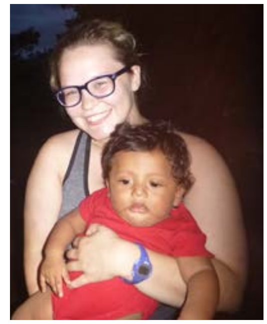


Operación de Agua Potable

Operation Clean Water

For the Community of Quebrada Caracol

Ngöbe–Buglé Comarca, Panama

December 10, 2015

Clean Water Consulting

Sarah Stoolmiller, Elizabeth Wohlford, Michael Cherng, Nick Rademacher

Michigan Technological University

Water Supply and Watershed Protection for Quebrada Caracol, Panama

Submitted to:

Dave Watkins, PhD, PE – Michigan Technological University
Mike Drewyor, PE – Michigan Technological University
Leigh Miller – Peace Corps Volunteer
Quebrada Caracol Community

Mission Statement:
The mission of Clean Water Consulting is to provide reliable, sustainable, and clean water to the community of Quebrada Caracol, which is located in the Ngöbe–Buglé Comarca of Panama. The team will provide renovation recommendations of the current system as well as a new pipeline design that extends the current system to more homes to provide safe drinking water.

Acknowledgements:
Clean Water Consulting would like to thank the following people for their support throughout this project:

Peace Corps Volunteer

Leigh Miller, F.E.

International Senior Design Professors

David Watkins, PhD, P.E.

Mike Drewyor, P.E. P.S.

Quebrada Caracol Community

Submitted By:

Sarah Stoolmiller

Nick Rademacher

Elizabeth Wohlford

Michael Cherng

Disclaimer:

This report titled "Operación Agua Potable, Clean Drinking Water for the Community of Quebrada Caracol," represents the efforts of undergraduate students in the Civil, Environmental, and Mechanical 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.

Contents

List of Figures

List of Tables

Executive Summary

Four engineering students, Sarah Stoolmiller, Elizabeth Wohlford, Nicholas Rademacher, and Michael Cherng, also known as Clean Water Consulting (CWC), traveled from Chicago, Illinois, USA to the community of Quebrada Caracol located in Panama. On the team are two civil engineering students, a mechanical engineering student, and an environmental engineering student. While in Quebrada Caracol, they collected data, met the community members, and conversed with the community's assigned Peace Corps Volunteer (PCV), Leigh Miller. It was decided upon by the PCV and community members that the current water quality is unacceptable. Due to this, CWC's main goals are to address the poor water quality and inadequate water distribution system. CWC has made recommendations in order to bring the community safe drinking water.

A spring-fed water distribution system currently exists in the community; it is estimated to have been built in the year 2000. The infrastructure of the system has not had the care needed to remain operational. New lids need to be built for the spring box and water storage tank. There are also many damaged pipes throughout the system, and the chlorination system needs to be relocated upstream of the storage tank. CWC utilized the software program EPANET 2.0 to model the existing water distribution system. Using this model, the team was able to model the system servicing three additional homes.

When CWC returned to Houghton, MI, USA after collecting data on their trip to Panama, they did a complete assessment of the data they collected. While in the community, water quality tests were performed to assess the types of bacteria present, and sources of potential contamination were identified. The water was found not to meet potable standards. A spring box protection plan of the spring was created by CWC. This plan includes redesigning a lid that will fully cover the opening to the spring. Another part of the spring box protection plan is to divert contaminated water that is running over from a nearby spring. CWC suggested that a trench be dug to divert runoff water.

In order for CWC to perform the requested water shed analysis, the watershed perimeter was mapped using a Garmin eTrex 10 handheld Global Positioning System (GPS). These data points were uploaded into Google Earth®. The area of the watershed was found to be about 55,000 square meters.

Clean Water Consulting has made these recommendations for the community of Quebrada Caracol in order to supply them with potable, accessible water. The cost of these updates has been projected at approximately $5,120.00, with the community volunteering 190 hours to total $1,520.00 of labor. This report is to be submitted to Leigh Miller, Peace Corps Volunteer, for further consideration and possible implementation.

1.0 Community Background

The village of Quebrada Caracol is located in the Ngöbe–Buglé Comarca in western Panama. A comarca is similar to a reservation, where a substantial number of indigenous people live. There are no roads suitable for motorized vehicles to access the village directly. There is a path that takes about 75 minutes walking time from the paved road to the church. The community of Quebrada Caracol is relatively new. It was established less than 25 years ago. The common language is Spanish, although the older generations still speak the native language of Ngöbe. Younger generations understand the Ngöbe language, but rarely speak it. A map that shows the location of Quebrada Caracol within the country of Panama can be seen in Figure 1 and a picture of the community's location within the comarca can be seen in Figure 2 [1].

Figure 1: Location of Quebrada Caracol within Panama

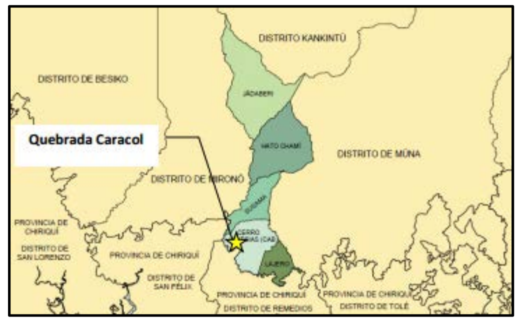


Figure 2: Location of Quebrada Caracol within Comarca

Data was collected by the Peace Corps Volunteer (PCV), Leigh Miller, showing walking distances between houses and community gathering spots. This data can be seen graphically in Figure 3 [1]. It should be noted that the unit of measurement for distance is in minutes of walking time. Clean Water Consulting (CWC) found that it took them about 1.5 times as long to travel the same distances, showing that actual travel time is highly subjective. In order to combat the subjectivity of the measurements provided by the PCV, Global Positioning System (GPS) points were collected by CWC at the locations indicated in Figure 3.

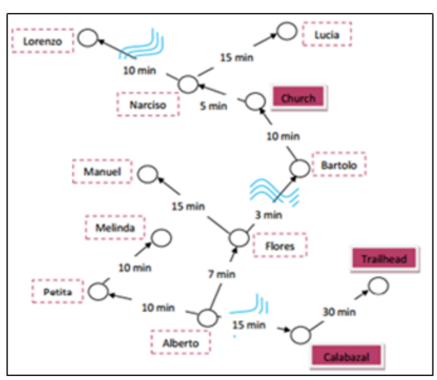


Figure 3: Walking travel times collected by PCV of Quebrada Caracol

Before CWC arrived in the village, the PCV collected some initial data about the residents in the community. It was found that there are 233 residents living in the community and 103 currently living outside of the community [1]. The reason for the large population not residing in the village is due to low economic opportunity within the village. As a means to make a living, male residents, mostly between the ages of 18-34, seek work as construction workers, field workers, security guards or cooks outside of the community.

The largest age groups in the community are 0-9 years and 10-17 years [1]. This is hypothesized to be due to both poor health standards, leading to a lower life expectancy, and residents living outside of the community for work opportunities. Women often have five to ten children and start their families at a young age. This results in many young children in the community.

There is an elementary and middle school that children in the village can attend. The elementary school is about a 30 minute walk down the mountain from most homes in Quebrada Caracol. The middle school is in the nearby town of Cerro Iglesias. This is about a 60 to 90 minute walk up the mountain from Quebrada Caracol. The school day is set to be from seven in the morning to one in the afternoon. The PCV told CWC that often school will only run from eight in the morning to noon, because the teachers choose to come late and leave early. CWC observed some children did not leave for school on most weekdays. The PCV explained that attendance is variable as the children may be needed at home. Most adults in the village do not have formal education past elementary school.

These initial observations and measurements by the PCV were found to be very helpful to CWC, not only before arriving to the village, but also as a reference after returning to America. Most of CWC's interaction with community members took place during dinner time while visiting the house of their cook. It was observed that the strongest bonds within the community were within families. Multiple generations live in the same home and extended family have a strong bond. This relationship was evident between the PCV's host mom and host aunts, observed the last night CWC was in the village. Their shared religion, following the Seventh Day Adventist Church, also bonded community members. The community members belonging to the church followed rules such as no dancing, no wearing jewelry, and no alcohol or caffeine consumption.

The experience of going to the village helped CWC have, not only a physical foothold on the topography they would be engineering around, but also a cultural appreciation for the community and environment in which they were designing the water distribution system.

1.1 Problem Description

Water use measurements were collected by the PCV, and can be seen below in Figure 4 [1]. The table shows a wide spread in the amount of time it takes for a family to receive water. The amount of water used per day per capita ranges from half a gallon to four gallons. There is no obvious trend between the distance a family is from water and the amount of water they use. It was observed that usually children collected the water for the family. Often large plastic containers were used to collect water. They held multiple gallons of water, so one trip may be all that would be needed for a day's worth of water.

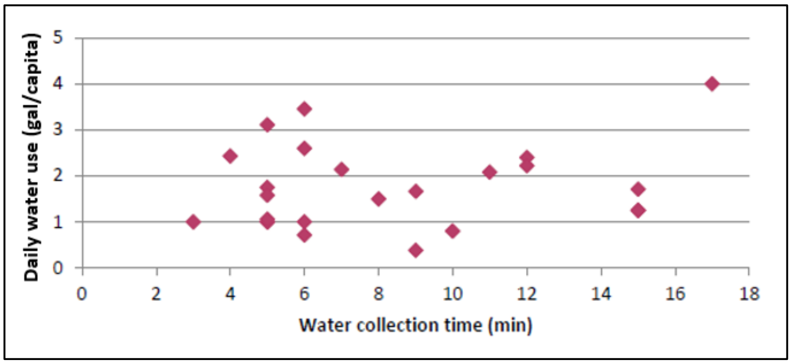


Figure 4: Water Use and Access in Houses without Spigots

Table 1 below outlines the goals the community made with the PCV in regards to their water and sanitation system prior to CWC's arrival [1]. The current aqueduct was built approximately 15 years ago. Infrastructure includes the spring box, water storage tank, chlorination box, and about 900 meters of PVC piping for the water to flow from the spring box to the serviced home. Lids on the spring box, water storage tank, and chlorination box are not form fitting. Some have open crevices for the elements or insects to enter. There is vegetation growing on and around the water holding tank and the chlorination box. Damaged parts of the pipe throughout the system have been replaced or patched with plastic bags. Much of the pipe is not properly installed in the ground. It is exposed and vulnerable to damage.

Table 1: Intersection of Goals

Community Goal	Environmental Health Project Objective
Aqueduct Repair	1. Water committees will adopt water system management methods
	2. Potable water systems will be rehabilitated
Latrines	1. Community access to sanitation

The current chlorination system is not being supplied with chlorine. Waterborne illnesses are of concern of the community and PCV. If the water proves not to be safe for human consumption, sources of contamination need to be determined and addressed. A mapping of the watershed will need to be done in order to determine the activities within the watershed that potentially contribute to the contamination. The main goals CWC will be addressing are the water quality, protection of the water source and its watershed, and rehabilitation of the aqueduct system.

2.0 Data Collection and Analysis

During the eight days that Clean Water Consulting was in the Quebrada Caracol community, they collected three main sets of data. The three sets data centered on watershed analysis, water quality assessment, and the evaluation of the current infrastructure quality. The watershed was mapped and assessed for potential sources of pollution. The natural spring that supplies water to the aqueduct system was tested to find the specific types of contaminants. The aqueduct system was assessed for potential points of contamination and other issues with the infrastructure. In the following sections these data and analyses will be discussed in detail.

2.1 Watershed Data Collection

The first day of surveying entailed marking waypoints on the Garmin eTrex 10 handheld GPS while identifying the perimeter of the watershed. These waypoints were marked every 20-30 meters along ridgelines that surround the watershed. Some breaks were more evident than others, but the team used their best judgement to determine boundaries of the watershed. The second day of surveying involved mapping the ridgelines and fence-lines within the watershed. A “control” GPS was placed at the spring box and the elevation was recorded in five-minute intervals throughout the process of marking waypoints. Each of the waypoints marked on the GPS were recorded in the field book, listing the latitude and longitude coordinates, elevation, and the time the point was marked. The waypoints marked on the GPS were converted to Google Earth format using a software called EasyGPS. This software converts the GPS files from a GPX format to KML, allowing them to be opened in Google Earth.

2.2 Watershed Analysis

Listed in Table 9 of Appendix A is the data specific to each waypoint marked while surveying the watershed. The coordinates of each waypoint were all accepted as accurate, for the satellite signal near the top of the mountain was strong. The elevation given by GPS is based on barometric pressure, rather than satellite positioning, so there is a possibility of elevation fluctuations due to the weather. Recording the elevation changes at the spring box in five-minute intervals provided a means of determining the change in elevation with respect to time. The elevations from the control GPS at the spring box can be found in Appendix A. By recording the times at which each waypoint was marked, the plan was to adjust the elevations using readings from the control GPS. However, analyzing the elevations recorded from the control GPS revealed that the fluctuation in elevation occurred randomly, varying by ten meters over a period of ten minutes. The resulting conclusion is that adjusting the elevations to compensate for error in the GPS is not necessary, as the elevation changes did not display consistent variation with respect to time. Thus, the elevation data collected is accepted as accurate. An average of all of the elevations recorded at the spring box were used as the spring box’s elevation.

Figure 5: Waypoints collected outlining watershed area and geographic features

The waypoints gathered in Panama were mapped and converted to Google Earth using the software, EasyGPS. Additional waypoints were placed to identify boundaries which CWC was unable to reach by foot due to steep terrain and thick underbrush. The polygon feature in Google Earth was used to highlight the area of the watershed by selecting the waypoints that mark the perimeter of the watershed. Figure 5 displays the waypoints gathered for the watershed imported into Google Earth. Figure 6 represents the area of the watershed using the polygon feature. Once the watershed polygon was completed, its properties were copied and entered into *Earth Point*, which provides tools for analyzing Google Earth data. The *Earth Point* shapes tool yielded a perimeter of 943 meters and a total area of 54,734 square meters. The elevation difference between the highest point, Waypoint 18, and the spring box, Waypoint "TOMA", is 100 meters. The waypoints along the ridgelines within the watershed were identified to illustrate various slopes that are present within the watershed. The fence-lines were located to identify the property boundaries to which the project is restrained. These boundaries may influence the feasibility of various methods used in protecting the watershed.

Figure 6: Area of Watershed Found Using Google Earth Polygon Feature

2.3 Water Quality Data Collection

Testing the water quality was performed using 3M Petrifilm count plates. The first set of samples were taken in the morning of August 12th, 2015. These samples were taken from the water inside of the spring box, seen below in Figure 7, and runoff water flowing alongside the spring box, seen below in Figure 8.

Figure 7: Runoff Water Identified by Red Oval

Figure 8: Spring Box with Lid Open

The following three types of 3M Petrifilm count plates were used: Aerobic #6400 [2], E. coli/coliform #6404 [3], and enterobacteriaceae #6420 [4]. One milliliter of water was applied to each Petrifilm using an eyedropper. The protective film was then slowly rolled down onto the sample to ensure even coverage. A supplied spreader was used to ensure full distribution of the water on the film. Ten aerobic, ten enterobacteriaceae, and ten E. coli/coliform count plate samples were taken from inside of the spring box. Similarly, ten aerobic, ten enterobacteriaceae, and ten E. coli/coliform count plate samples were taken from the runoff near the spring box. The time of collection was recorded for each of the

60 samples and stored between pages of a notebook. The notebook was then placed in a black garbage bag located inside a tent to incubate overnight. The samples incubated in the tent for approximately 22 of the 24 total incubation hours. The tent was in direct sun for about 10 of those 22 hours.

The second set of water quality samples were collected on August 13th, 2015, following the same procedure. It was noted that these Petrifilm count plates had been unrefrigerated for over 48 hours. These samples were taken from the only existing tap on the distribution system. The tap water was sampled under three conditions: untreated, chlorinated, and boiled. Ten aerobic, ten enterobacteriaceae, and ten E. coli/coliform count plate samples were taken from the tap of the spring box. Three of each type of test were used to sample the chlorinated water, and two of each test were used to sample the boiled water. Time of collection was recorded for every sample. All samples were then laid on top of a black garbage bag and put in the sun to incubate. At sundown, they were moved into the garbage bag and into the tent, where they stayed for 20 hours.

The first set of samples were ready after being incubated for approximately 24 hours by 12 PM CST on August 13th. The colonies on each of the 60 count plates were counted and recorded by the four team members. Several photos of the incubated count plates can be viewed in Appendix B. The team members' counts were compared for accuracy. The aerobic count plates did not have a recessed dish to fill with the sample, so the area that the water sample covered was also counted. This enabled the number of colonies to be recorded in comparison to the area of the test plate utilized. The area of the circle that the E. coli/coliform and enterobacteriaceae tests covered is approximately 19.625 cm^2, in which 1 mL of water covers. The samples collected from the tap were evaluated approximately 30 hours after collection.

2.4 Water Quality Analysis

The water source of concern is a spring that supplies the community's water distribution system. A spring box is utilized to collect water produced by the spring and protect it from contamination. There is another spring located above the spring box, from which the water runs down the mountain and over the lower spring box. This upper spring is not located in the Comarca. It is located on a cattle rancher's land and is used to water his cattle. There is also a family that lives near this upper spring that uses it for bathing and doing laundry. The aerobic bacteria tests account for all of the bacteria present in the water. The E. coli/coliform test gives a better understanding of the quality of the water. Total coliforms is usually the basis of potable water standards [5]. The enterobacteriaceae test is more specific than the total coliforms test. This tests for specific bacteria including salmonella, Yersinia, and Shigella. This is important, because these are the diseasing causing bacteria. Shigella is the leading cause of diarrhea in the world. An estimated annual 163 million cases of Shigella infection occur in the developing world, resulting in more than 1 million deaths [6]. Salmonella is of concern, for some strands of the bacteria can cause typhoid fever [7]. E.coli is also of concern regarding potable water standards. The E.coli are found on the same test as the total coliform plate however, when they are incubated, they are large and blue, as opposed to the small red coliforms. All of these bacteria are transmitted by contaminated feces.

Table 2 shows the amount of colonies per 1 milliliter of water for the samples taken directly from the spring box. Table 3 shows the same collected data for the runoff water. It is to be noted that all colonies counted were coliform colonies for the E.coli/total coliforms count plates with the exception of two samples. The fourth sample from both the spring box and the runoff had an E. coli colony. Photos of these samples can be found in Appendix B. The samples highlighted in orange were found to be outliers in the data set, as they had far more colonies than their counterparts. Although they are significantly different, they are not being omitted from the data because they do not affect recommendations in regards to the quality of the water. The samples collected from the tap, chlorinated, and boiled water were inconclusive. This could be due to the count plates being unrefrigerated for too long, but it is more likely the result of incubating the samples in direct sunlight.

Table 2: Bacteria count from spring box sampling

	Spring Box				
	Aerobic Bacteria	E. coli/total coliforms			Enterobacteriaceae
Sample #	Colonies per 1 mL	# of counted coliform colonies	# of counted E. coli colonies	Colonies per 1 mL	Colonies per 1 mL
1	482	10	0	11	5
2	169	5	0	6	9
3	96	11	0	11	14
4	26	12	1	13	14
5	57	25	0	25	22
6	44	8	0	8	35
7	34	31	0	31	26
8	39	25	0	25	12
9	19	7	0	8	10
10	41	23	0	23	20

Table 3: Bacteria count from runoff sampling

	Runoff				
	Aerobic Bacteria	E. coli/total coliforms			Enterobacteriaceae
Sample #	Colonies per 1 mL	# of counted coliform colonies	# of counted E. coli colonies	Colonies per 1 mL	Colonies per 1 mL
1	263	73	0	73	49
2	112	87	0	87	58
3	56	62	0	62	58
4	77	69	1	70	43
5	83	80	0	80	53
6	2181	58	0	58	51
7	242	60	0	60	56
8	130	30	0	30	55
9	136	38	0	38	67
10	748	41	0	41	40

It has been determined that fecal contamination is the cause of the poor water quality. Table 4 shows the potable water standards for the World Health Organization, the United

States Environmental Protection Agency, and the country of Panama. The minimum total coliform count collected from the spring box water was six colonies per one milliliter of water. Of the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), and the Panamanian governmental regulations, the most strict drinking water standards come from the World Health Organization. The WHO's drinking water standards are set at 0 total coliforms per milliliter of water. The least strict standards come from the Panamanian government which are set at 0.1 total coliforms per milliliter of water [8]. The number of total coliform colonies counted in both the spring box and runoff water far exceed these limits. Due to these findings CWC has determined that treatment will be necessary for the water to be safely consumed by the Quebrada Caracol community members.

Table 4: Potable Water Standards across Organizations

		Potable Water Standards		
		World Health Organization	US Evironmental Protection Agency	Panama Regulations
	Units			
Total Coliform	Colonies/ 1 mL	0	<0.01	0.1
Fecal Coliform (includes E. coli)	Colonies/ 1 mL	0	<0.01	0

2.5 Infrastructure Analysis

While in Panama, CWC identified multiple issues within the current aqueduct system. These issues left unattended will negatively affect the health of the community members consuming water from the system.

The team observed poor condition of much of the PVC pipe throughout the system. Many points along the pipeline are exposed to the surface, increasing its vulnerability to damage by cattle and humans walking on it. There are also sections of pipe that are missing throughout the system as can be seen in Figure 29 in Appendix K. The pipe at the inlet of the storage tank had been damaged and was inadequately repaired with plastic bags. A picture taken in Panama showing the current state of this pipe can be seen in Figure 9.

Figure 9: Broken pipe leading to inlet of water storage tank

Another observation CWC made while in Panama was that lids covering the spring box and storage tank were crumbling and did not completely cover the openings. CWC noticed that the overflow and ventilation pipes of the spring box and storage tank were not adequately screened. The lack of proper screening allows leaves, insects, and other vermin to enter the pipes. Figure 10 below shows how termites had entered the overflow pipe in the water storage tank.

Figure 10: Termites entering water storage tank overflow pipe

A final analysis was performed on the current water chlorination system. The chlorination system is composed of a T-pipe and chlorination tab holder that is located downstream of the storage tank. A picture of this current system can be seen in Figure 30 and 31 located in Appendix K. The PCV told CWC that the chlorinator has not been used for a substantial amount of time. Currently, the water system only supplies one house and it occasionally stops supplying water due to broken parts upstream.

3.0 Design

The aqueduct system extension design that CWC created will expand the current aqueduct system from servicing one family to servicing four families. Current system components were modeled in the computer aid design software, SOLIDWORKS, and a hydraulic system analysis was performed using the open source software, EPANET. A new chlorination system is suggested by CWC. The following sections further explain the recommendations to rehabilitate the gravity fed aqueduct system that CWC analyzed for the community of Quebrada Caracol.

3.1 Water Distribution System

CWC created a SOLIDWORKS design consisting of major components of both the current system and recommended changes. These components include the spring box, holding tank, chlorine tab distributer, and run off diversion. The spring box, holding tank, and chlorine tab distributer were modeled using hand drawn dimensions that the team gathered while on site. The lid designs were also modeled in SOLIDWORKS and designed based upon the measurements of the storage tank and spring box openings.

3.1.1 Spring Box

The current spring box is made of concrete and has an irregular opening on the top that can be accessed by removing the existing lid. Figure 11 below shows the spring box. A detailed dimension drawing can be seen in Appendix C. Measurements that the computer aided design and technical drawings were based upon were collected while CWC was in Quebrada Caracol.

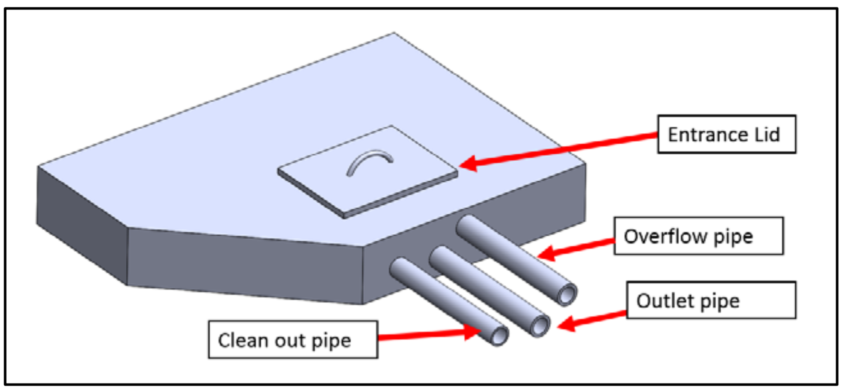


Figure 11: Spring box with pipe details

3.1.2 Storage Tank

The current holding tank it can be seen in Figure 12. Water runs through the pipe system from the spring box into an inlet pipe that is guarded by a concrete box without a lid. The water then drops from this inlet pipe into the 1104.5 gallon holding tank. There is a lid on the top of the holding tank, but it does not securely fit the opening. There is moss and other vegetation growing on the exterior surface of the storage tank's walls. From the measurements collected on site in Panama a detailed drawing of the storage tank was created and can be found in Appendix C.

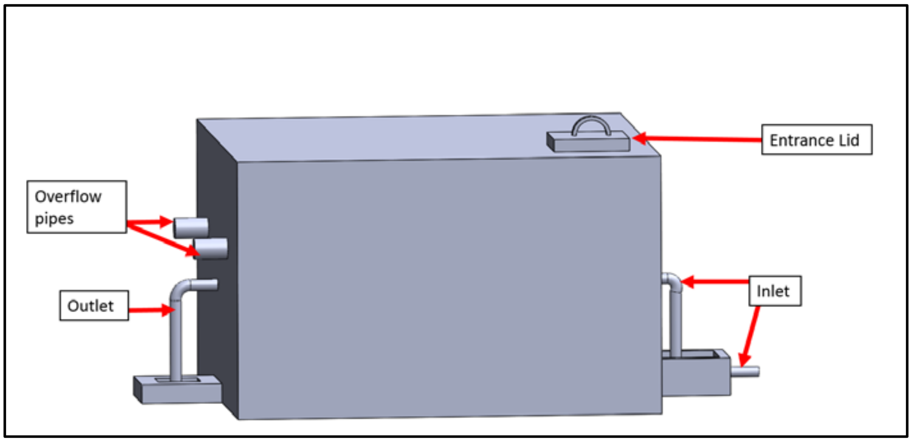


Figure 12: Storage tank with key components highlighted

3.1.3 Chlorination System

The current chlorinator is situated downstream of the storage tank so that the chlorination process occurs as it proceeds to the outlet. This chlorinator was supplied monthly with chlorine tablets, so that it could continue to chlorinate the water as it flows across the bottom of the bottom tablet and flows outward. According to the PCV, it has not been supplied with tablets for a substantial amount of time. The current system was created in SOLIDWORKS with the dimensions recorded in Panama. Figure 13 shows the model with key components labeled.

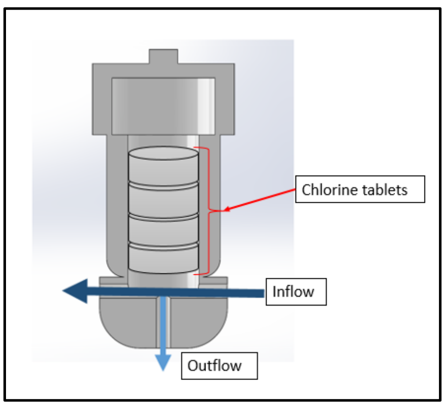


Figure 13: Current system for water chlorination

There are three holes around the circumference of the current chlorination system and a hole located at the bottom. Water flows from the storage tank outlet pipe to a Standard T style PVC pipe. Pictures CWC took of the current chlorination system can be found in Appendix K.

3.2 Hydraulic Model

A hydraulic model of the water distribution system was created using EPANET, which is a software that simulates water movement over an extended period of time. Listed in Table 10 in Appendix A is the surveying data provided by the Peace Corps volunteer that was used to design the distribution system. The system schematic of the EPANET hydraulic model can be seen in Figure 12.

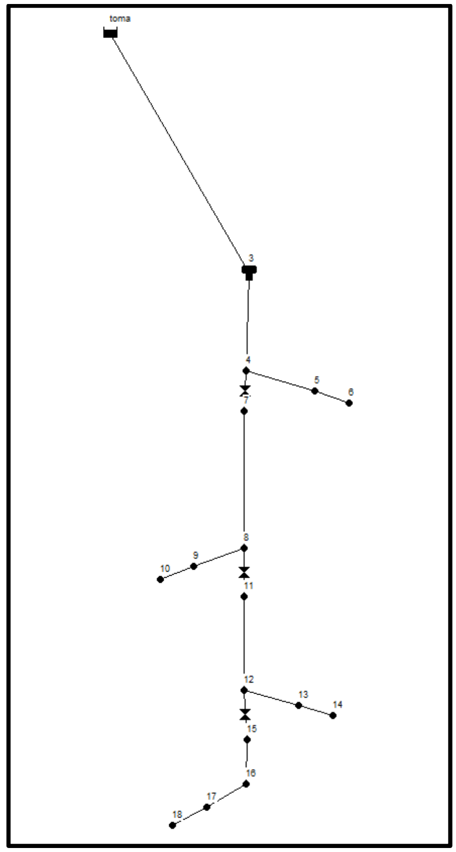


Figure 14: EPANET hydraulic model, network map of water distribution system

Household water demands were calculated based on eight people per house using 30 gallons per day per person, as suggested by MINSA [8]. This usage was converted to liters per minute (Lpm) per household as demonstrated in the equation below. This yields a base demand of 0.63 Lpm per household. It should be noted that the spring is capable of supplying this demand during the rainy season, with a discharge of 17.22 Lpm. The discharge from the spring in the dry season is only 0.34 Lpm; thus, the spring is not capable of supplying the suggested base demand.

$$\frac{30\ gal}{person * day} * \frac{8\ people}{household} * \frac{3.79\ L}{1\ gal} * \frac{1\ day}{24\ hr} * \frac{1\ hr}{60\ min} * \frac{1\ day}{24\ hr} = 0.63\ \frac{Lpm}{household}$$

A demand pattern that represents the water usage during a typical day is another useful parameter of EPANET. The demand pattern was determined based upon observations made during CWC's stay in the village. It was noted that water collection generally occurred during the morning after sunrise and again in the evening before sunset. As displayed in Figure 13, the demand pattern was determined to account for these peak water usages.

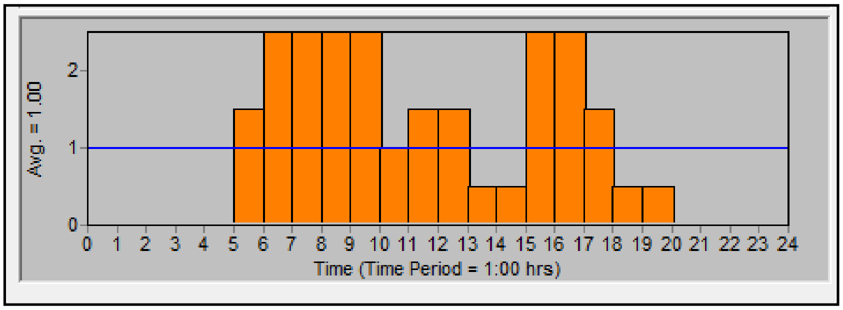


Figure 15: Water demand pattern over 24-hour period

The hydraulic model was utilized to analyze the performance of the water distribution system under various conditions. CWC was asked to evaluate the pressures at each faucet for given combinations of faucets being used simultaneously. According to the hydraulic model, the house located at the end of the distribution system, node 18 in Figure 12, experiences a pressure of 156 psi when all taps are closed. Table 6 shows the pressures at each node throughout the system when all taps are closed. The highlighted nodes are the taps. The pressures with varying open taps are shown in Appendix D. Since the pressure is much higher than the recommended tap pressure of 40-80 psi, CWC has researched flow reducing discs. More information on these discs can be found in section 3.3.4 of this report.

Table 5: Static pressure at nodes throughout system

Node	**6**	**10**	**14**	**18**
Pressure Head (psi)	27	84	87	156

At peak demand, which occurs in hours 7-10, and 16-17, the demand is still less than the inflow into the tank. Therefore, the tank overflows continuously and stays full at all times. This is shown in Figure 14.

3.3 Recommended System Improvements

CWC has compiled a set of recommendations to improve the current water distribution system. Details about these recommended system improvements is included in detail within this section.

3.3.1 Replace Piping

Much of the PVC pipe of the current system is exposed to the surface thus much more vulnerable to damage. An unburied system PVC system is especially vulnerable in the village's circumstances due to the regular storms and activity leading to occasional incidents damaging the system. Additionally, prolonged exposure to UV light could cause loss in impact strength [16]. Vinidex provides several guidelines for trench depth and width giving the outer diameter of the pipe [17]. Based off CWC recommends that damaged pipes need to be replaced and buried to improve the system's productivity and integrity. By doing this, the pipes are not continually exposed to UV and overall damage.

3.3.2 Redesign Lids

To replace the deteriorating lids, CWC designed a new lid to prevent contamination within the storage tank and spring box. The lid design was made following EPA's recommendations on hatches for drinking water. They recommend a frame around the opening at least 4 inches tall and a water tight seal on the lid. [Environmental Protection Agency, "EPA Region 8 Drinking Water Unit Tech Tips: Sanitary Protection of Reservoirs: Hatches] The new lid design entails the addition of a four-inch tall frame surrounding the opening of the storage tank. This frame is designed to prevent pooling water from entering the storage tank at the lid. The bottom portion of the lid will extend into the opening of the storage tank to ensure that it is positioned properly. A two-inch wide by half-inch thick neoprene gasket will be fixed around the lid to prevent water and vermin from entering. Finally, a handle is constructed from No. 4 rebar will enable easy removal of the lid.

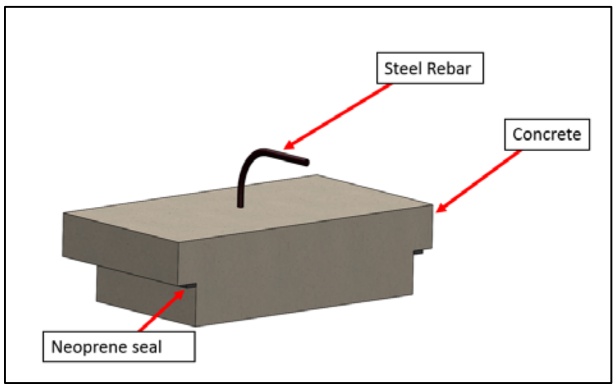


Figure 16: Cross section of new lid with key components outlined

Figure 17: Isometric view of spring box and storage tank lid

3.3.3 Install Valves

To easily access potentially broken pipes, it is suggested valves be installed. This would enable for sections of the pipe network to be turned off while the rest of the sections are still able to receive water. There are also valves along the main line of the system in order to keep water from continuing down the line if there is a break. The water will then be stored in the holding tank instead of wasted [16].

3.3.4 Pressure Reducing Discs

Within the designed pipe network the pressure head for the given sections of pipe are all within normal limits with exception to node 6. This is the final node in the system and it has a pressure head of 155 psi. This amount of pressure is well above the suggested operating pressure of 40-80 psi. A cost effective solution to this problem is installing pressure reducing discs into the pipe network within the section of pipe in incremental sections. A previous PCV in Panama, Brianna Drake, did research on these discs, in which CWC based their calculations on her work. The following equation was used to determine the size of the hole used in flow reducing discs [9]. CWC preferred this option because the use of these disks does not require widely varying pipe sizes to accommodate for the same pressure.

$$\Delta h = -\theta \frac{Q^2}{d^4}$$

Δh is the change in pressure, ϴ is a coefficient in Drake's report, Q is the flow in m^3/sec, and d is the diameter of the hole in the pressure reducing disk. Drake uses 0.68 for ϴ, refer to her report for more details.

$$0.195in * \frac{m}{39.3701in} = 0.004953m$$

$$\Delta h = -0.68 * \frac{\left(0.000125\frac{m^3}{s}\right)^2}{0.004953m^4} = 18m = 25\,psi$$

To reduce the costs to create the flow reducing disks, the CWC calculated for a pressure head decrease based of the diameter of available nails. This was done to simplify the process for the village. To cause a pressure drop of 25 psi, the shank diameter of the nail is 0.195 inches. CWC found a diameter of 0.195 inches would create a pressure relied for 25 psi. A disc is to be placed between nodes 8 and 9, between 12 and 13, and four discs between nodes 17 and 18. Adding these discs will give the pressure results shown in Table 7. Calculations that determined these values can be found in Appendix E.

Table 6: Reduced pressures at taps with use of flow reducing discs

Node	Pressure with no discs (psi)	Number of discs to be added	Pressure with discs (psi)
10	83.7	1	58.7
14	86.5	1	61.5
18	156.2	4	56

3.3.5 CTI Chlorinator

CWC suggests installing the, "CTI – 8 Chlorinator" as the main chlorination system. It is economical and simple, the CTI - 8 Chlorinator has valves and baffles to adjust the flow. [13] Though a preliminary study, it proves to be sustainable, eliminate all traces of bacteria, and greatly reduced the Acute Diarrheal Disease incidents. The system can be seen in Figure 14.

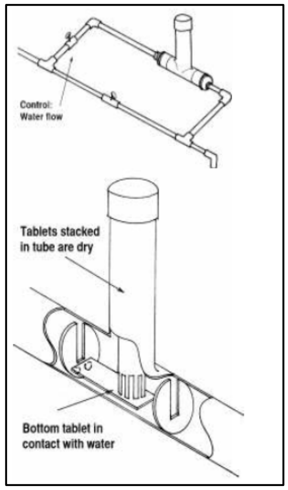


Figure 18: CTI chlorinator system schematic

This new chlorination apparatus will be installed upstream of the storage tank so the chlorine will have more contact time with the water. After the new chlorinator is in place, the old chlorinator will be properly disposed. The concentration time of chlorine was found to be 83.93 mg-min/L. This is more than adequate time to decontaminate the water of common harmful bacteria such as E. coli and other fecal bacteria. This calculation can be found in Appendix F. After installation, CWC recommends to the village to maintain the chlorine tablet count in the chlorinator to insure that it won't open the possibility of leaving water untreated.

3.3.6 Mesh Guard to cover Pipes

The EPA recommends that the tank overflow and ventilation pipes should be screened with #24 stainless steel mesh to keep vermin out of the supply system [12]. Their recommendation is based on the fact that # 24 mesh is sufficient at keeping numerous pests from infiltrating the system while allowing air and excess water to exit. They emphasize this because insects carry pathogens and many are capable of infiltrating meshes with larger spacing [12].

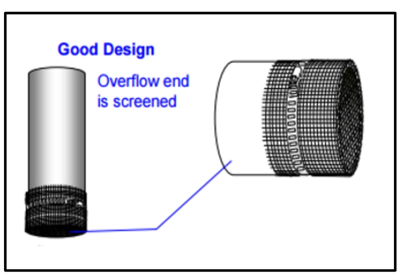


Figure 19: Schematic showing mesh over pipes

3.3.7. Tap Stands at Outflow

In order to ensure that the community members could obtain water from the aqueduct system CWC designed tap stands to be placed at the end of each branch of the aqueduct system. The tap stands will also ensure that the chlorinated water is being properly used, and not just left to run onto the ground. These tap stands will consist of PVC pipe, a ball valve, and concrete. Figure 20 shows a schematic of CWC's proposed tap stand design. This design was created because the basic geometric shapes will be easy to construct, and because the ball valve and PVC pipe are economically feasible and easy to replace if needed. In order to shape the concrete wooden molds will be used. A detailed procedure outlining the construction of the tap stands can be found in Appendix I. Care was taken to ensure that the outflow from the tap stands is adequate for the community members by having the outflow pipe diameter measure 12.7 mm.

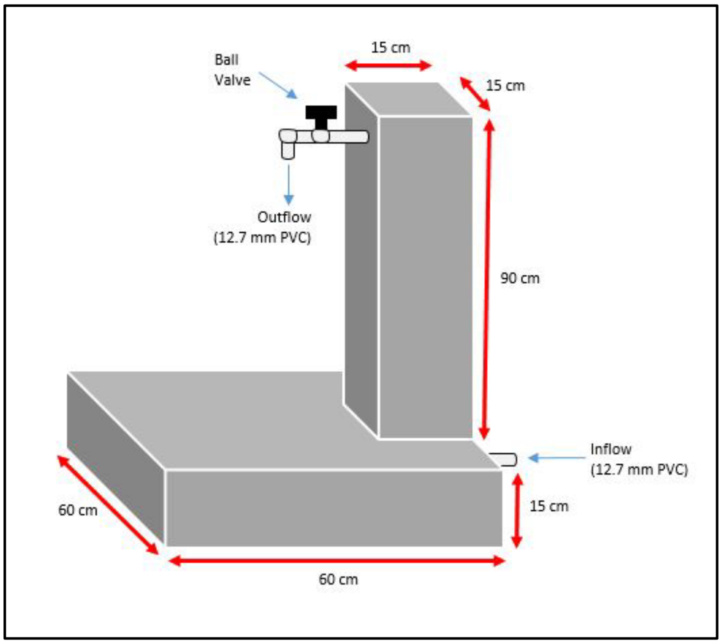


Figure 20: Proposed tap stand design

3.4 Runoff Diversion

Analyzing the boundaries and characteristics of the watershed is crucial to protect the water supply from contamination. Located directly upstream of the spring box is another spring that is used by a neighboring farmer to water his cattle, posing the risk of fecal contamination. Preventing the farmer from using this spring as a watering hole will be a challenge since the watering hole is located on his land. This same spring that is located on the farmer's land is also used by the nearby household for bathing and washing laundry, posing as another source of contamination. It is also our assumption that the stream from this watering hole may be used for open defecation, as the nearby home did not have a latrine or other sources of water. Eliminating these potential sources of contamination involve restricting the use the watering hole for laundry, bathing, and defecating. Latrine placement should be kept a minimum of 100 meters away from the drinking water source, as suggested by the Ministerio de Salud de la Republica de Panama (MINSA) [8].

Due to runoff water running alongside and on top of the spring box, CWC fears that it will contaminate the spring water used for the community. For this reason they wish to divert it away from the spring box. Figure 21 shows the current state of the system. Figure 22 shows a conceptual sketch of what the team proposes to be done.

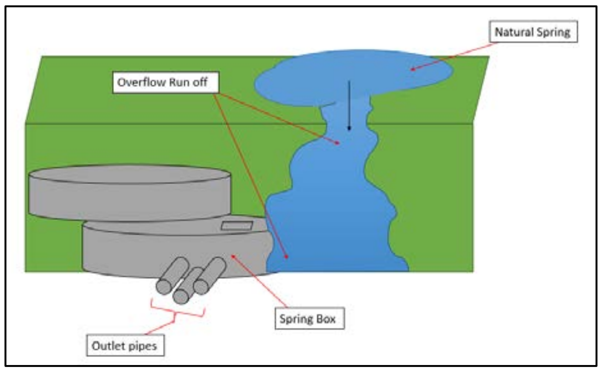


Figure 21: Current state of above spring runoff

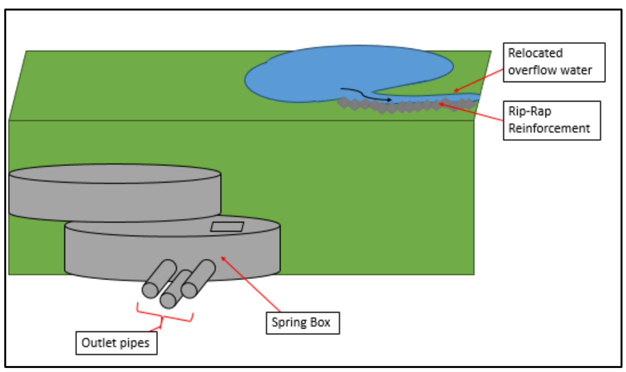


Figure 22: Suggested runoff diversion

The CWC team also thought that it would be wise to add a reinforcement along the side of the slope made out of concrete blocks. It is suggested that about twelve to thirteen inches is dug out and the blocks placed in order to help inforce that side of the hill and prevent the run off to overflow from the created trench during the rainy season.

To estimate the amount of water the trench needs to divert, CWC has calculated the peak discharge of runoff from the watershed for a given design storm. For this calculation, the runoff coefficient was assumed to be 0.62 due to a high clay content and light prairie grass [15]. The most intense rainfall in David, Panama in the last five years occurred in November 2010. This storm had a rainfall intensity is 178 mm/day [14]. Using this intensity, a runoff coefficient of 0.62, and the watershed area of 54,734 square meters, the peak discharge is 70 L/s. This calculation can be found in Appendix G.

The CWC team also thought that riprap should be placed along the trench diverting the runoff. The riprap should form a layer along the sides of the trench to reduce the intensity of the runoff concentrated in the trench and reduce the erosion expected from the flow otherwise. It does this by disrupting the flow coming across it, reducing the velocity and helps sequentially stabilizes the slope.

The rip rap should consist of a layer of large loose angular stones, because they cause more friction in contrast to streamline stones. Before installation, the vegetation, roots, and debris needs to be removed from the subgrade [19]. Annually and after every major storm, the riprap needs to be checked to make sure if the stones need to be replaced; new disruptions and obstructions should be cleared to avoid changing the flow patterns [19].

4.0 Materials and Labor Costs

The design recommendations are broken into the following five main categories: Piping improvements, chlorinator improvements, lid improvements, tap stand construction, and tools and equipment. The total cost of the various materials and the overall materials cost can be seen below in Table 7. This breakdown allows the community to see the costs associated with each category. This can allow for the community to select specific parts of the project to be completed at different times if funding the project all at once is not possible.

Table 7: Breakdown of key material component costs

Task	Price
Piping Improvements	$ 4,350.00
Chlorinator Improvement	$ 100.00
Lid Improvements	$ 255.00
Tap Stands	$ 200.00
Tools and Equipment	$ 680.00
Total	$ 5,585.00

Table 9 outlines the labor costs associated with the construction. The overall labor costs total $1,552.00, but CWC is assuming that the majority of unskilled labor will be volunteered from the community. The labor cost was estimated to associate a monetary value to the efforts being contributed by the community members. This total labor cost was calculated assuming a laborer makes eight dollars a day. The greatest individual improvement will be purchasing the pipe, as well as the labor associated with laying it. There is approximately 1,200 meters of pipe to install.

Table 8: Breakdown of key labor tasks costs

Task	Work hours	Labor Value
Buy and Transport Materials	26	$ 208.00
Runoff Diversion	32	$ 256.00
Existing Storage Tank Updates	24	$ 192.00
Piping	108	$ 864.00
Total	**190**	**$ 1,520.00**

5.0 Construction Schedule

From talking with the local PCV and through observations of the construction site, CWC has determined the following schedule in order to complete the work of updating and installing the chlorination and pipe network system. The construction schedule Gantt chart can be found in Appendix H.

In addition, a construction and maintenance manual has been provided for the Quebrada Caracol water distribution system. This manual includes preparation and installation procedures for each component of the system, such as trench digging, PVC pipe installation, creating molds, and mixing the concrete. The team estimates the total project time taking about 35 work days to complete with eight workers working 30 hours per week on the project. A detailed construction schedule can be found in Appendix I. The team estimates the workers working only Monday through Friday, as they take Saturday's off for religious reasons and then Sunday's off for time to be with family.

It should be noted that the community members will be involved with this process as much as possible. Through their involvement, it is hoped that they have a greater sense of ownership of the project. Although they will not be paid individually, their work hours are converted to a dollar amount to show how invested the community would be when this project is implemented. The detailed construction and maintenance manual can be seen in Appendix J. The detailed labor cost breakdown can be seen in Appendix F.

6.0 Conclusion

The team now presents this final report with suggested updates, and project planning detail. This should help to supply the community of Quebrada Caracol with drinking water that they can drink without fear of bacterial contaminants commonly found in untreated water. The goal for this project was to protect the water supply of the community of Quebrada Caracol. This goal has been achieved, as Clean Water Consultants have provided recommendations of improvements to be made to the water distribution system. These improvements include replacing the existing piping, creating new lids for the storage tank and spring box, installing a new chlorinator upstream of the storage tank, and constructing tap stands at each of the homes to be serviced.

To protect the spring that supplies the water distribution system, a new lid to fully cover the opening is recommended. A second lid will also be created for the water storage tank. A nearby unprotected spring flows on and near the spring box. This is a potential cause of contamination. To eliminate this potential contamination, it is recommended that this water be diverted by a trench to be dug so that the water flows away from the spring and spring box.

CWC's design for Quebrada Caracol includes extending the current water distribution system from servicing one home to servicing four homes. The piping will be properly installed, buried twelve inches below the ground and will utilize proper fittings. A new chlorination system will be installed upstream of the storage tank to adequately disinfect the water of disease causing bacteria. Tap stands are recommended at each home that the system services. At three of the four houses, the pressure at the taps were found to be too high for taps. Flow reducing discs are recommended to be added between the main pipeline and the taps to reduce the pressure. Valves will be installed throughout the system to make maintenance easier. If a pipe breaks, the valve upstream of the break can be turned to off and the water flow will cease.

The construction time of this project is estimated to be about 35 days. The community will be volunteering their time as laborers as their monetary contribution to this project. Hypothetical labor costs total $1,550.00. Material costs for this project are estimated to be $5,588.00.

To be sure the system is sustainable, maintenance is extremely important. Regular cleanings of the storage tank and check-ups of the chlorinator are crucial. New chlorine tablets will need to be placed in the chlorinator once a month in order to ensure safe drinking water for the users.

7.0 References

1. Miller, Leigh. "Quebrada Caracol Analysis and Development Plan." (2015). Print.
2. "3M™ Petrifilm™ Aerobic Count Plates." *3M™ Food Safety Website – Product Catalog:* . N.p., 2015. Web. 20 Aug. 2015.3M.
3. "3M™ Petrifilm™ E.coli/Coliform Count Plates." *3M™ Food Safety Website – Product Catalog:* . N.p., 2015. Web. 20 Aug. 2015.
4. "3M™ Petrifilm™ Enterobacteriaceae Count Plates." *3M™ Food Safety Website – Product Catalog:* . N.p., 2015. Web. 20 Aug. 2015.
5. "Drinking Water Contaminants." *United State Environmental Protection Agency*. N.p., 29 Oct. 2014. Web. 16 Sept. 2015. <http://water.epa.gov/drink/contaminants/#Microorganisms>.
6. "Shigella Food Poisoning." *About Shigella*. Ed. Marler Clark. N.p., n.d. Web. 28 Oct. 2015. <http://www.about-shigella.com/>.
7. "Typhoid Fever." *Health Topics*. World Health Organization, n.d. Web. 28 Oct. 2015. <http://www.who.int/topics/typhoid_fever/en/>.
8. Waite, Marilyn. *Sustainable Water Resources in the Built Environment*. N.p.: IWA Publishing, 2010. 162-64. Web. 16 Sept. 2015. <https://books.google.com/books?id=MeYmo5L6ecEC&pg=PA162&lpg=PA162&dq=panamanian+drinking+water+standards&source=bl&ots=mwwKdBy054&sig=vS_bNlMhaPRkJvBp1PySoR1gFAI&hl=en&sa=X&ved=0CD0Q6AEwBWoVChMIj72x08>.
9. "What Is a Watershed?" *EPA*. N.p., n.d. Web. 25 Aug. 2015. <http://water.epa.gov/type/watersheds/whatis.cfm>.
10. EasyGPS. Computer software. EasyGPS. Vers. 5.48. TopoGrafix, 17 Aug. 2015. Web. 20 Aug. 2015. <http://www.easygps.com/>.
11. "Watershed." 8.304753 N and 81.819357 W. Google Earth. March 5, 2006. August 20, 2015.
12. Environmental Protection Agency, 'EPA Region 8 Drinking Water Unit Tech Tips, Sanitary Protection of Drinking Water Storage Tanks: # 24 Mesh Non-corrodible Screen'. [Online] Available:http://www2.epa.gov/sites/production/files/2014-05/documents/tech_tip_24_mesh_screen.pdf. [Accessed: 28-Sep-2015].
13. Compatible Technology International, 'Effectiveness of CTI Water Chlorinator at controlling bacterial contamination in rural Nicaragua's drinking water', 2015. [Online]. Available: http://www.compatibletechnology.org/images/Nicaragua%20Water%20Study%20.pdf. [Accessed: 21- Sep- 2015].
14. *Empresa de Transmision Electrica, S.A.*. Unimos Panama con Energia, n.d. Web. 18 Nov. 2015.

<http://www.hidromet.com.pa/datos_diarios.php?estacion=6&mes=11&ano=2010>.

15. *Rational Equation Calculator*. LMNO Engineering, Research, and Software, Ltd., n.d. Web. 18 Nov. 2015. <http://www.lmnoeng.com/Hydrology/rational.php>.
16. Learned and Job, '10 in. Round Valve Box in Black/Green-53211 - The Home Depot', *The Home Depot*, 2015. [Online]. Available: http://www.homedepot.com/p/Orbit-10-in-Round-Valve-Box-in-Black-Green-53211/202206747. [Accessed: 06- Dec- 2015].
17. "Above Ground Installation for PVC Pipe." *Vindex Pty Ltd.* N.p., n.d. Web. 9 Nov. 2015. <http://www.vinidex.com.au/technical/pvc-pressure-pipe/above-ground-installation-for-pvc-pipe>
18. "Below Ground Installation." *Vindex Pty Ltd.* N.p., n.d. Web. 9 Nov. 2015. http://www.vinidex.com.au/technical/pvc-pressure-pipe/below-ground-installation/
19. "Riprap" *Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas*. N.p., n.d. Web. 9 Dec. 2015. <lshs.tamu.edu/docs/lshs/end-notes/riprap-2389874252/riprap.pdf>.

8.0 Appendices

Appendix A: Waypoint Markings

Table 9: Surveying waypoints

Waypoint	Latitude (ddd.hhh)	Longitude (ddd.hhh)	Elevation (m)	Time
1	N 08.30453	W 081.82073	420	11:07 AM
2	N 08.30462	W 081.82057	422	11:10 AM
3	N 08.30470	W 081.82045	426	11:12 AM
4	N 08.30484	W 081.82029	428	11:13 AM
5	N 08.30499	W 081.82002	435	11:15 AM
6	N 08.30504	W 081.81985	438	11:24 AM
7	N 08.30518	W 081.81974	441	11:26 AM
8	N 08.30529	W 081.81956	442	11:28 AM
9	N 08.30534	W 081.81937	445	11:30 AM
10	N 08.30534	W 081.81916	451	11:33 AM
11	N 08.30531	W 081.81896	453	11:35 AM
12	N 08.30527	W 081.81872	456	11:39 AM
13	N 08.30524	W 081.81858	460	11:43 AM
14	N 08.30526	W 081.81839	466	11:46 AM
15	N 08.30545	W 081.81824	473	11:49 AM
16	N 08.30567	W 081.81821	483	11:56 AM
17	N 08.30573	W 081.81794	490	12:00 PM
18	N 08.30581	W 081.81755	492	12:17 PM
19	N 08.30566	W 081.81746	489	12:19 PM
20	N 08.30538	W 081.81792	484	12:23 PM
21	N 08.30528	W 081.81820	472	12:25 PM
22	N 08.30503	W 081.81836	467	12:29 PM
23	N 08.30519	W 081.81829	468	12:31 PM
24	N 08.30512	W 081.81796	471	12:39 PM
25	N 08.30488	W 081.81826	461	12:45 PM
26	N 08.30466	W 081.81818	453	12:47 PM
27	N 08.30466	W 081.81819	453	12:47 PM
28	N 08.30446	W 081.81811	449	12:49 PM
29	N 08.30429	W 081.81833	431	1:00 PM
30	N 08.30428	W 081.81847	428	1:01 PM
31	N 08.30415	W 081.81865	425	1:03 PM
32	N 08.30401	W 081.81888	418	1:07 PM
33	N 08.30390	W 081.81902	411	1:09 PM
34	N 08.30438	W 081.82081	408	8:31 AM
35	N.A.	N.A.	N.A.	N.A.
36	N 08.30387	W 081.81914	410	8:53 AM
37	N 08.30386	W 081.81927	408	8:56 AM
38	N 08.30384	W 081.81947	407	9:03 AM
39	N 08.30391	W 081.81964	403	9:07 AM
40	N 08.30392	W 081.81978	399	9:13 AM

Waypoint	Latitude (ddd.hhh)	Longitude (ddd.hhh)	Elevation (m)	Time
41	N 08.30390	W 081.81985	395	9:15 AM
42	N 08.30391	W 081.82005	387	9:19 AM
43	N 08.30388	W 081.82011	385	9:21 AM
44	N 08.30383	W 081.82020	380	9:24 AM
45	N.A.	N.A.	N.A.	N.A.
46	N 08.30399	W 081.82011	385	9:43 AM
47	N 08.30402	W 081.82011	385	9:44 AM
48	N 08.30407	W 081.82008	384	9:45 AM
49	N 08.30411	W 081.82011	386	9:46 AM
50	N 08.30414	W 081.82028	386	9:46 AM
51	N 08.30412	W 081.82047	387	9:47 AM
52	N 08.30412	W 081.82067	386	9:48 AM
53	N 08.30416	W 081.82086	395	9:49 AM
54	N 08.30416	W 081.82009	391	9:57 AM
55	N 08.30409	W 081.82009	391	9:57 AM
56	N 08.30407	W 081.82009	391	9:57 AM
57	N 08.30406	W 081.82011	391	9:57 AM
58	N.A.	N.A.	N.A.	N.A.
59	N 08.30398	W 081.82009	392	9:59 AM
60	N 08.30396	W 081.82003	393	10:00 AM
61	N 08.30395	W 081.82002	392	10:00 AM
62	N 08.30394	W 081.82000	391	10:01 AM
63	N 08.30452	W 081.82037	430	10:09 AM
64	N 08.30452	W 081.82058	419	10:09 AM
65	N 08.30453	W 081.82050	417	10:10 AM
66	N 08.30453	W 081.82022	418	10:12 AM
67	N 08.30450	W 081.81993	415	10:13 AM
68	N 08.30443	W 081.81973	410	10:13 AM
69	N 08.30410	W 081.81964	408	10:13 AM
70	N 08.30402	W 081.81960	408	10:14 AM
71	N 08.30393	W 081.81953	405	10:14 AM
72	N 08.30390	W 081.81945	405	10:15 AM
73	N 08.30402	W 081.81901	408	10:17 AM
74	N 08.30410	W 081.81899	410	10:18 AM
75	N 08.30425	W 081.81903	415	10:18 AM
76	N 08.30439	W 081.81909	416	10:19 AM
77	N 08.30450	W 081.81918	420	10:19 AM
78	N 08.30470	W 081.81931	423	10:20 AM
79	N 08.30475	W 081.81941	425	10:20 AM
80	N 08.30480	W 081.81952	426	10:21 AM

Table 10: Key points in system defined

Waypoint	Latitude (ddd.hhh)	Longitude (ddd.hhh)	Elevation (m)	Time
IACQ	N 08.29618	W 081.81891	216	N.A.
Lunch	N 08.30260	W 081.81810	402	N.A.
Out	N 08.29722	W 081.82038	237	11:37 AM
Tank	N 08.30008	W 081.81937	282	N.A.
Toma	N 08.30397	W 081.82022	380	N.A.

Table 11: Control GPS data at spring box taken August 14, 2015

Time	Elevation (m)	ΔElevation (m)
10:45 AM	385	
10:55 AM	379	-6
11:05 AM	389	4
11:10 AM	388	3
11:15 AM	388	3
11:20 AM	384	-1
11:25 AM	390	5
11:30 AM	386	1
11:35 AM	389	4
11:40 AM	384	-1
11:45 AM	382	-3
11:50 AM	381	-4
11:55 AM	384	-1
12:00 PM	389	4
12:05 PM	389	4
12:10 PM	393	8
12:15 PM	391	6
12:20 PM	390	5

Table 12: Control GPS data at spring box taken August 15, 2015

Time	Elevation (m)	ΔElevation (m)
8:40 AM	401	-16
8:45 AM	381	4
8:50 AM	384	1
8:55 AM	384	1
9:00 AM	383	2
9:05 AM	387	-2
9:10 AM	398	-13
9:15 AM	393	-8
9:20 AM	389	-4
9:25 AM	391	-6

Table 13: Conduction line for water distribution system in Quebrada Caracol

Start Point	End Point	Horiz. Dist. (m)	Vert. Dist. (cm)	Up or Down	Comments
Toma	1	9	150	d	Spring box fence
1	2	5	166	d	Shade
2	3	5	156	d	*New 45 elbow needed
3	4	6	163	u	
4	5	10	135	d	Big tree
5	6	11	200	d	
6	7	30	154	d	Creek, big tree
7	8	12	190	d	
8	9	8	176	d	
9	10	3	177	d	Beginning of hill
10	11	2	110	d	
11	12	3	185	d	
12	13	4	180	d	
13	14	3	187	d	
14	15	4	183	d	
15	16	3	187	d	
16	17	4	174	d	
17	18	4	200	d	
18	19	4	178	d	
19	20	4	182	d	

Start Point	End Point	Horiz. Dist. (m)	Vert. Dist. (cm)	Up or Down	Comments
20	21	4	179	d	
21	22	6	188	d	
22	23	5	176	d	
23	24	4	180	d	
24	25	3	174	d	
25	26	2	183	d	Shade, little cliff
26	27	4	187	d	Wire fence
27	28	3	179	d	Big tree
28	29	4	170	d	
29	30	5	185	d	
30	31	6	195	d	
31	32	5	183	d	
32	33	6	184	d	
33	34	6	188	d	
34	35	5	190	d	
35	36	4	170	d	
36	37	3	170	d	*New elbow, beginning of bridge
37	38	3	180	d	*Additional support needed
38	39	6	189	d	
39	40	4	110	d	
40	41	4	191	d	
41	42	25	173	d	*New elbow, end of bridge
42	43	13	170	d	Farm
43	44	13	166	d	
44	45	12	172	d	
45	46	25	180	d	Amado's fence
46	49	15	173	d	
49	50	31	78	d	
50	51	31	146	u	
51	52	31	0	u	
52	Tank	23	200	d	
Caracol Mini-distribution system (Elvia, Narciso, Eliseo, Celmira)					
Tank	53	31	112	d	
53	55	31	113	d	By Juanita's house
55	56	12	164	d	
56	57	8	179	d	
57	58	10	190	d	
58	59	25	100	u	
59	72	19	190	d	

Start Point	End Point	Horiz. Dist. (m)	Vert. Dist. (cm)	Up or Down	Comments
72	73	9	184	d	
73	74	18	185	d	
74	75	3	34	d	*New branch for Elvia
75	76	9	182	d	
76	77	4	155	d	
77	78	5	179	d	
78	79	8	160	d	
79	80	31	149	d	
80	81	7	30	u	*New faucet for Elvia
74	82	8	180	d	
82	83	11	193	d	
83	84	10	200	d	
84	85	12	166	d	
85	86	14	161	d	
86	87	10	179	d	
87	88	11	182	d	
88	89	14	172	d	
89	90	12	200	d	
90	91	13	181	d	
91	92	12	200	d	
92	93	8	176	d	
93	94	6	192	d	
94	95	8	195	d	
95	96	8	175	d	*Burned tube, 1m
96	97	7	115	d	*Burned tube, burned tee, 2m
97	98	9	150	d	
98	99	9	188	d	*Burned tube, 1m
99	100	8	200	d	
100	101	7	166	d	
101	102	8	165	d	
102	103	6	163	d	*Burned tube, 1m
103	104	8	200	d	Trail
104	105	8	174	d	
105	106	7	112	d	Branch of Narciso
106	107	14	182	d	
107	108	36	114	d	Faucet of Narciso
105	109	14	188	d	
109	110	9	157	d	
110	111	9	200	d	Fence

Start Point	End Point	Horiz. Dist. (m)	Vert. Dist. (cm)	Up or Down	Comments
111	112	10	186	d	
112	113	11	123	d	Branch of Eliseo
113	114	33	-50	u	
114	115	25	-70	u	Faucet of Eliseo
113	116	19	170	d	
116	117	16	174	d	
117	118	31	150	d	Branch of Celmira, 2m
118	122	29	175	d	

Appendix B: Photos of Incubated Count Plates

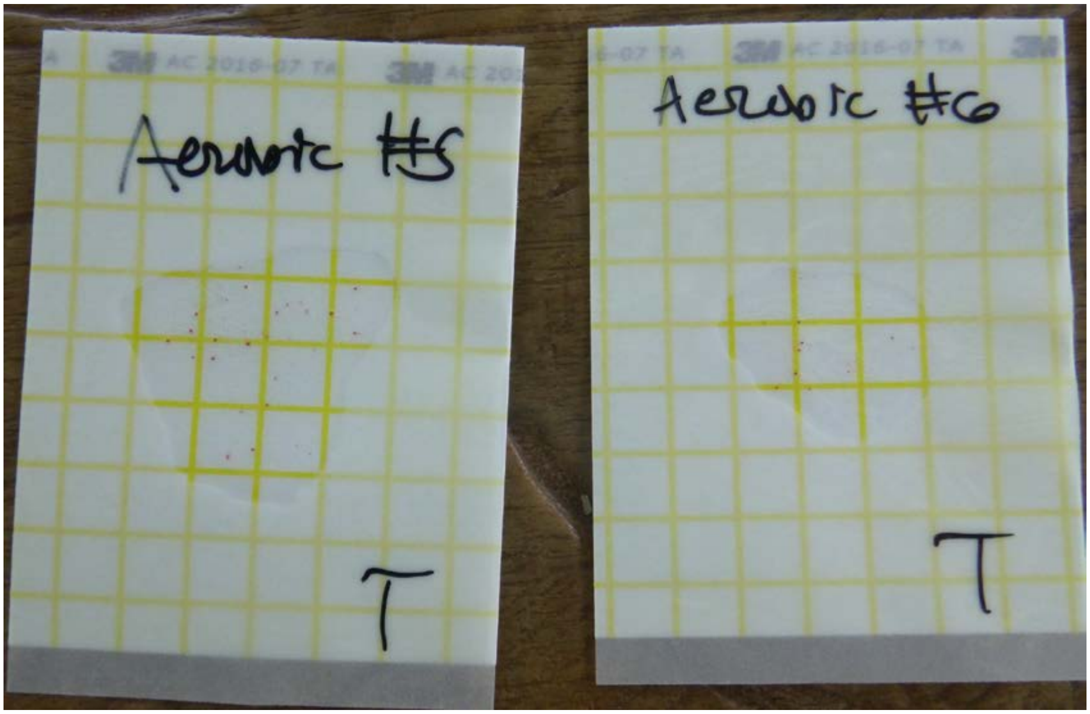


Figure 23: Aerobic bacteria count plate example from the spring box

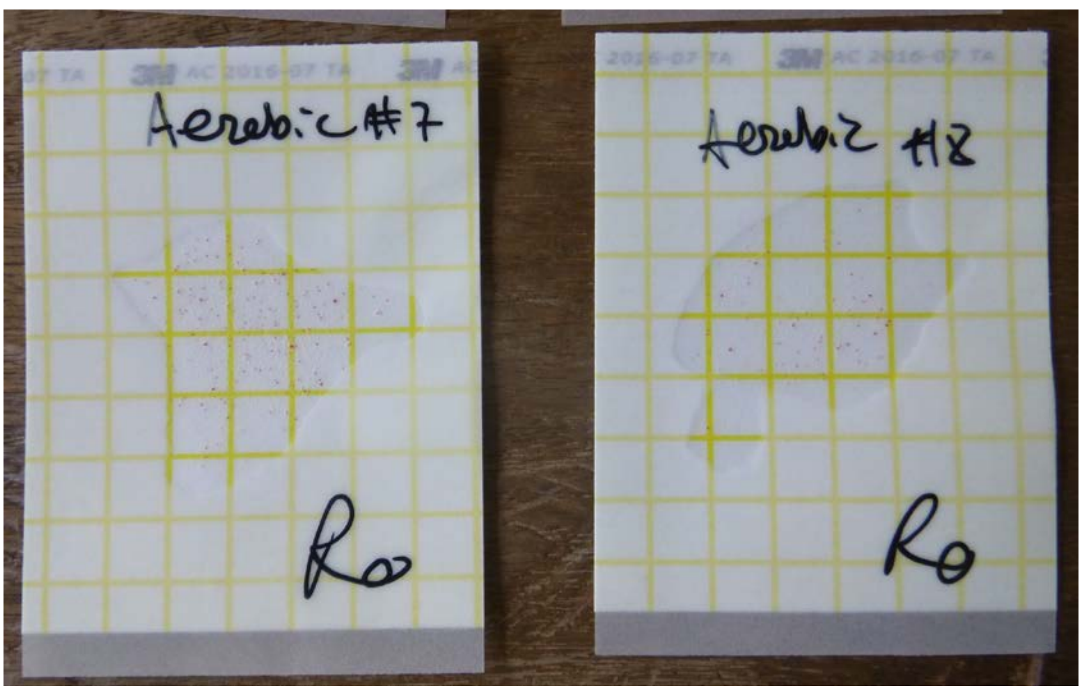


Figure 24: Aerobic bacteria count plate example from the runoff

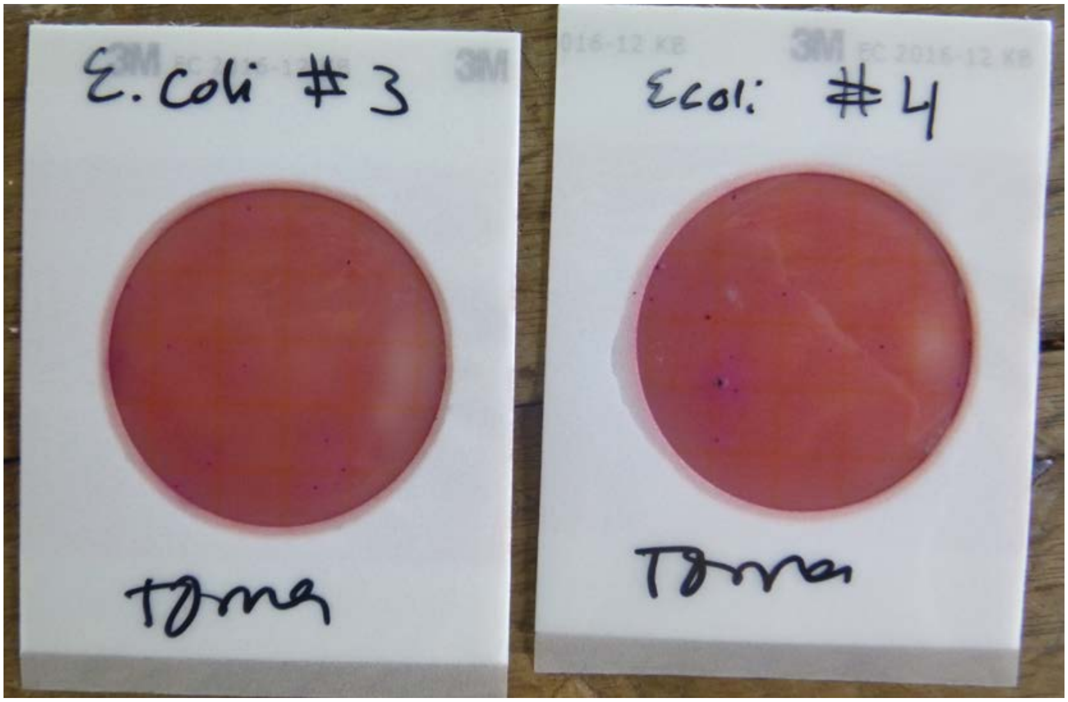


Figure 25: E.coli/coliform count plate example from the spring box

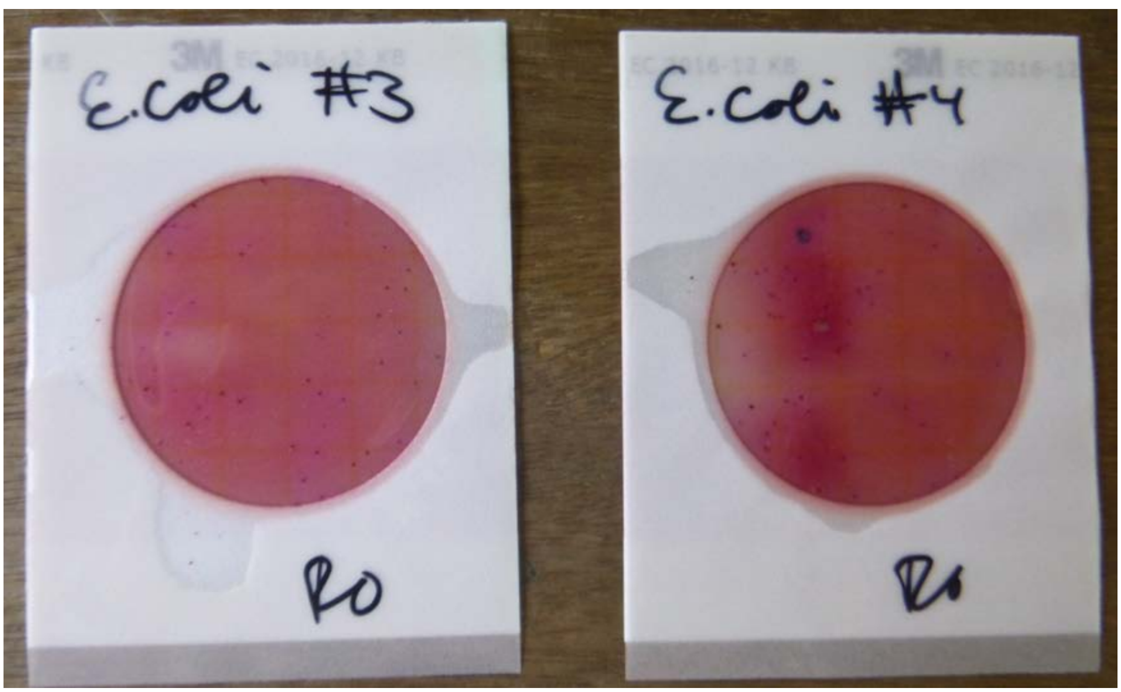


Figure 26: E.coli/coliform count plate example from the runoff

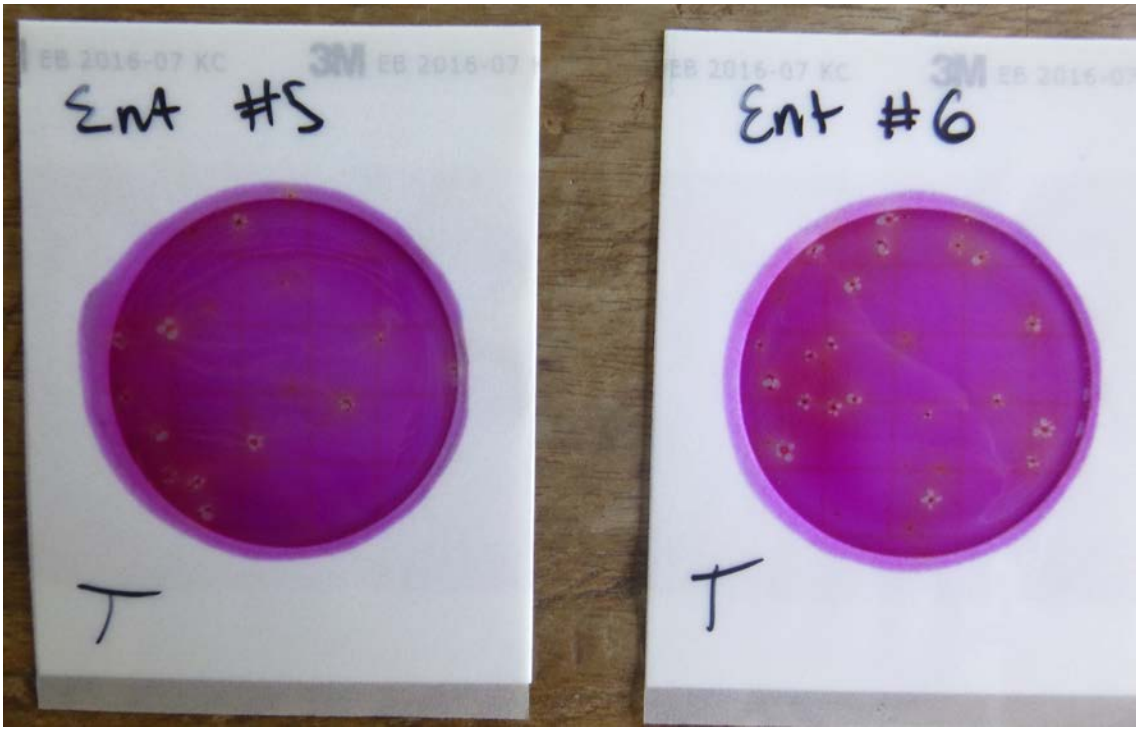


Figure 27: Enterobacteriaceae count plate example from the spring box

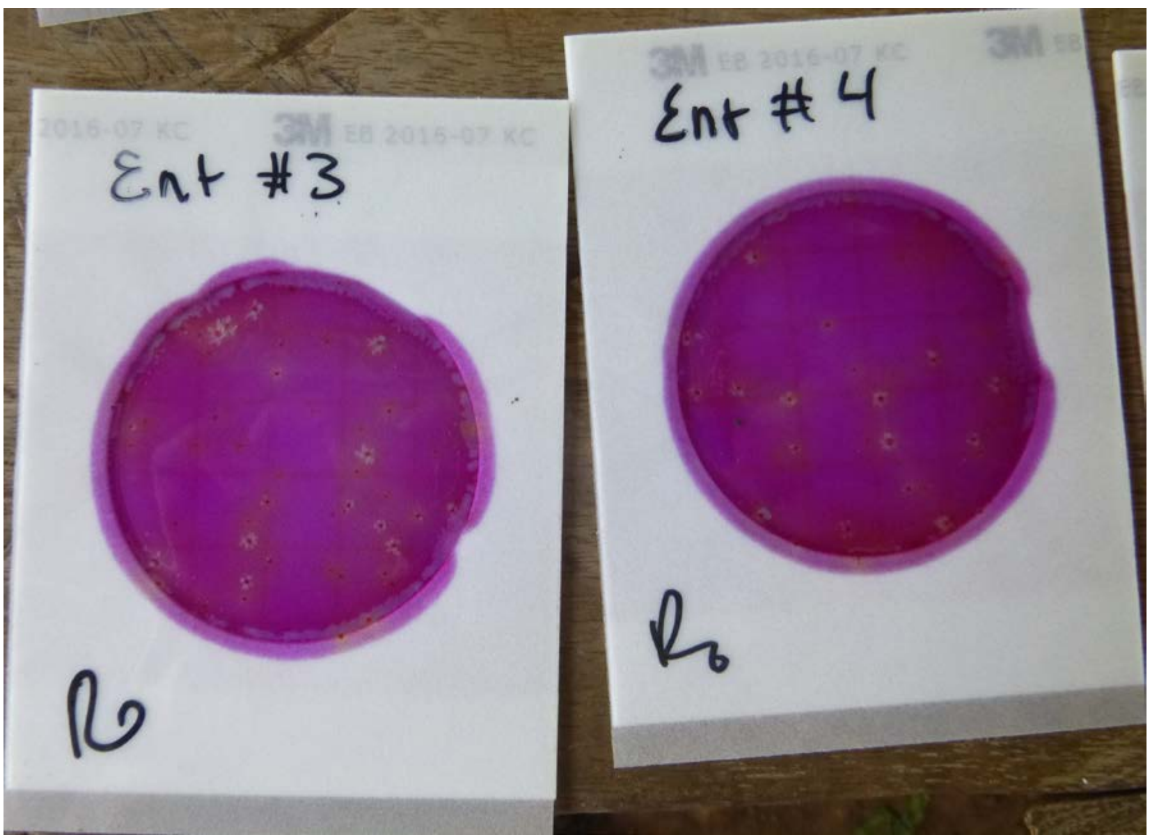
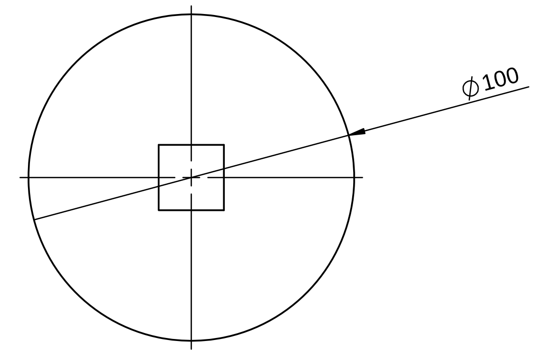
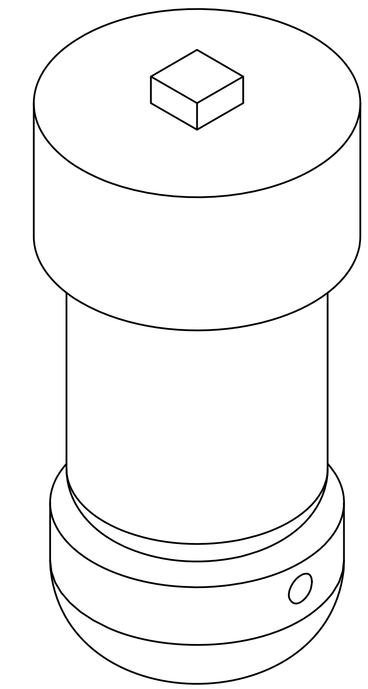


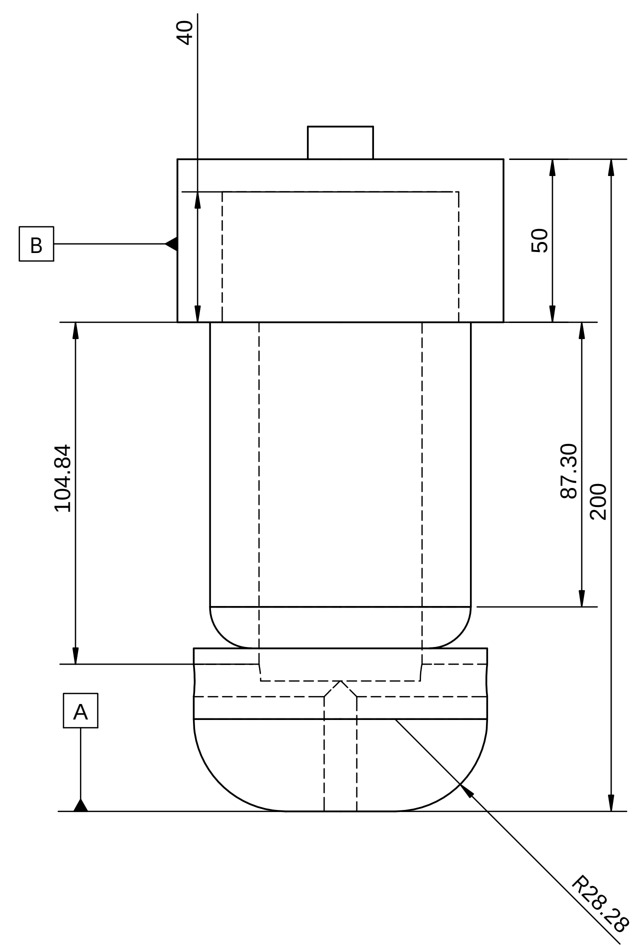
Figure 28: Enterobacteriaceae count plate example from the runoff

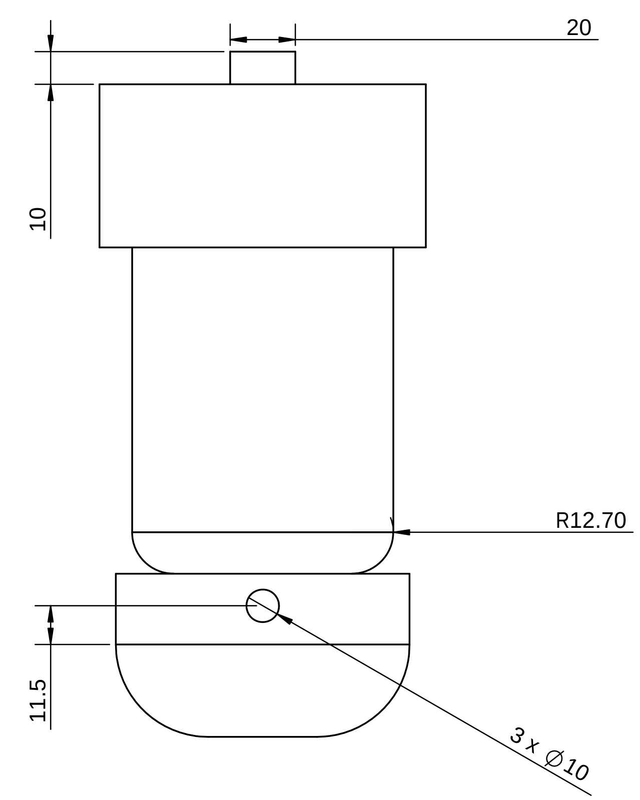
Appendix C: SOLIDWORKS Detailed Drawings

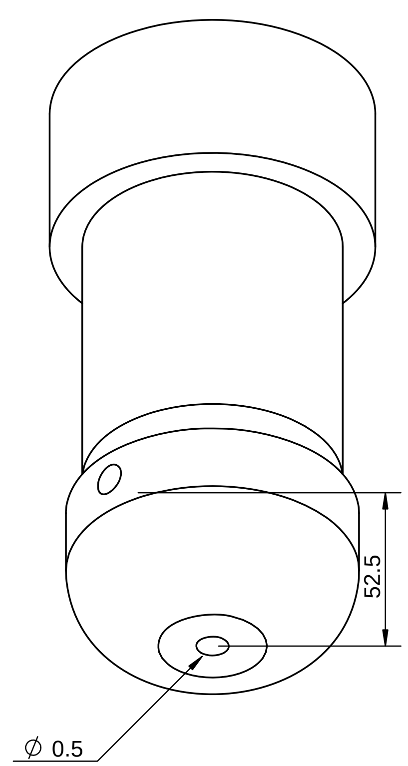
NOTES:
1. User drops tablets by unscrewing the top of the Chlorine Tablet. There is room for maximum of two tablets at a time.
2. Water enters chamber through holes on side of the holder. There are a total of three of these holes.
3. Chlorinated water exits the chamber from the bottom of the holder.
4. Water with chlorine continues to flow down the pipe system.



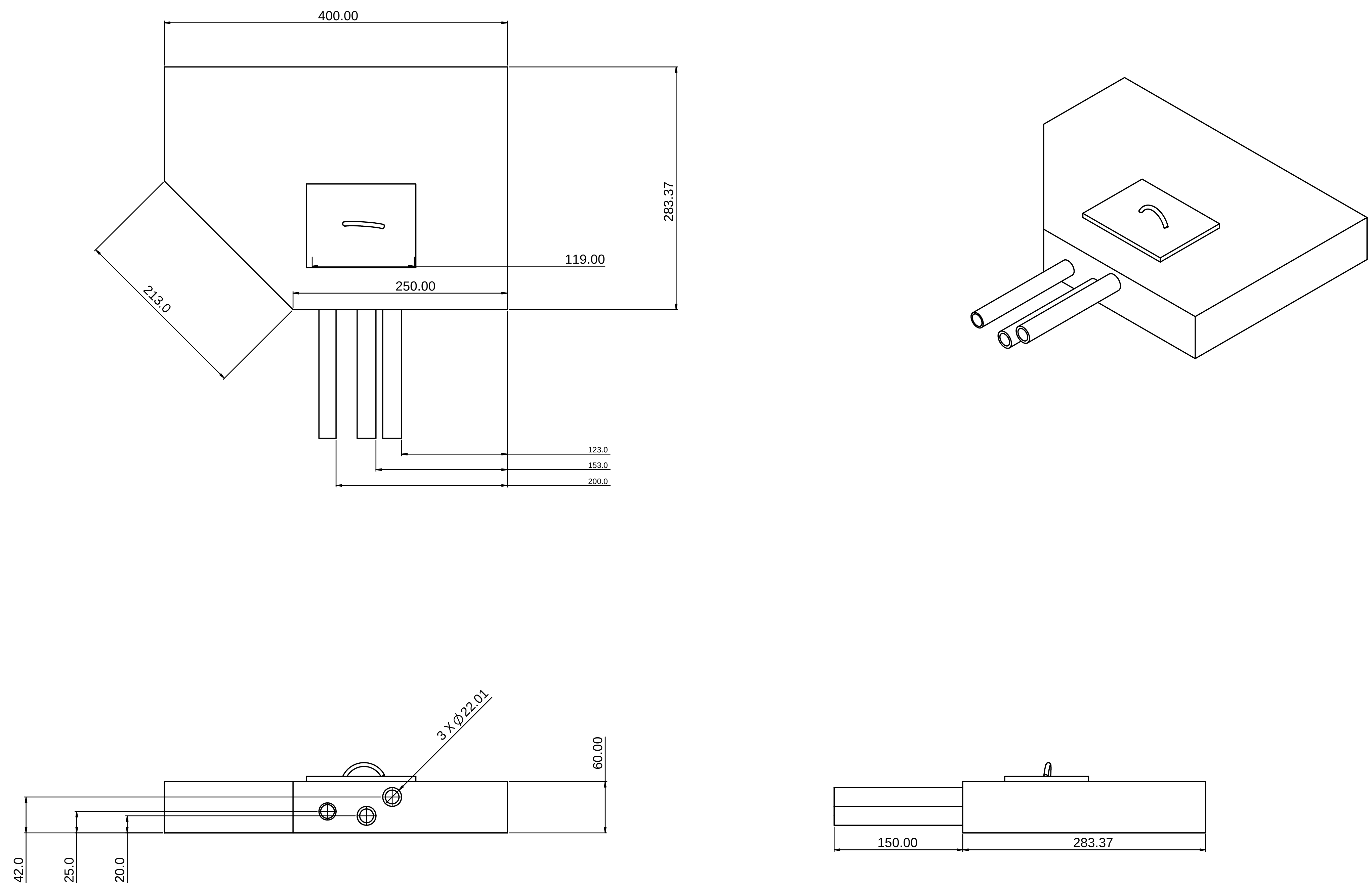








		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	E. Wohlford		
			CHECKED			TITLE:
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE C DWG. NO. ChlorineTabletHolder REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

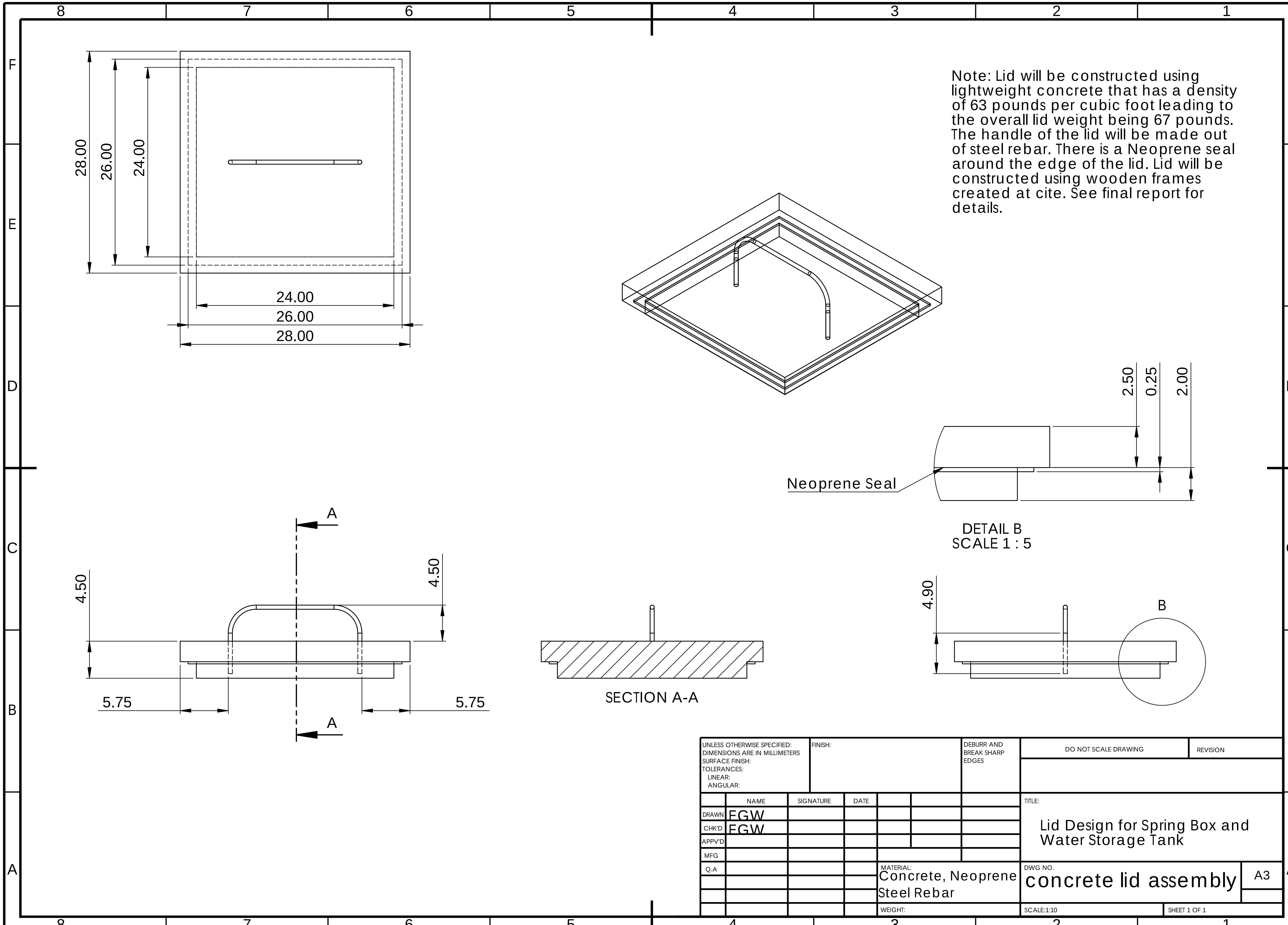
DWG NO. Toma

A0

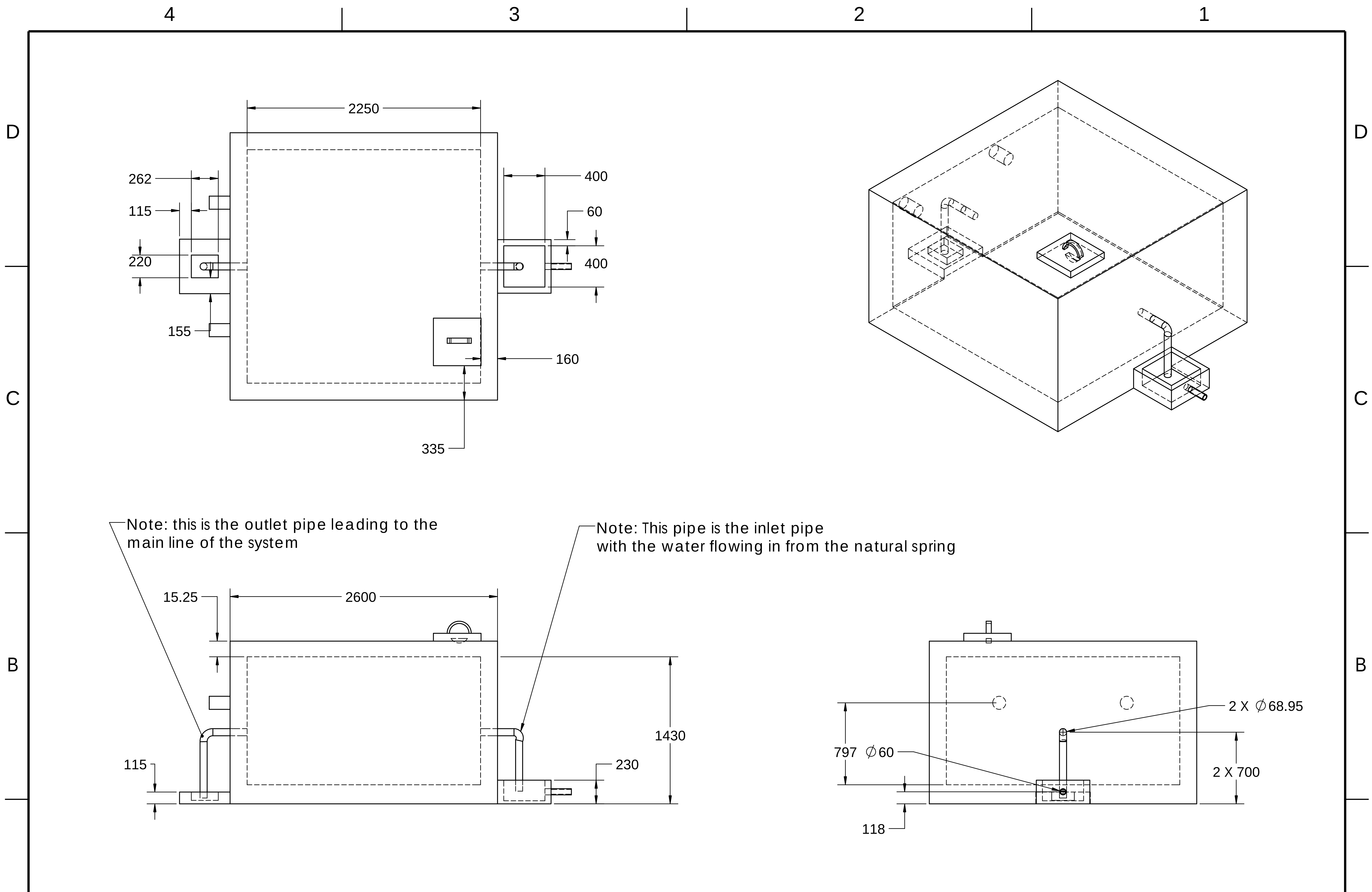
WEIGHT:

SCALE:1:100

SHEET 1 OF 1



28.00
26.00
24.00
24.00
26.00
28.00
Note: Lid will be constructed using lightweight concrete that has a density of 63 pounds per cubic foot leading to the overall lid weight being 67 pounds. The handle of the lid will be made out of steel rebar. There is a Neoprene seal around the edge of the lid. Lid will be constructed using wooden frames created at cite. See final report for details.
2.50
0.25
2.00
Neoprene Seal
DETAIL B
SCALE 1 : 5
A
4.50
4.50
5.75
5.75
A
SECTION A-A
4.90
B
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN EGW
CHK'D EGW
APPV'D
MFG
Q.A
TITLE:
Lid Design for Spring Box and Water Storage Tank
MATERIAL:
Concrete, Neoprene
Steel Rebar
WEIGHT:
DWG NO.
concrete lid assembly
A3
SCALE:1:10
SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	EGW	
CHECKED	EGW	
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
C	HoldingTank	

SCALE: 1:48 WEIGHT: SHEET 1 OF 1

Appendix D: Pressure Table with Various Taps Open

Table 14: Pressures with varying open taps via EPANET analysis

Situation	Node	Pressure (PSI)
6 open	6	17.01
	10	83.54
	14	86.38
	18	156.1
6 & 10 open	6	16.68
	10	74.70
	14	85.90
	18	155.6
6 & 14 open	6	16.68
	10	83.06
	14	77.36
	18	155.5
6 & 18 open	6	16.68
	10	83.06
	14	85.86
	18	146.7
10 open	6	26.66
	10	75.01
	14	86.21
	18	155.3
10 & 14 open	6	26.33
	10	74.26
	14	76.91
	18	155.1
10 & 18 open	6	26.33
	10	74.26
	14	85.42
	18	146.3
14 open	6	26.66
	10	83.37
	14	77.67
	18	155.8
14 & 18 open	6	26.33
	10	82.62
	14	76.81
	18	146.2
18 open	6	26.66
	10	83.37
	14	86.17
	18	147.0
6,10, &14 open	6	16.1
	10	73.7
	14	76.4
	18	154.5
6,10, &18 open	6	16.1
	10	73.7
	14	84.9
	18	145.7

Situation	Node	Pressure (PSI)
6,14, &18 open	6	16.1
	10	82.1
	14	76.3
	18	145.6
10, 14 &18 open	6	25.8
	10	73.0
	14	75.6
	18	144.9
All	6	15.4
	10	72.3
	14	74.8
	18	144.2

Appendix E: Concrete Calculations

Table 15: Concrete calculations for lids

Lid Improvements

Concrete Required		
Lid - Upper Portion		
Length =	70	cm
Width =	70	cm
Height =	5	cm
Volume =	24500	cubic cm
Concrete Required =	0.025	cubic m
Lid - Lower Portion		
Length =	60	cm
Width =	60	cm
Height =	3	cm
Volume =	9000	cubic cm
Concrete Required =	0.009	cubic m
Raised Lip		
Outside Length =	28	cm
Outside Width =	28	cm
Inside Length =	24	cm
Inside Width =	24	cm
Height =	10	cm
Volume =	784	cubic cm
Concrete Required =	0.001	cubic m
Total Quantity Required:	0.034	cubic m
Wet-to-dry ratio:	1.3	
Dry Materials Required:	0.045	cubic m
Losses Due to Handling (10%):	0.004	cubic m
Volume of Dry Materials:	0.049	cubic m
Cement:Sand:Gravel Mix Ratio:	1:2:3	
Cement Required:	0.008	cubic m
assuming 0.028 cu m per sack	0.3	sack
Sand Required:	0.016	cubic m
	16	L
Gravel Required:	0.025	cubic m
	25	L

Table 16: Concrete calculations for tap stands

Tap Stands

Concrete Required		
Base Quantity		
Length =	60	cm
Width =	60	cm
Height =	15	cm
Volume =	54000	cubic cm
Concrete Required =	0.054	cubic m
Riser Quantity		
Length =	15	cm
Width =	15	cm
Height =	90	cm
Volume =	20250	cubic cm
Concrete Required =	0.02	cubic m
Total Quantity Required:	0.074	cubic m
Wet-to-dry ratio:	1.3	
Dry Materials Required:	0.097	cubic m
Losses Due to Handling (10%):	0.010	cubic m
Volume of Dry Materials:	0.106	cubic m
Cement:Sand:Gravel Mix Ratio:	1:2:3	
Cement Required:	0.018	cubic m
assuming 0.028 cu m per sack	0.6	sack (44 kg)
Sand Required:	0.035	cubic m
	35	L
Gravel Required:	0.053	cubic m
	53	L

Appendix F: Cost Estimate

Material Cost								
	Product	Units	Quantity	Price per unit			Total Cost	
Piping Improvements	PVC Pipe, 32 mm, Schedule 40	3 m	340	$	10.73	per 3 m	$	3,648.20
	PVC Pipe, 15 mm, Schedule 40	3 m	90	$	4.13	per 3 m	$	371.70
	PVC Tee Ftting, 32 mm x 32 mm x 15 mm	each	5	$	2.82	per 3 m	$	14.10
	PVC Coupling, 32 mm, Schedule 40	each	90	$	0.67	per 3 m	$	60.30
	PVC Coupling, 15 mm, Schedule 40	each	22	$	0.20	per 3 m	$	4.40
	PVC Elbows 45°, 32 mm, Schedule 40	each	3	$	1.31	per 3 m	$	3.93
	PVC Elbows 90°, 32 mm, Schedule 40	each	2	$	1.08	per 3 m	$	2.16
	PVC Ball Valve, 32 mm, Schedule 40	each	4	$	14.75	per 3 m	$	59.00
	PV Ball Valve, 15 mm, Schedule 40	each	5	$	6.90	per 3 m	$	34.50
	PVC End Cap, 32 mm, Schedule 40	each	1	$	0.75	per 3 m	$	0.75
	Sheet PVC (50 mm x 300 mm)	each	2	$	5.05	per 3 m	$	10.10
	PVC Cement (950 mL)	each	2	$	14.52	per 3 m	$	29.04
	Valve Box, 250 mm, Round	each	4	$	9.78	per 3 m	$	39.12
	Mesh, No. 24, Stainless Steel	sq m	1	$	75.00	1.4 sq m	$	75.00
	Piping Improvements Total						$	4,352.30
Chlorinator Improvement	PVC Tee, 100 x 100 mm, Schedule 40	each	1	$	13.86	each	$	13.86
	PVC Pipe, 100 mm, Schedule 40	3 m	1	$	27.01	per 1.5 m	$	27.01
	PVC couplings, 100 mm, Schedule 40	each	2	$	4.80	per unit	$	9.60
	PVC cap, 100 mm, Schedule 40	each	1	$	5.83	per unit	$	5.83
	PVC Pipe, 75 mm, Schedule 40	each	1	$	19.70	per 1.5 m	$	19.70
	Sheet PVC, 1/4" (6mm)	each	2	$	5.05	per unit	$	10.10
	PVC Cement (950 mL)	each	1	$	4.68	each	$	4.68
	Sheet Metal Screws, #4 x 1/2", Stainless Steel	box of 100	1	$	6.01	per box	$	6.01
	Chlorinator Improvement Total						$	96.79
Lid Improvments	Lumber, 50 mm x 100 mm	3 m	6	$	2.18	each	$	13.08
	Plywood Forms, 1219 mm x 2438 mm	each	1	$	15.97	eaech	$	15.97
	No.16 Nails, 9 cm	box of 200	2	$	11.85	per box	$	23.70
	Portland Cement	44 kg bag	1	$	10.50	per bag	$	10.50
	Fine Sand	L	33		-	per L		N.A.
	Course Gravel	L	49		-	per L		N.A.
	Steel Mesh, 38 mm opening, 600 mm x 1200 mm	ea	1		87.61	each	$	87.61
	No. 4 Rebar	m	2	$	7.72	per m	$	15.44
	Neoprene Sheet, 1 cm thick, 5 cm x 1500 cm	ea	1	$	80.69	each	$	80.69
	Neoprene Adhesive, 300 mL	ea	1	$	9.22	each	$	9.22
	Lid Improvements Total						$	256.21
Tap Stands	Lumber, 50 mm x 100 mm x 3m	3 m	6	$	2.18	each	$	13.08
	Plywood Forms, 1219 mm x 2438 mm	each	1	$	15.97	each	$	15.97
	No.16 Nails, 9 cm	box of 200	2	$	11.85	per box	$	23.70
	Portland Cement	44 kg bag	3	$	10.50	per bag	$	31.50
	Fine Sand	L	142		-	per L		N.A.
	Course Gravel	L	212		-	per L		N.A.
	Steel Mesh, 38 mm opening, 600 mm x 1200 mm	each	1	$	87.61	each	$	87.61
	No. 4 Rebar (3 m long)	each	6	$	5.20	per 3 m	$	31.20
	PVC Pipe, 15 mm, Schedule 40	3 m	2	$	4.13	per 3 m	$	8.26
	PVC Elbows 90°, 15 mm, Schedule 40	each	14	$	0.30	per unit	$	4.20
	PV Ball Valve, 15 mm, Schedule 40	each	5	$	6.90	per unit	$	34.50
	Tap Stands Total						$	203.06
Tools/Equipment	Pipe Cutter	each	1	$	44.25	each	$	44.25
	Hammers	each	2	$	17.84	each	$	35.68
	Spade Shovel	each	5	$	27.69	each	$	138.45
	Pickaxe	each	2	$	55.00	each	$	110.00
	Wheel-barrow, 170 L Capacity, Flat-Free Tires	each	1	$	79.98	each	$	79.98
	Concrete Mixing Box, 34 L Capacity	each	2	$	7.60	each	$	15.20
	Plastic Bucket, 18.9 L	each	5	$	9.88	each	$	49.40
	Cordless Drill (rental)	week	1	$	56.00	per week	$	56.00
	Concrete Saw (ental)	each	2	$	75.00	per day	$	150.00
	Tools/Equipment Total						$	678.96
Total Project Cost							$	5,587.32

Task Name	Duration, days	Laborers	Labor days	Labor Cost
Buy and Transport Materials				
Buy materials	1	2	2	$ 16.00
Transport materials	3	8	24	$ 192.00
New System				
Runoff Diversion				
Transport materials to site	4	4	16	$ 128.00
Site prep	1	4	4	$ 32.00
Build forms	1	4	4	$ 32.00
Dig trenches	1	4	4	$ 32.00
Lay rip rap	1	4	4	$ 32.00
Existing Storage Tank Updates				
Transport materials to site	1	4	4	$ 32.00
Clean current system	1	4	4	$ 32.00
Replace broken pipes	1	4	4	$ 32.00
Install "Chlorinator"	1	4	4	$ 32.00
Build forms for lids	1	4	4	$ 32.00
Build lids	1	4	4	$ 32.00
Piping				
Dig trench for pipes	5	8	40	$ 320.00
Install pipe from Spring box to holding tank	1	8	8	$ 64.00
Install pipe from main line from holding tank	1	8	8	$ 64.00
Install pipe from main line to houses	1	8	8	$ 64.00
Test system	1	8	8	$ 64.00
Cover pipe system	2	8	16	$ 128.00
Create tap stand mold	1	4	4	$ 32.00
Build tapstands	2	8	16	$ 128.00
Total			**190**	**$ 1,520.00**

Appendix G: CTI Chlorinator Chlorination Time Calculations

Concentration of chlorine and contact time are both important factors in being sure the water is rid of bacterial contaminants. Using the flow rate of water into the tank over the chlorine tablets, the volume of flow over the tables, the residence time of the water in the tank, and a baffle coefficient, a concentration time was found to be 84 mg-min/L. This is plenty of time for the water to be disinfected of pathogens found in the water quality tests, as stated in section 2.4 of this report. The contact time for the water in pipes between the storage tank and first faucet depends on the volume of pipe. The equation for determining the volume in a pipe can be seen below.

$$Volume\ (L) = Length\ of\ pipe\ (ft) * \pi * \left(\frac{Pipe\ Diameter\ (in)}{2}\right)^2 * \left(\frac{\frac{28.31L}{ft^3}}{\frac{144\ in^2}{ft^2}}\right)$$

Flow	Tablet life	Volume of flow over tablet	Starting weight of tablet	Rate of dissolution	Residence time	Baffle coefficient	Concentration Time
L/min	days	L	mg	mg/L	minutes		mg-min/L
17.22	7	1.7358E+05	2.0000E+05	1.152	242.8	0.3	83.93

$$Concentration\ \left(\frac{mg}{L}\right) \times Time\ (min) \times Baffle\ coefficient\ = Contact\ Time\ \left(\frac{mg - min}{L}\right)$$

Concentration = 1152 mg/1000L

Residence time = 242.75 minutes

Baffle coefficient = 0.3

1.152mg/L x 242.75 min x 0.3 = 83.93 mg-min/L

Appendix H: Calculation for Peak Discharge

The peak discharge from the watershed was calculated using the rational method. The runoff coefficient, *c* for pasture land/prairie grass is 0.12-0.62 [15]. Taking the clayey soil into consideration, 0.62 was used as a conservative approach. A rainfall intensity, *i* of 178 mm/day represents the largest storm event experienced in the past five years [14]. The area of watershed was found to be 54,734 m^3. The sample calculation can be seen below.

$$Q = c \cdot i \cdot A$$

$$Q = (0.62) \times \left(178\,\frac{mm}{day}\right) \times \left(\frac{1\,m}{1000\,mm}\right) \times (54{,}734\,m^2) = 60{,}040\,\frac{m^3}{day}$$

$$Q = \left(60{,}040\,\frac{m^3}{day}\right)\left(\frac{1000\,L}{1\,m^3}\right)\left(\frac{86{,}400\,sec}{day}\right) = 69.9\,Lps$$

$$Q = 70\,Lps$$

Appendix I: Construction Schedule

Construction Manual

The following manual addresses the process to rehabilitate the water distribution system that supplies the Quebrada Caracol community with drinking water.

Material and Tool Procurement

a) The list of materials and tools provided in Appendix F need to be obtained and transported to the Quebrada Caracol community. Upon arrival, the tools and materials will need to be carried or transported to the construction location.

Site Preparation

a) Prepare all necessary preparation. Clear necessary vegetation around the spring box, holding tank, chlorination chamber, and along the entire length of the existing pipeline. Remove larger obstructions when necessary.
b) Located and expose all sections of the existing system. The new pipeline will follow the same path as the existing pipeline. Dig a 30-cm deep trench the width of a shovel-head along the entire length of the pipeline, when feasible.

Pipeline Construction

a) The following materials and equipment will be used to construct the pipeline.

Item	Unit	Quantity
PVC Pipe, 32 mm, Schedule 40	3 m	340
PVC Pipe, 15 mm, Schedule 40	3 m	90
PVC Tee Ftting, 32 mm x 32 mm x 15 mm	each	5
PVC Coupling, 32 mm, Schedule 40	each	90
PVC Coupling, 15 mm, Schedule 40	each	22
PVC Elbows 45°, 32 mm, Schedule 40	each	3
PVC Elbows 90°, 32 mm, Schedule 40	each	2
PVC Ball Valve, 32 mm, Schedule 40	each	4
PV Ball Valve, 15 mm, Schedule 40	each	5
PVC End Cap, 32 mm, Schedule 40	each	1
Sheet PVC (50 mm x 300 mm)	each	2
PVC Cement (950 mL)	each	2
Valve Box, 250 mm, Round	each	4
Mesh, No. 24, Stainless Steel	sq m	1
Pipe Cutter	each	1
Spade Shovel	each	5
Pickaxe	each	2

b) The flow in the pipeline must be blocked prior to constructing the new pipeline. This can be done at the spring box by removing the cap on the cleanout line and placing it on the outflow pipe inside the spring box.

c) Cut the existing overflow pipe 15 cm from the spring box, connect a ball valve, and add a 3-m section of 32-mm PVC pipe.
d) Cut the existing inflow pipe 15 inches from the spring box and connect a ball valve. Then place a 1 m section of 32-mm PVC and attach a 45-degree fitting.
e) Construct the pipeline, beginning at the spring-box and proceeding toward the storage tank. This line is to be constructed with 32-mm PVC pipe.
    a. Connect the sections using regular socket fittings. Use 45-degree fittings when necessary. Thoroughly clean the ends of each PVC section and apply PVC cement prior to connecting each section.
f) Continue constructing the pipeline from the storage tank to the faucet locations.
    a. The main line is to be constructed with 32 mm PVC and the service lines (branches) are to be constructed with 15 mm PVC.
    b. Use reducing tee-fittings to branch off the main line.
g) Test the system to ensure there are no leaks.
h) Bury the pipe to prevent damage from foot-traffic and UV penetration.
i) Cover all cleanout, overflow, and ventilation pipes with No. 24 stainless steel mesh to prevent contamination.

Lid Construction

a) The following tools and materials are used in constructing the new lids.

Item	Unit	Quantity
Lumber, 50 mm x 100 mm	3 m	2
Plywood Forms, 1219 mm x 2438 mm	each	1
No.16 Nails, 9 cm	box of 200	2
Portland Cement	44 kg bag	1
Fine Sand	L	33
Course Gravel	L	49
Steel Mesh, 38 mm opening, 50 mm x 50 mm	each	2
No. 4 Rebar	100 cm	2
Neoprene Sheet, 1 cm thick, 5 cm x 25 cm	each	8
Neoprene Adhesive, 300 mL	each	1
Concrete Mixing Box, 34 L Capacity	each	1
Plastic Bucket, 18.9 L	each	5
Cordless Drill (rental)	week	1
Concrete Saw (rental)	day	2

b) Construct a wood form based on the dimensions of the new lids specified in technical drawing, which can be viewed in Appendix C. The inner dimensions of the form should match the dimensions of the lid.
    a. The upper portion of the lid measures 70 cm by 70 cm with a thickness of 5 cm. The lower portion of the lid measures 60 cm by 60 cm with a thickness of 2.5 cm. This provides the lid with 5 cm overhang.

c) Place a 50 cm by 50 cm sheet of steel mesh in the lower portion of the form, using a scrap PVC pipe to prop it up 2.5 cm from the base of the mold.
d) Construct a 30 cm long handle using a No. 4 rebar and secure it to the steel mesh using steel wire. The handle should protrude from the upper portion of the lid and be situated in the center of the lid.
e) Mix and pour the concrete as specified below in *Concrete Mixing Directions*.
f) Remove the form after allowing the concrete to cure for 7 days.
g) Adhere 5 mm neoprene strips along the bottom side of the overhang using neoprene adhesive.
h) Cut the existing spring box opening 60 cm x 60 cm using a concrete saw; this will allow the new lid to fit properly.

Note: The form will be utilized to create two lids: one for the spring box and one for the storage tank.

Chlorination Improvements

a) The following materials and equipment will be used to construct the chlorinatior.

Item	**Unit**	**Quantity**
PVC Tee, 100 x 100 mm, Schedule 40	each	1
PVC Pipe, 100 mm, Schedule 40	3 m	1
PVC couplings, 100 mm, Schedule 40	each	2
PVC cap, 100 mm, Schedule 40	each	1
PVC Pipe, 75 mm, Schedule 40	each	1
Sheet PVC, 1/4" (6mm)	each	2
PVC Cement (950 mL)	each	1
Sheet Metal Screws, #4 x 13 mm, Stainless Steel	box of 100	1
Pipe Cutter	each	1
Cordless Drill (rental)	day	1

b) Remove the existing chlorination device and replace it with a section of pipe.
c) Assemble the CTI8 Chlorinator following the directions provided by Compatible Technologies Incorporated, which is provided in in the following link: https://wiki.umn.edu/pub/EWB/Guatemala_Simajuleu/Chlorinator_Manual_compressed.doc
d) The chlorinator should be located 3 m upstream of the storage tank.
    a. Place two tee-fittings on the pipeline with 60 cm separation and position a ball valve in between them.
    b. Connect a 15 cm long section of 15 mm PVC to each tee-fitting and attach a 90-degree fitting to the other end. Place a ball-valve on the pipe connected to the upstream tee-fitting.
    c. Insert the chlorinator using the provided reducing couplings.
e) Level the chlorinator to ensure proper flow.

Tap Stand Construction

a) The following materials and equipment will be used to construct the tap stands.

Item	Unit	Quantity
Lumber, 50 mm x 100 mm x 3m	3 m	6
Plywood Forms, 1219 mm x 2438 mm	each	1
No.16 Nails, 9 cm	box of 200	2
Portland Cement	44 kg bag	3
Fine Sand	L	142
Course Gravel	L	212
Steel Mesh, 38 mm opening, 600 mm x 1200 mm	each	1
No. 4 Rebar (3 m long)	each	6
PVC Pipe, 15 mm, Schedule 40	3 m	2
PVC Elbows 90°, 15 mm, Schedule 40	each	14
PV Ball Valve, 15 mm, Schedule 40	each	5
Pipe Cutter	each	1
Hammers	each	2
Concrete Mixing Box, 34 L Capacity	each	2
Plastic Bucket, 18.9 L	each	5
Cordless Drill (rental)	day	1

b) Level the ground of the proposed tap stand location.

c) Construct a wood form that will be utilized to construct four tap stands.
   a. The base measures 60 cm by 60 cm with a height of 15 cm.
   b. The tap stand riser measures 15 cm by 15 cm with a height of 90 cm.
   c. The riser is to be mounted on top of the base, flush and centered with one side.

d) Place a 50 cm by 50 cm sheet of steel mesh in the lower portion of the form, using a scrap PVC pipe to prop it up 5 cm from the base of the mold.

e) Cut out an opening in the back of the base for the inflow pipe and one near the top of the riser for the outflow (faucet).

f) Route the 15 mm PVC pipe into the base, up the riser, and out the opposite side of the riser using 90-degree fittings.

g) Mix and pour the concrete as specified below in *Concrete Mixing Directions*.

h) Remove the form after allowing the concrete to cure for 7 days.

i) Attach ball valve to outflow, followed by a short section of pipe and a 90-degree fitting to direct the water downward like a faucet.

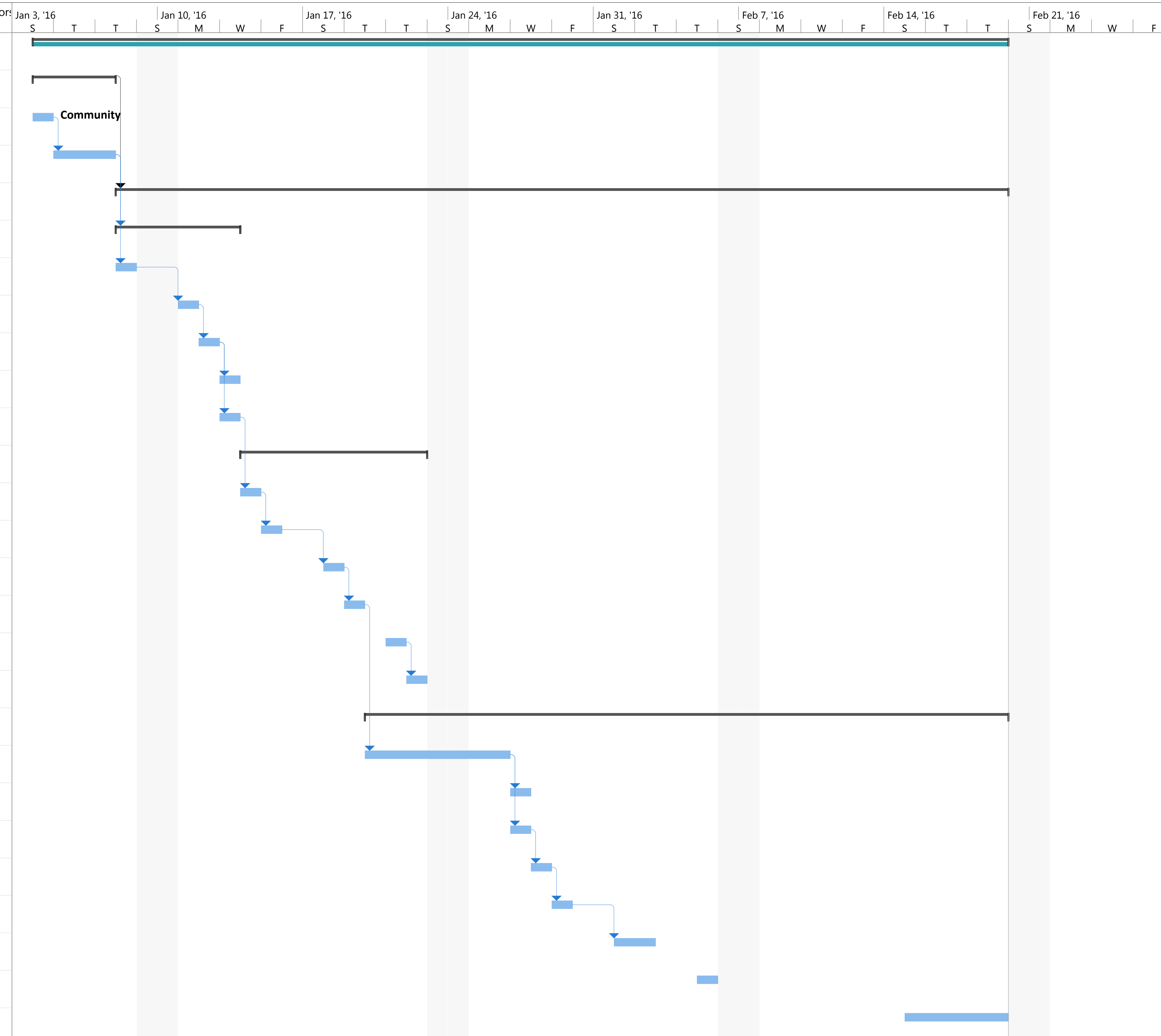
j) Connect to the pipeline.

Concrete Mixing Directions

The concrete used for improving the spring box and water storage tank, tap stands, and runoff diversion should be mixed using a 1:2:3 ratio of cement, sand, and gravel, respectively. Mix the ingredients in equal increments and add water to achieve a workable consistency. The target water-to-cement ratio is 1:3.

When the concrete reaches a workable consistency at which it flows, it will be poured into the forms. While pouring the concrete, tap the sides of the form and stir the concrete to prevent air from being entrapped in the mixture. Level the concrete with a flat board upon filling the form and cover with a damp cloth to retain the moisture content and protect from rain.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**CWC - Quebrada Caracol Implementation Plan**	**35 days**	**Mon 1/4/16**	**Fri 2/19/16**	
2	**Buy and Transport Materials**	**4 days**	**Mon 1/4/16**	**Thu 1/7/16**	
3	Buy materials	1 day	Mon 1/4/16	Mon 1/4/16	
4	Transport materials	3 days	Tue 1/5/16	Thu 1/7/16	3
5	**New System**	**31 days**	**Fri 1/8/16**	**Fri 2/19/16**	**2**
6	**Runoff Diversion**	**4 days**	**Fri 1/8/16**	**Wed 1/13/16**	**4**
7	Transport materials to site	1 day	Fri 1/8/16	Fri 1/8/16	4
8	Site prep	1 day	Mon 1/11/16	Mon 1/11/16	7
9	Build forms	1 day	Tue 1/12/16	Tue 1/12/16	8
10	Dig trenches	1 day	Wed 1/13/16	Wed 1/13/16	9
11	Lay rip rap	1 day	Wed 1/13/16	Wed 1/13/16	9
12	**Existing Storage Tank Updates**	**7 days**	**Thu 1/14/16**	**Fri 1/22/16**	
13	Transport materials to site	1 day	Thu 1/14/16	Thu 1/14/16	11
14	Clean current system	1 day	Fri 1/15/16	Fri 1/15/16	13
15	Replace broken pipes	1 day	Mon 1/18/16	Mon 1/18/16	14
16	Install "Chlorinator"	1 day	Tue 1/19/16	Tue 1/19/16	15
17	Build forms for lids	1 day	Thu 1/21/16	Thu 1/21/16	
18	Build lids	1 day	Fri 1/22/16	Fri 1/22/16	17
19	**Piping**	**23 days**	**Wed 1/20/16**	**Fri 2/19/16**	
20	Dig trench for pipes	5 days	Wed 1/20/16	Tue 1/26/16	16
21	Install pipe from Spring box to holding tank	1 day	Wed 1/27/16	Wed 1/27/16	20
22	Install pipe from main line from holding tank	1 day	Wed 1/27/16	Wed 1/27/16	20
23	Install pipe from main line to houses	1 day	Thu 1/28/16	Thu 1/28/16	22
24	Test system	1 day	Fri 1/29/16	Fri 1/29/16	23
25	Cover pipe system	2 days	Mon 2/1/16	Tue 2/2/16	24
26	Create tap stand mold	1 day	Fri 2/5/16	Fri 2/5/16	
27	Build tapstands	5 days	Mon 2/15/16	Fri 2/19/16	



Project: QuebradaCaracol_Projec
Date: Thu 12/10/15

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

Appendix J: Maintenance Manual

Maintenance Manual

The following manual addresses the process to maintain the water distribution system in the Quebrada Caracol community.

Concrete Component Maintenance

The water distribution system should be thoroughly inspected on an annual basis. The masonry components, such as the spring box, water storage tank, and tap stands, should be inspected for cracks. Any identified cracks should be patched with a mortar mix of 1:1:3 (1 part water, 1 part sand, 3 parts cement). Repair the cracks with the mortar mix and allow 7 days to cure.

Pipeline Maintenance

The exposed sections of the piping system should be checked for leaks on a monthly basis. Identified leaks should be repaired by replacing the damaged section of pipe. Thoroughly clean the pipe and apply PVC cement to all connections.

Chlorination Maintenance

The chlorinator should be inspected on a daily basis to ensure the water is being properly treated. To service the chlorinator, close the control valve and open the bypass valve. Remember to keep the bypass closed during normal operation to adequately disinfect the water.

Appendix K: Additional Photos from Quebrada Caracol, Panama

Figure 29. Sections of current pipe system in Quebrada Caracol community

Figure 30. Current chlorination tablet holder used in Quebrada Caracol community

Figure 31. Standard T style PVC pipe that holds chlorination tablet holder