6	12	33
H5d	Remove Forms	3	2	6	33
H6a	Handles	4	1	4	34
H6b	Create Form	1	2	2	34
H6c	Pour Concrete	1	3	3	34
H6d	Allow Concrete to Set	72	0	0	34-37
H7	Connect Piping to Tank	8	1	8	37
P9	Test the System	1	Everyone	0	38
P9a	Maintenance (as needed)	5	2	10	39
P10	Cover All Piping	8	6	48	40
Total Man Hours				2876	

Spring Captures

S1. Drainage Channel

- Divert normal flow path away from spring before beginning construction
- Shovels can be used to dig channel

S2. Temporary Water Reserve

- Place a temporary water container at spring, so fresh water will be readily available for concrete mixing

S3. Excavation

- Dig out the soft sediments until the eyes of the spring are clearly exposed.
- Take caution not to dig into the impermeable layer of sediment.
- Tools to be used are a pickaxe and shovel

S4a. Base Construction

- Delineate the edges of the base with wood shuttering. [12]
- The base should be close to the eye of the spring and extend approximately one meter forward from the eye and across the full width of the base.

- Base thickness should be 100mm [12]

- Lay Rebar in 0.33 m spacing across width of base. Lay rebar in 0.33 m spacing across length of base [9]
- Concrete mixture should be a (1:4:8) mixture. Add water just enough to make mixture cohesive, but ensure not to add too much water. [12]
- Minimize air pockets by tamping the mixture. This can be done by heavy banging
  and shaking the form or ramming within the mixture with a steel rod. [8,16]
- Concrete will take 3 days to set before any weight can be applied
- While concrete is hardening, maintain moisture in the concrete by placing old damp cement bags, rags, etc. over top. These coverings should be wetted daily. [12]

S4b. Set Concrete

- Wait 3+ days for concrete to dry

S5a. Wall Construction

- Use wood shuttering to create framework for 100 mm thick walls [12]
- Front and side walls can be erected simultaneously.
- Per recommendation of [9] walls should be reinforced with rebar in 0.15m intervals.
  - Position rebar in 0.15m spacing across width of wall. Position rebar in 0.15m spacing across length of wall.

S5b. Pour Concrete

- Mix concrete with cement, sand, and gravel in (1:2:4) ratio. [12]
- Pour concrete
  - Install overflow, outflow, and cleanout piping in the front wall.
- Affix the cleanout plug to cleanout pipe and shut-off valve to outflow pipe

S5c. Set Concrete

- Concrete will take 3 days to set
  - While concrete is hardening, maintain moisture in the concrete by placing old damp cement bags, rags, etc. over top. These coverings should be wetted daily.

S6. Cover Construction

- Construct wooden form for 100 mm thick cover. [12]
- Lay Rebar in 0.4 m spacing across width of top. Lay rebar in 0.4 m spacing across length of top. [9]

S6a. Mix concrete with cement, sand and gravel in a (1:2:4) ratio. [15]

- Pour concrete and allow concrete to sit and harden.

- Minimize air pockets by tamping the mixture. This can be done by heavy banging and shaking the form or ramming within the mixture with a steel rod. [8,16]
- While concrete hardens, maintain moisture in the concrete by placing old damp cement bags, rags, etc. over mixture. These coverings should be wetted daily. [15]

Holding Tank

H1. Excavation of Site - Tank site needs to be excavated to create level ground for the tank to be built on. Trenches will also need to be excavated for the wall footings.

H2. Wall Footing Foundations -

H2a. Place Gravel and Pour Concrete

- Place and level 0.10 m of gravel in excavated trenches. Then pour concrete footings on top.

H2b. Allow Concrete to Set

H3. Wall Construction -

H3a. Ladder Rungs

- 14 pieces of 0.60 m need to be formed into ladder rungs to access the
manhole.

H3b. Create Forms for Walls

- Basic forms need to be built, rebar, ladder rungs and the 6 piping locations need to be placed.

H3c. Pour Concrete for Walls

- Mix concrete, pour walls and let sit until concrete is dried.

H3d. Allow Concrete to Set

H3e. Remove Forms

H4. Roof Construction -

H4a. Create Forms for Roof

- Place wood beams, plywood and rebar. Create form to leave opening for manhole
  - A piece of plywood will be placed supported by horizontal and vertical beams for the roof to be poured on top of.

H4b. Pour Concrete for Roof

- Mix concrete, pour roof and let sit until concrete is dried.

H4c. Allow Concrete to Set

H4d. Remove Forms

- Cut inside forms into small pieces to remove through manhole

H5. Floor Construction - To be completed after roof is done so no contamination occurs

H5a. Lay Gravel

- Gravel should slope towards cleanout and outlet pipe.

H5b. Place Rebar

H5c. Pour Concrete for Floor

- Mix concrete, pour floor and let sit until concrete is dried.

H5d. Allow Concrete to Set

H6. Manhole Cover-

H6a. Handles

- Form handles from ⅜” rebar

H6b. Create Form

- Build basic form, place wire mesh for support and rebar handles

H6c. Pour Concrete for Cover

- Mix concrete, pour cover and let sit until concrete is dried.

H6d. Allow Concrete to Set

H7. Connect Piping to Tank

Piping Network

P1. Excavation of pipe network:

P1a: Dig Trenches

- Dig trenches about 1ft. deep.
- You will put up caution tape as you go along the network.

P2. Lay Pipe network

P2a. Lay piping

- Measure out along the network the amount of pipe need at each section and cut pipe with a saw for each deviation in the network. For example, if there is a 5ft section of pipe the pipe with need to be cut shorter.
- needed before an incline you will cut a 5ft section from the 20ft pipe section provided.

P2b. Pipe Fittings

- Add pipe fittings as you go along the network. This will also be taking into consideration the coupling fittings at each pipe section. For the coupling fittings one or two people will be applying the solvent at each fitting as the rest of the crew is installing the network.

P2c. Install couplings

P3a. Valley Crossing

P3a. Dig anchors for valley crossings

P3b. Prepare for Concrete
P3c. Pour Concrete on Base
P3d. Set Concrete Base
P3e. Pour Concrete Tower w/Rebar
P3f. Set Concrete Tower
P3g. Prepare Stringers
P3h. String Pipe for Valley Crossing

P4. UV Spray

- Spray the 4” PVC Pipe and 2” PVC Pipe that is going to be exposed with the UV Protection spray

P5a. Excavate

- Dig a hole for the base of the concrete anchor for the 40m river crossing.
    - 21 inches deep (0.5m + 25 mm [Est])
    - 1.25 m long
    - 1 m wide

P5b. Prepare for concrete

- Place wooden planks around the hole to form the concrete
- Fill bottom layer with 1 inch or 25 mm of gravel
- Lay rebar across the base
    - 3, 1.25-meter vertical support
    - 4, 1-meter horizontal support

P5c. Anchor Base
P5d. Set Concrete
P5e. Pour Concrete Tower

- Pour 0.25 m of concrete
- Lay rebar
- Pour another 0.25 m of concrete
- Lay rebar
- Pour 0.2 m of concrete
- Lar rebar and top with the last 0.05 m of concrete

P5f. Set Concrete Tower
P6. Prepare Stringers

- Lay out the main cable and pipe on solid ground with appropriate sag
- Attach the cable eyelet at the appropriate distances
- Cut the wire rope to the appropriate length to the coordinating sag at that point
- Wrap the 3/16” wire rope around the cable eyelet with appropriate turn back length, attach two cable clamps alone the turn back. Wrap the bottom part around the pipe.

P7: Stringing Pipe for River Crossing

- A few people will guide the pipe through the stringer bottoms onto the other side

P8: Tree anchor Construction

- Use 2 elbows to guide pipe along the tree
- Attach cable and clamps to tree

P9: Test system before burying pipe

- Run the system after everything is connected. Have all workers along the piping system to check for any leaks.

P9a. Maintenance

- If maintenance is needed on the pipe, fix it before burying the pipe. Retest after the maintenance is complete.

P10: Bury the pipe

- Cover all piping if there are no maintenance needed.

Appendix 9. Cost Estimate Tables

Table 24 Cost Estimate of Materials for Water Distribution System

Materials				
Material	**Quantity**	**Units**	**Unit Cost**	**Cost**
Cement (500 lbs)	30	each	$50.00	$1,477.60
Sand	345	ft3	$2.00	$690.00
Aggregate	531	ft3	$1.72	$913.32
Rebar	1,375	ft	$0.20	$275.00
2in Pipe Mesh Screen	11	count	$16.00	$176.00
Valves	53	count	$12.79	$677.87
Cleanout Plug	7	count	$6.79	$47.53
Wood shuttering (4x4m)	2	count	$14.00	$28.00
Plywood (4' by 8')	80	m2	$4.03	$322.40
Wood Planks (2" by 2")	33	m	$0.58	$19.14
90-degree Elbow (2in)	43	count	$3.99	$171.57
Reinforcement Mesh (42" By 84")	1	sheet	$7.75	$7.75
Hardware for Forms	[redacted]			$200.00
UV Spray Paint	4	Can	$5.00	$20.00
SDR 26 (2.in)	5,005	ft	$0.80	$4,004.00
SDR 26 (1.5in)	2,860	ft	$0.50	$1,430.00
Air Valves	5	count	$19.99	$99.95
45-degree Elbow (1.5in)	13	count	$2.99	$38.87
45-degree Elbow (2in)	10	count	$3.99	$39.90
90-degree Elbow (1.5in)	102	count	$1.99	$202.98
Couplings (1.5 in)	141	count	$2.99	$421.59
Couplings (2 in)	248	count	$0.69	$171.12
Y (2in)	4	count	$1.99	$7.96
Y (1.5 in)*	3	count	$2.99	$8.97
T (2in)	13	count	$1.59	$20.67
T (1.5 in)	12	count	$2.99	$35.88
Coupling Solvent	8	count	$9.79	$78.32
PVC 4" (10 ft)	4	ft	$4.79	$19.16
3/16" Wire rope (250 ft)	1	ft	$29.49	$29.49
1/4" Wire rope (200ft)	1	ft	$51.49	$51.49
1/4 SS wire rope thimble	7	count	$0.99	$6.93
3/8 x 6 Jaw & Eye turnbuckle	1	count	$4.59	$4.59
3/16" Stainless Steel Rope Clip	35	count	$1.35	$47.25
Total				$11,700

Table 25 Cost Estimate of Equipment for Water Distribution System

Equipment			
Tools	Quantity	Unit Price	Total Price
Shovel	6	$20	$120
Saw	3	$17	$51
Metal Cutting Hack Saw Blade	1	$23	$23
Buckets	10	$4	$40
Hammer	3	$25	$75
Screwdriver Set	1	$25	$25
Measuring Tape	3	$10	$30
Workman Gloves	7	$10	$70
Pickaxe	3	$10	$30
Caution Tape (100 ft. rolls)	2	$11	$22
Total			$460

Enclosed Gantt Chart for Construction