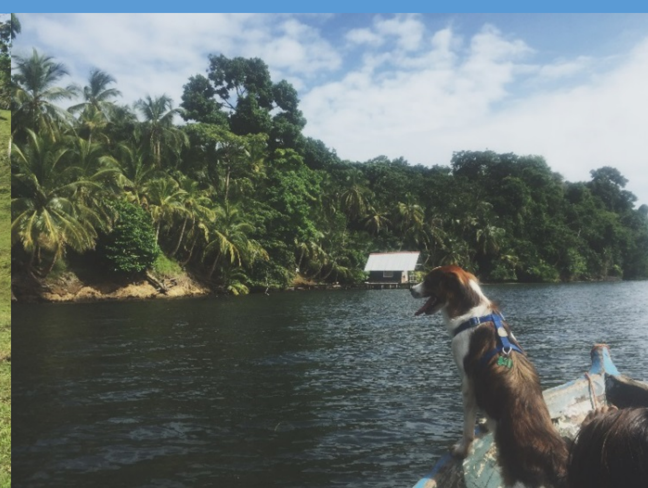
2015

WATER RESOURCE DEVELOPMENT VALLE ESCONDIDO, PANAMÁ



T O D O
ENGINEERING
D E B E

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Disclaimer:

This report titled “Valle Escondido, Panama Water Resource Development,” represents the efforts of undergraduate students in Civil and Environmental Engineering Department of Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report ***should not*** be considered professional engineering.

Mission Statement

Todo Debe Engineering strives to make sustainable and innovative design recommendations that can be feasibly implemented in a community based on their financial constraints and resource availability. In addition, TDE aspires to instill comprehension of the system's function as to insure the prolonged use and maintenance of proposed designs. Design packages are also comprised of sanitation improvements, in order to further develop the water resource network.

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Executive Summary

Todo Debe Engineering (TDE) is a team of four Environmental Engineering undergraduate students from Michigan Technological University (MTU). The team of four traveled to Panama in August 2015 as part of MTU's iDesign program, which offers an international alternative to traditional senior design projects at the university. TDE traveled to the community of Valle Escondido in western Panama and was fortunate enough to have the assistance of Katie Ahern, the community's Peace Corps Volunteer (PCV).

The purpose of this project is to apply undergraduate engineering skills to remedy a water supply issue within the community. This includes modifications to an existing aqueduct system to offer increased storage, source protection and water treatment. Additionally, diversification of sources is recommended in the form of individual rainwater catchment tanks.

The existing aqueduct travels 0.55 miles from a spring source to four storage tanks at the top of the community. Water then flows downhill 0.52 miles from the tanks through branches of the distribution system supplying water to 17 homes. Eighty percent of the existing line is unburied and therefore exposed to damage from farm animals, humans and sunlight. As a result, frequent fecal coliform contamination of the aqueduct system occurs. TDE was able to identify large amounts of E. coli present in some of the taps on the aqueduct system. Bleach treatment of the water in the storage tanks is seldom and sporadic. Furthermore, the spring source produces a large amount of sediment in the water transport pipes, and storage tanks.

Analysis of data collected in Panama allowed TDE to model the existing aqueduct system in EPANET, as well as develop design schematics, construction procedures and cost estimates for the proposed spring box, in-line chlorinator, rainwater catchment tanks and overall aqueduct improvements. The recommended spring box is constructed from concrete and features an open bottom and backside to allow spring flow to enter the box and PVC line that transports the water to the community. The chlorinator is also constructed of PVC and offer sufficient treatment for the pathogens commonly found in the waters of this region. The rainwater catchment is also constructed of concrete and will offer each home a supplement to the aqueduct system in the form of an 85 gallon tank with a first flush system. Lastly, it is recommended that the aqueduct be replaced with a uniformly sized pipe. The existing non-uniform pipeline has the potential to negatively affect pressure and flow within the system. Since it is recommended that the pipe be buried, it is best that new PVC be installed to minimize future problems. A 2.0" PVC pipe will carry the water from the spring source to the storage tank, while a 1.0" PVC pipe will form the central distribution line through the community and 0.5" PVC pipe will branch from the main line to each respective home.

Todo Debe Engineering has made the above recommendations with the intention of providing a clean and sufficient quantity of water to the community of Valle Escondido.

1. Introduction

Todo Debe Engineering (TDE) is a team of four Environmental Engineering undergraduate students from Michigan Technological University (MTU). The team of four traveled to Panama in August 2015 as part of MTU's iDesign program, which offers an international alternative to traditional senior design projects at the university. TDE traveled to the community of Valle Escondido in western Panama and was fortunate enough to have the assistance of Katie Ahern, the communities Peace Corps Volunteer (PCV). Katie had lived in the community for over a year and formed an invaluable bond with the community that allowed TDE to not only feel welcome, but appreciated and able to accomplish the tasks at hand. The team was informed prior to traveling that the community possessed a dated but functional aqueduct system used by almost half of the community but was experiencing frequent cases of waterborne illnesses. Therefore, TDE chose to spend their time in the community conducting water quality tests and collecting survey data to offer improvements to the existing aqueduct, as well as suggest some supplementary practices, such as rainwater catchment.

Valle Escondido is situated on an island, with soils mostly comprised of clay. As a result of this, practices of open-defecation and farming in close proximity to houses has left them with frequent fecal coliform contamination of their water. TDE conducted water quality tests to identify sources and concentrations of this contamination. Furthermore, the elevation and layout of the aqueduct system was obtained so that is could be analyzed with hydraulic modeling software upon returning to MTU. The following design offers detailed recommendations and plans to protect the water source at the spring, add 17 homes to the system, as well as ensure that the spring source and non-spring sources provide a sufficient quantity of clean water to the village. These design elements include a spring box, water storage management, water treatment and supplemental water supply via individual rainwater catchment tanks.

1.1 Community Background

The community of Valle Escondido, shown in Figure 1, is situated in the northwestern part of Panama in the province of Bocas del Toro, on Isla San Cristóbal. This region receives large amounts of rain throughout most of the year, and most of the island is covered in rainforest. Valle Escondido is home to 30 families and roughly 300 people of the Ngöbe indigenous group. The community has a very low income, provided mostly through agriculture and some small stores located on the island. The community has hosted Peace Corps volunteers for the past 7 years, and is currently in the agricultural development stage of their Peace Corps program.

Figure 1: View of the center of the community Valle Escondido

1.2. Problem Description

Valle Escondido had already constructed their own aqueduct system to direct water from springs in the higher elevations down the community. They have a functioning political system for its management, with an aqueduct president and treasurer. However, only half of the community is currently using this system, while other homes use wells that have been dug in the ground, exposing the water to the surface runoff. The community experiences significant health problems due to poor water quality caused by open defecation as well as close placement of livestock to the community and water sources. Frequently community members are infected with amoebas, worms, parasites, and conjunctivitis (pink eye). The current Peace Corps volunteer had recently begun a project to construct ferrocement rainwater collection tanks for houses to supplement their current water supply with cleaner water.

Based on this information, the team decided to assess the current water sources in the community to see which sources provided the cleanest water (and which sources could have been the cause of the illnesses), as well as the aqueduct system itself, to see if improvements could be made to increase supply, quality, and efficiency.

2. Data Collection

The team conducted tests of existing wells and springs currently in use by the community. Some families were connected to the aqueduct system while others used shallow wells located near their homes for water. Unfortunately, these wells were susceptible to contamination from livestock, the environment, and people. Figure 2 shows the team collecting a water sample from one of these shallow drinking wells.

The various water sources were tested using 3M Petrifilm tests to determine the levels of E. coli and total coliform bacteria. In accordance with the use and interpretation guide provided by 3M, 1 mL of contaminated water was placed in the center of the agar and then the sample was spread and sealed using the plastic coating and circular spreader. The E. coli/total coliform samples incubated for 48 hours while the aerobic bacteria incubated for 36 hours [1]. Two samples of both E. coli and aerobic bacteria petrifilms were taken at each site. Samples of water collected from existing rainwater catchments, water from kitchen sink nozzles, and water treated with chlorine were also tested. Water sources that were located near farming or agricultural areas were also tested for nitrates, to see if fertilizers were contributing to poor water quality. Photos of most of the wells where samples were taken, as well as the spring currently supplying the aqueduct (*ojo viejo*), are shown in Appendix A.

Figure 2: Team members collect water samples from wells for quality testing

Another issue within the community included a lack of water pressure to a few homes. There were some homes at similar elevations that received different amounts of water to their kitchen sinks. The team collected data by using the volume-time method to calculate the time needed to fill a 1.18 liter water bottle. For high, medium, medium-low, and low elevations within the community, two homes were sampled at each elevation in order to obtain average flow rates.

To gain an understanding of the current aqueduct system, the team worked with the local aqueduct president to survey the main water line and the distribution system. Figure 3 shows a sketch of the whole system drawn by the aqueduct president. During the survey of the main water line, from the springs to the storage tanks, the rangefinder was used in order to determine the distance and elevation change from each point on the line. Additionally, the team noted where changes in pipe size occur. The survey data collected will be used to determine pressure and head loss in the line.

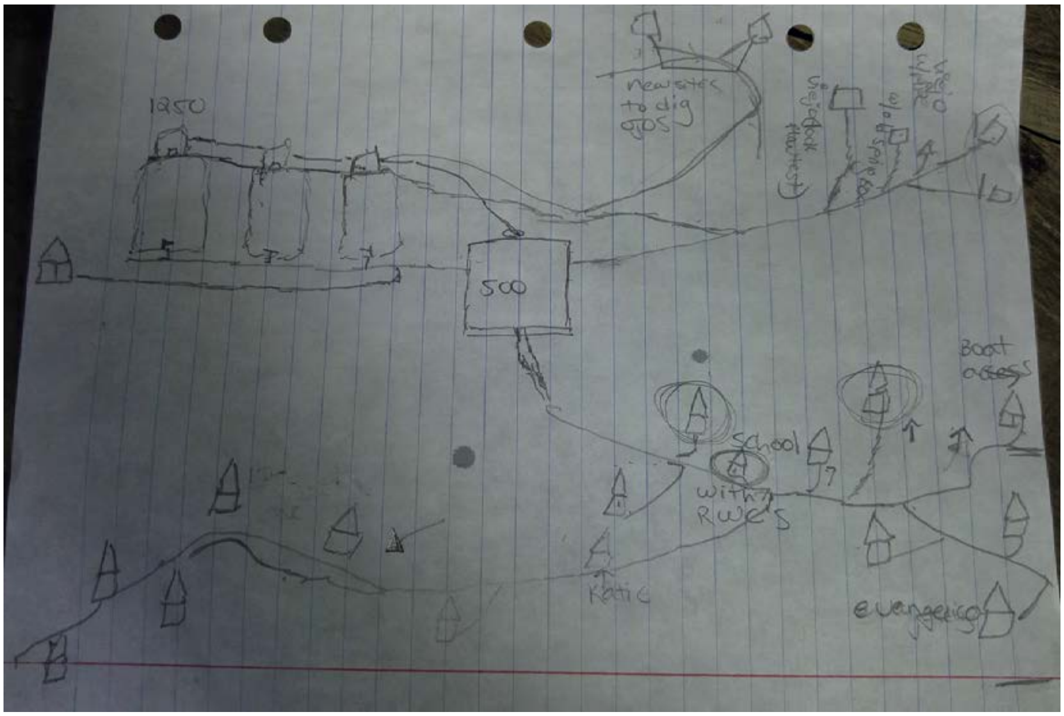


Figure 3: Sketch of the aqueduct collection and distribution lines in Valle Escondido based on a drawing by the Aqueduct President.

The team also took survey and GPS readings of all homes in the community. Homes currently connected and possibly connected in the future were noted for design of the aqueduct system. Survey data will be useful in determining if more homes can be added to the water line.

3. Data Analysis

3.1 Water Quality - Bacterial Contamination

Images of the 3M petrifilms used to test water quality are shown in Appendix B. High counts of coliform bacteria (present in fecal matter) and E. coli were found in all of the shallow wells used by community members for drinking, bathing, or laundry. Often there were such large numbers of coliform bacteria (indicated by red colonies) that there were too many to count for the accuracy of these plates (which is a maximum of 300 colonies) [1]. This means that there could have been more growth, but the food source in the agar was not enough to sustain that much growth. Fecal coliform contamination is dangerous and can cause many diseases. A very dangerous coliform that can make people violently ill is the E.coli strain, which was indicated by blue colonies on these count plates. All wells showed E.coli contamination ranging from 1 to 10 colonies per milliliter of water. Figure 4 shows the locations of these wells around the community, with the white polygon representing the PCV's house in the center of the community. The contamination of the wells is a result of the open defecation practiced near these sources, as well the livestock grazing fields that were near many of the wells. Other natural fecal contamination could occur from wildlife in the area.

Figure 4: Water Quality Test points in Valle Escondido

The rainwater catchment systems also contained some coliform bacteria, but compared to the wells, the rainwater had significantly less bacteria. The rainwater samples averaged about 65 coliform bacteria per milliliter of sample, compared to the 300+ bacteria per milliliter that was found in the well samples. There also was no presence of E. coli in the rainwater. This indicates that the rainwater, while it contains some contamination, is much safer for use than the water from the wells.

Spring sources tested contained the least amounts of coliforms compared to the wells and rainwater sources. The count plates for the spring samples averaged about 25 coliform bacteria per milliliter, and zero E.coli bacteria. These springs are the current source for the aqueduct system in the community. The smaller but still significant amount of coliform bacteria found at the spring is thought to be present because of surface water runoff from the farm fields above the spring. Additionally, since the current piping system is mostly above ground, contamination of the spring water occurs from breakages in the pipes by both people and livestock. The water tested from a tap in one of houses in the community contained aerobic bacteria, coliforms, and also E. coli. Water treated with bleach contained very few coliforms and no E. coli.

Table 1 summarizes all of the water quality data collected from the count plates. Note that plates that were considered "Too Many to Count" are listed as 300 coliform bacteria, for ease of calculating an average.

Table 1: Coliform and E.coli counts from 3M petrifilm growth plates for various water sources

Location	Coliforms 1	Coliforms 2	Coliforms AVG	E.coli 1	E.coli 2	E.coli AVG
Pozo 1	41	300	170.5	1	3	2
Pozo 2	300	300	300	6	5	5.5
Pozo 3	300	300	300	8	2	5
Pozo 4	142	300	221	3	11	7
Pozo 5	74	119	96.5	8	10	9
Bathing area	300	300	300	5	8	6.5
Ojo Viejo	28	20	24	0	0	0
Rainwater	39	94	66.5	0	0	0
Storage Tanks	100	NA	100	1	NA	1
Tap water	300	NA	300	1	NA	1
Chlorinated	15	NA	15	0	NA	0

Appendix B shows images of all the E.coli/Coliform count plates for all of the water sources tested in Valle Escondido, including the wells (*pozos*), the spring connected to the aqueduct (*ojo viejo*), the rainwater sample, storage tank water, tap water, and chlorinated water. Most water samples were tested twice to ensure more reliable results. Note that the E.coli colonies appear blue, while the red colonies are coliform bacteria.

3.2 Water Quality - Nitrate Contamination

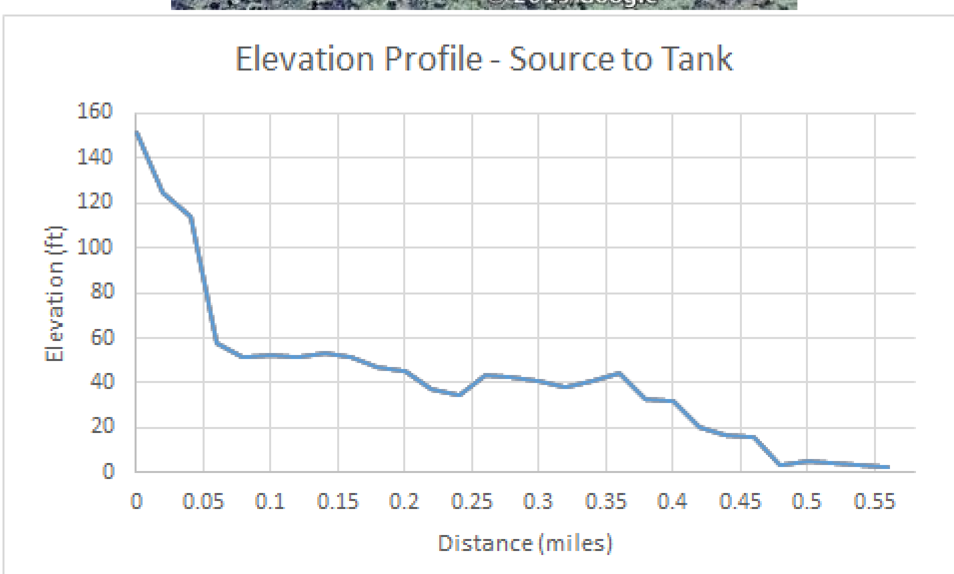
The team was able to test various water sources where there was a concern with overuse of fertilizers using field test kits and a handheld photometer from Nitrate Elimination Company in Lake Linden**,** MI. This kit is shown in Figure 5. Any sample containing more than 30 ppm Nitrate-N would be considered dangerous to overall health. The test kits utilize an enzymatic process and produce a magenta color indicating the concentration in the sample. This process is completed in methylcrylate cuvettes which are then placed in the handheld photometer, displaying the concentration of the sample on an Android device. All of the wells and the spring sources tested contained less than 1 ppm nitrate. Farm land located near wells and the spring source did not cause any high levels of nitrate to accumulate in the water sources. It may be advisable to retest these sites after a couple of years, as agriculture is expanding on the island.

Figure 5: NECi Field Kit & Photometer

3.3 Aqueduct Survey

The current aqueduct was surveyed in order to document the state of the system so that recommendations could be made for improvements or additions. Figure 6 shows a visual representation of the aqueduct connecting the spring to the holding tanks near the community center. Point 235 is the old spring system currently in use, while point 237 is a new spring found nearby that has the potential to be connected to the aqueduct line. Point 209 is the Peace Corps Volunteer’s home that is located in the center of the community. The team was also able to take elevation readings in order to get a more detailed land description of the current aqueduct system. Notes were made regarding locations of buried pipe versus exposed pipe and what type of environment the pipe was running through (pasture, jungle, houses). Additionally, the pipe size throughout the aqueduct was recorded. An elevation profile was created and is displayed in Figure 6. Using the figures it can be determined that the line from the source to the tanks has a greater elevation difference, resulting in a greater amount of head, while the line from the tank to community has a much smaller elevation difference.

The existing system features about 5100 feet of plastic PVC pipe in varying sizes, with the majority of the line being 2” or 1.5”, before decreasing to 0.5” in the community as it branches to the houses. As seen in Figure 6, it spans approximately 0.6 miles with 170 feet of elevation change from source to tank. This existing system supplies sufficient pressure the majority of the time. Additional houses being added to the system may require recommendations regarding replacement of sections and rerouting of aqueduct lines.



Figures 6a and 6b: GPS waypoints along aqueduct collection line (235 indicates spring location, while 213 shows the storage tanks), elevation profile

3.4 Flow Rate Evaluation

In order to determine the efficiency of the aqueduct system, the team took flow rate measurements at various homes. Two samples were taken at similar elevations to compare the flow of water to each household. Using the time-volume method, the flow rate at the kitchen sink valves was measured using a 1.18 L (40 oz) water bottle. Table 2 summarizes the results found at each home. Generally, houses at similar elevations should have similar water pressures, and therefore similar flow rates. However the results showed that the flow rates of homes on similar elevations varied. This can be a result of the existing piping network which may contain breakages or clogging of the pipes, or different pipe sizes connecting from the main water line into the homes.

Table 2: Flow rate results at various home elevations

Home Elevation	Trial 1 (sec)	Trial 2 (sec)	Trial 3 (sec)	Average Time (sec)	Flow Rate (L/min) (const. vol of 1.18L)
High	9.30	7.75	8.83	8.63	8.20
High	16.39	16.30	16.20	16.30	4.34
Medium	7.00	6.50	6.66	6.72	10.54
Medium	13.44	12.94	10.53	12.30	5.76
Medium-Low	3.53	2.92	3.23	3.23	21.92
Medium-Low	8.13	8.41	8.41	8.32	9.51
Low	21.27	20.97	21.02	21.09	3.36
Low	6.53	6.58	6.83	6.65	10.65

3.5 Rainwater Catchment

The rainwater catchment system was originally proposed by the Peace Corps Volunteer. This project is already in motion, so the only data to be collected for the rainwater catchment system was the area of the roofs which would collect the water. This was obtained by measuring the dimensions of the Peace Corps volunteers' house and estimating that family homes would have a similarly sized catchment areas.

4. Design Proposal

4.1 Rainwater Harvesting

Rainwater catchment has been recommended as a feasible alternative to lessen the demand on the aqueduct system. Monthly precipitation data in a nearby community, Changuinola, made it possible to determine both yearly and monthly averages of rainfall in this region of western Panama [2]. Figure 7 shows the yearly averages of rainfall, while Figure 8 shows monthly averages throughout the 47-year span. Figure 7 shows the high variance in rainfall throughout the years. Precipitation varies from approximately 100-350 mm/month. According to Figure 8, the month of September produces the least amount of rain, with an average of 106 millimeters per month. The average amount of precipitation per month was determined as approximately 200 mm/month, resulting in an estimated 2,400 mm of rain annually for this region of western Panama. This rainfall data also confirms the lack of dry seasons in the area.

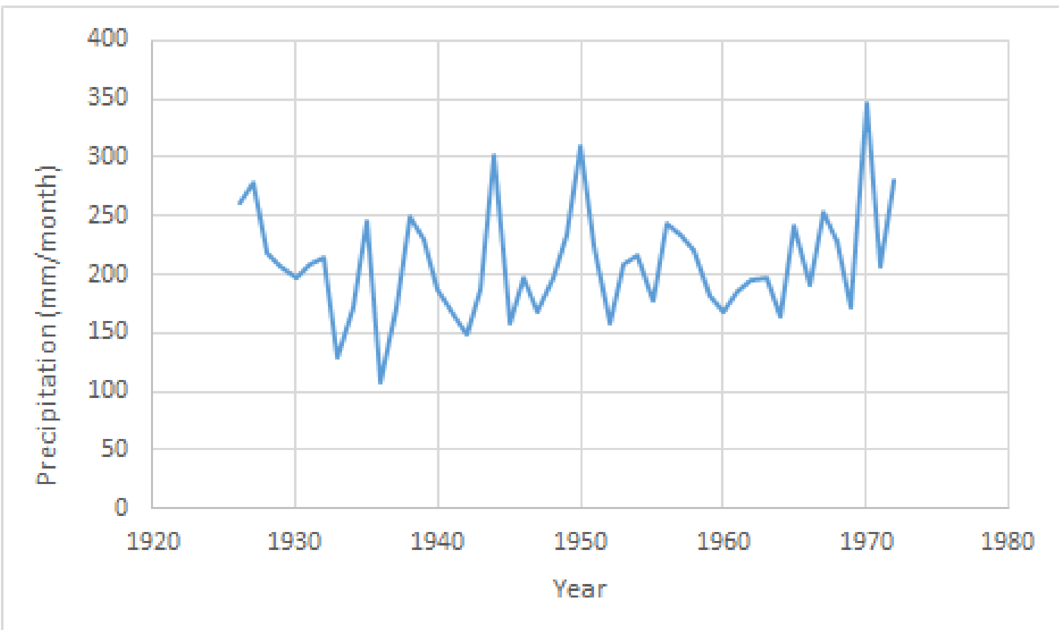


Figure 7: Changuinola yearly precipitation based on data from 1926-1972 [2]

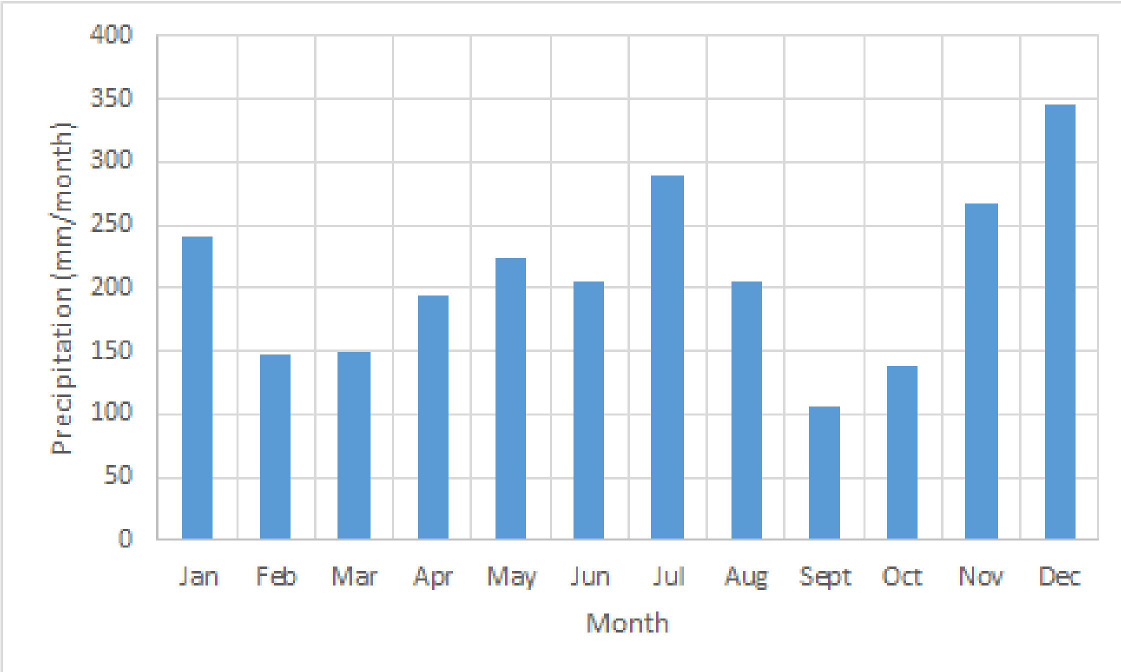


Figure 8: Changuinola monthly average precipitation based on data from 1926-1972 [2]

Equation 1, from Mihelcic et al, was used to determine the approximate supply for the various homes, given monthly averages for the Changuinola region from 1926-1972 [3].

$$Equation\ 1. \quad S = PAC$$

Where the supply, S, is determined by the amount of precipitation volume, P, the collection area of the roof, A, and the runoff coefficient, C. The runoff coefficient was determined to be 0.9. This value is the runoff coefficient for galvanized iron, which is comparable to the zinc roofs present within the community [3].

Using the PCV's home, estimates were used to calculate the possible surface available for rainwater collection. The PCV home was described to be smaller than average in terms of other community members' homes. Thus, estimates were made for two potential home sizes within the community, which were the PCV's home doubled or tripled in width. The estimated collection areas for these three home sizes are 7.8, 14.3, and 21.2 square meters, respectively.

The estimated roof area of the PCV's home, as well as the predicted rainwater supply available can be found in Appendix D. Further estimation of the supply available for larger sized homes throughout the community could be determined using these values. Using monthly precipitation averages for the 47 year data, it was possible to predict average monthly water supplies for various home sizes. The size of the ferrocement tanks would contain 85 gallon tanks, or 322 liters (Figure 9). Calculations indicate it is possible for the rainwater tanks to be continuously filled with sanitary drinking water with the assumed rainwater supply (Table 3). Depending on the size of the catchment area and the month, the supply of water present ranges from 745-6500 L.

Table 3. Rainwater supply dependent on various home sizes and average monthly precipitation

Supply (L)												
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
PCV House	1686	1032	1037	1353	1571	1432	2027	1435	745	963	1867	2407
Home doubled width	3115	1907	1915	2499	2901	2644	3745	2650	1377	1780	3449	4447
Home tripled width	4597	2814	2826	3688	4282	3903	5527	3911	2032	2627	5091	6563

Figure 9: First ferrocement rainwater collection tank constructed by Peace Corps volunteer and community members

Plastic PVC gutters need to be fitted to the roof in order to collect the rainwater. Prevention of sagging and clogging would be a priority. Properly spacing gutter hangers to support the piping, and cutting a small section out of the top of the gutter will reduce these issues.

Installing a first flush system would also be beneficial for maintaining sanitary drinking water. This low-maintenance system prevents sediment, insects, debris, bird droppings, and other undesirable substances that are washed off of the roof during the first flush of rain from entering the ferrocement tank [4]. Basic versions of a first flush system include the addition of PVC pipe and ball that fits within the pipes. Figure 10 shows a basic design of the potential system, provided by Arkitrek [5]. Upstream of the first flush system, it is also recommended to place a screen in the piping in order to remove large particles such as leaves or twigs. The screen would be sourced locally and would prevent any clogging or damage to the first flush system. Mesh screens are available in square foot sections, and approximately 3.5 sheets would be required for the 30 homes.

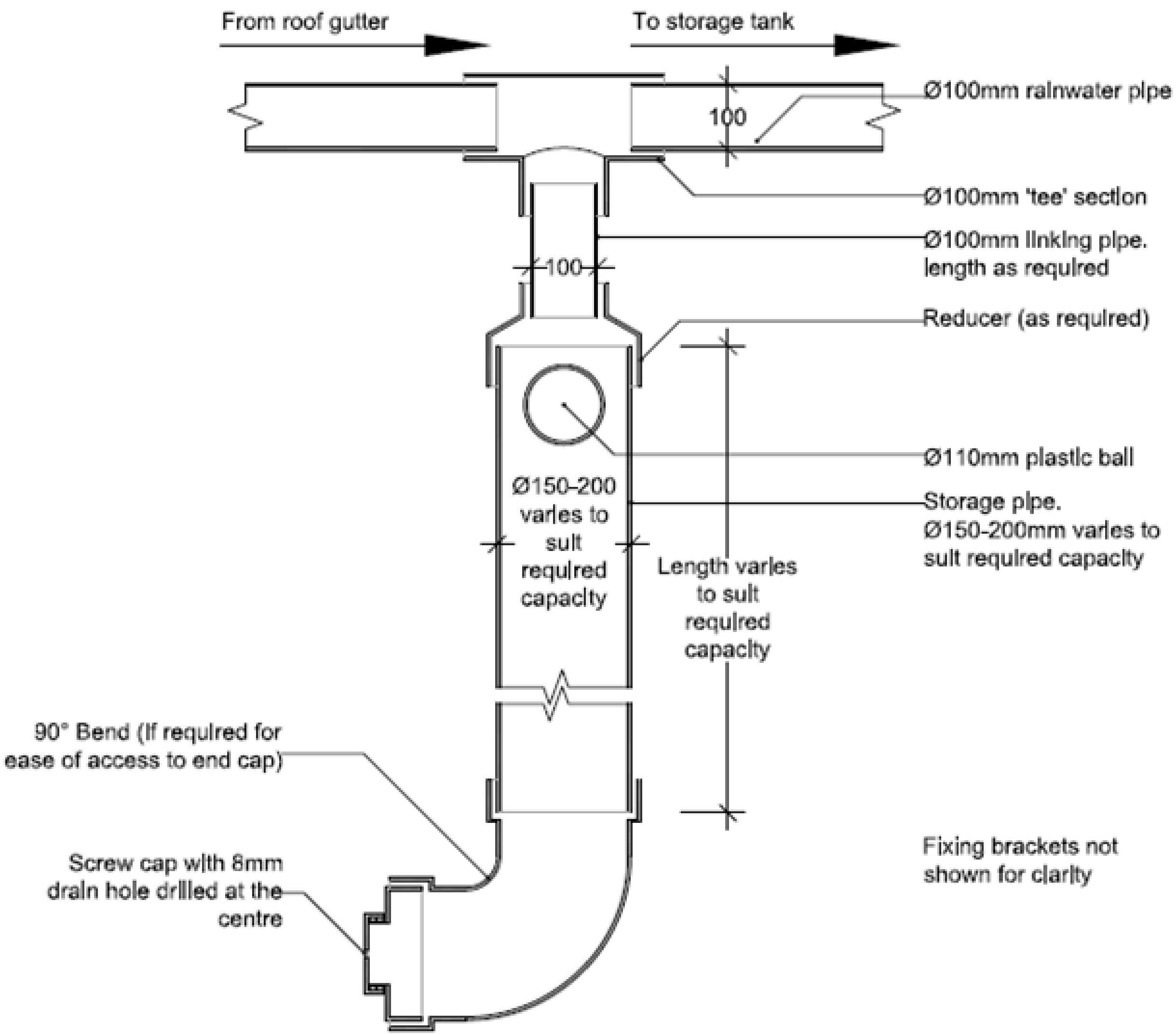


Figure 10: Design of Arkitrek first flush diverter [5]

It is highly recommended that ferrocement rainwater catchment basins be installed by homeowners to lessen the demand on the current aqueduct system, as well as provide needed water. No long period of rainwater deficiency in the western area of Panama occurs; therefore water can be collected any time throughout the year. Problems that may occur with the implementation of the rainwater catchment system would include finding and transporting materials for the first flush system, due to the location of the community on the island.

4.2 Source Protection

The major task in updating the aqueduct system in Valle Escondido will be the construction of a spring box. This will protect the spring sources from possible runoff contamination, which is the first step in ensuring clean water for the community. Testing showed that the quality of the water in the springs was relatively high (from a coliform bacteria standpoint) compared to the other water sources, but there is still a significant amount of sediments entering the source which could cause water quality issues. There is also the potential for future contamination due to land clearing for animal pastures and agriculture upstream of the spring.

The team was able to come up with an efficient and effective design for the springs currently servicing the Valle Escondido aqueduct. The spring box should be constructed with reinforced concrete. These materials are available to the community and will provide the needed durability and protection.

4.2.1 Design Specifications

Generally, there are two types of designs for a spring box: one with a bottom open to collect water from the spring below, and an open sided one to collect water flowing from uphill [6]. The spring pools feeding the aqueduct sat on steep hills, receiving flow from drainage above as well as below, therefore the team has decided to use an integrated design. Figure 11 shows a section-view sketch of this integrated design. The “open” side of the spring box will lack concrete but will be lined with large stones and/or gravel, to filter sediments from the water flowing into the box. This will still have a partial concrete wall for structural support and to prevent surface flow from entering the box, which is more likely to be contaminated.

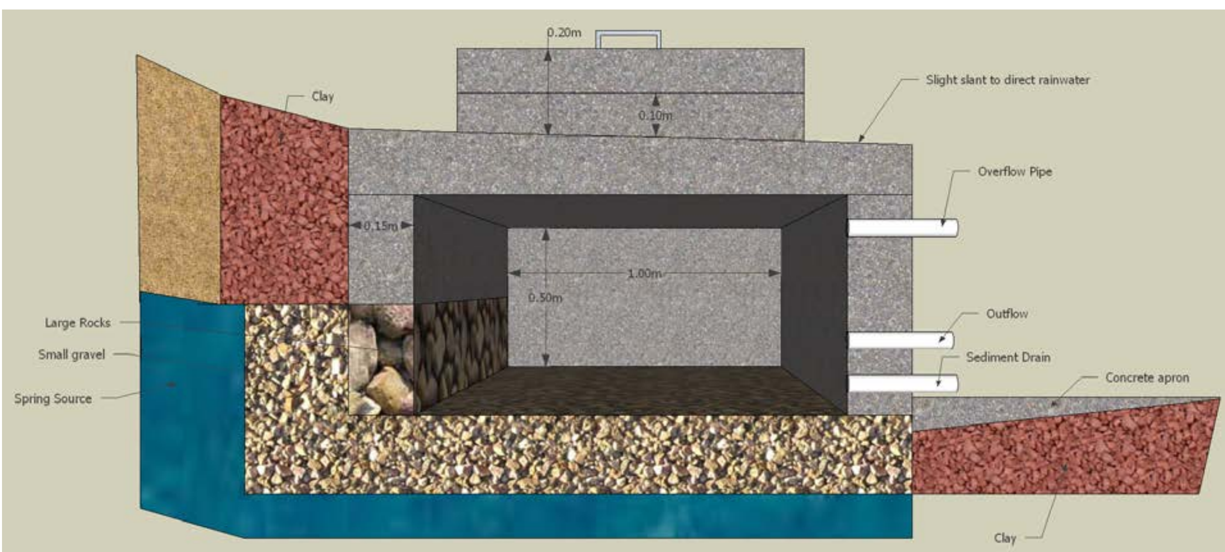


Figure 11: Spring box Schematic Side-view

Other important aspects of spring box include a concrete apron on the front of the box to prevent erosion from water flow from the overflow pipe, and from other surface flow around the spring box [6]. Since this box sits on a steep hill, support on the front side of the box will be important to ensuring its structural integrity. Trenches uphill from the spring box are also recommended, to divert surface flow away before it reaches the box. Also, clay pack around the spring box will provide additional support, as well as prevent surface flow from infiltrating around the spring box. Clay is readily available in the area around the spring box.

The spring box itself will include three different pipe outflows: the water line to the storage tanks; an open, screened pipe to allow for overflow in the event that the box fills completely; and a clean out drain with a valve. The sediment drain will be placed very low in the box to allow the sediments (which will settle to the bottom) to be flushed out. The overflow pipe should be placed very near the top of the front wall of the box, so water only flows out when the box is at its maximum capacity. The water line outflow should be lower so water flows through even when the water level is low, but should not be as low as the sediment drain.

The spring box was also designed with an opening (with a removable cover) to allow for maintenance and cleaning. The dimensions of the opening were estimated based on the space required for a person to be able to reach inside easily. Runoff can be prevented from seeping into the box from under the cover by including a ridge was designed around the opening which will divert water flow. This can be seen in Figure 11, and a detailed view of the top is given in Figure 12.

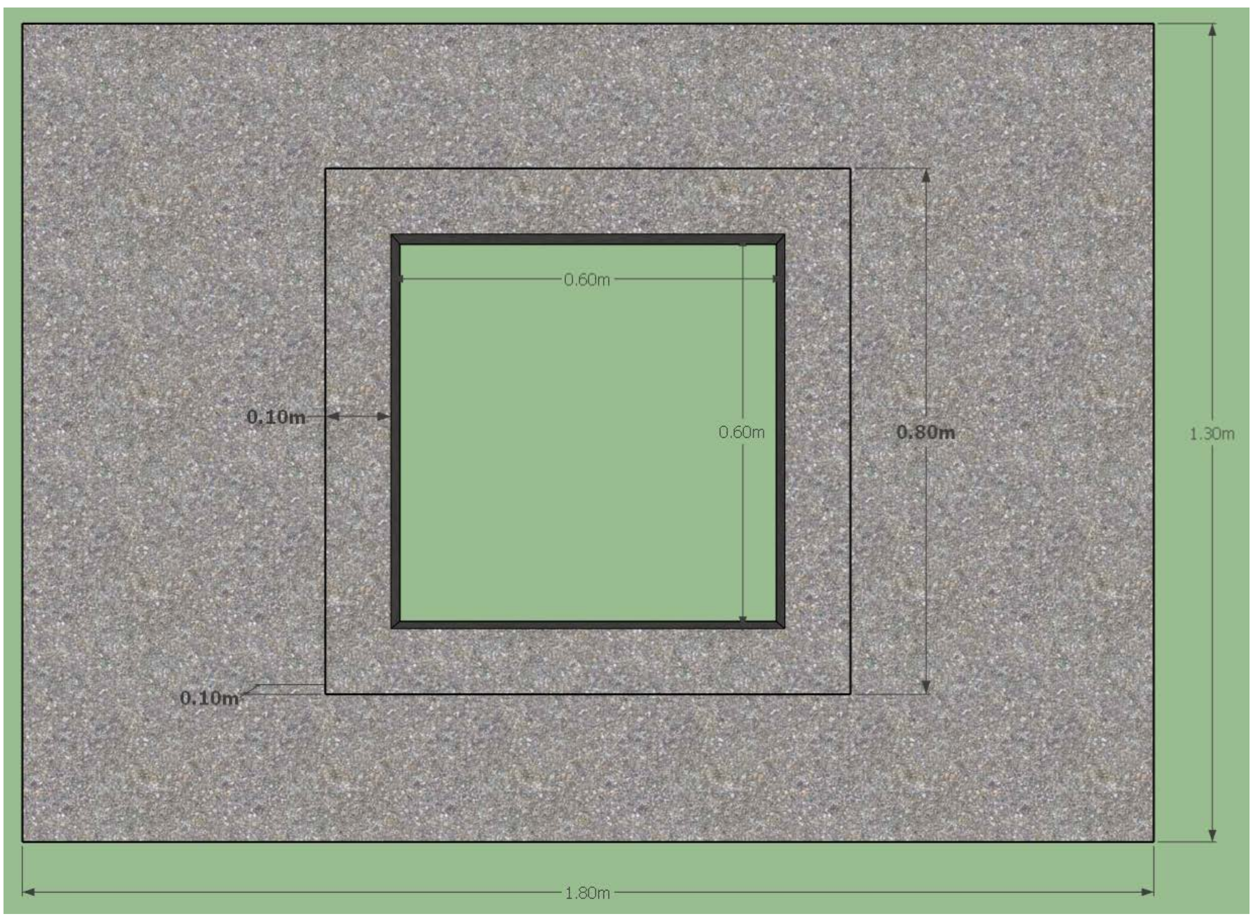


Figure 12: Top view of spring box showing opening with raised ridge

The overall dimensions of the spring box were determined using the current size of the spring pool in order to collect water as efficiently as possible. Based on visual estimates of the length and width of the pool, the team came up with the inner void dimensions shown in Table 4. The height was chosen to allow for some filling of the box, but it was kept as minimal as possible to reduce the amount of concrete required to construct the box. Based on the *Water for the World* manual on constructing spring boxes, the side walls should be approximately 0.15m thick to allow for proper support [6]. Based on this information, the team could then calculate the outside dimensions of the box. These dimensions are summarized in Table 4 and Figure 13.

Table 4: Dimensions for spring box design

Dimension	Inner Chamber (m)	Outer Wall (m)	Opening (m)	Cover (m)
Length	1.5	1.8	0.6	0.7
Width	1	1.3	0.6	0.7
Height	0.5	0.65		
Back wall		0.25		
Thickness	0.15	0.15	0.15	0.15

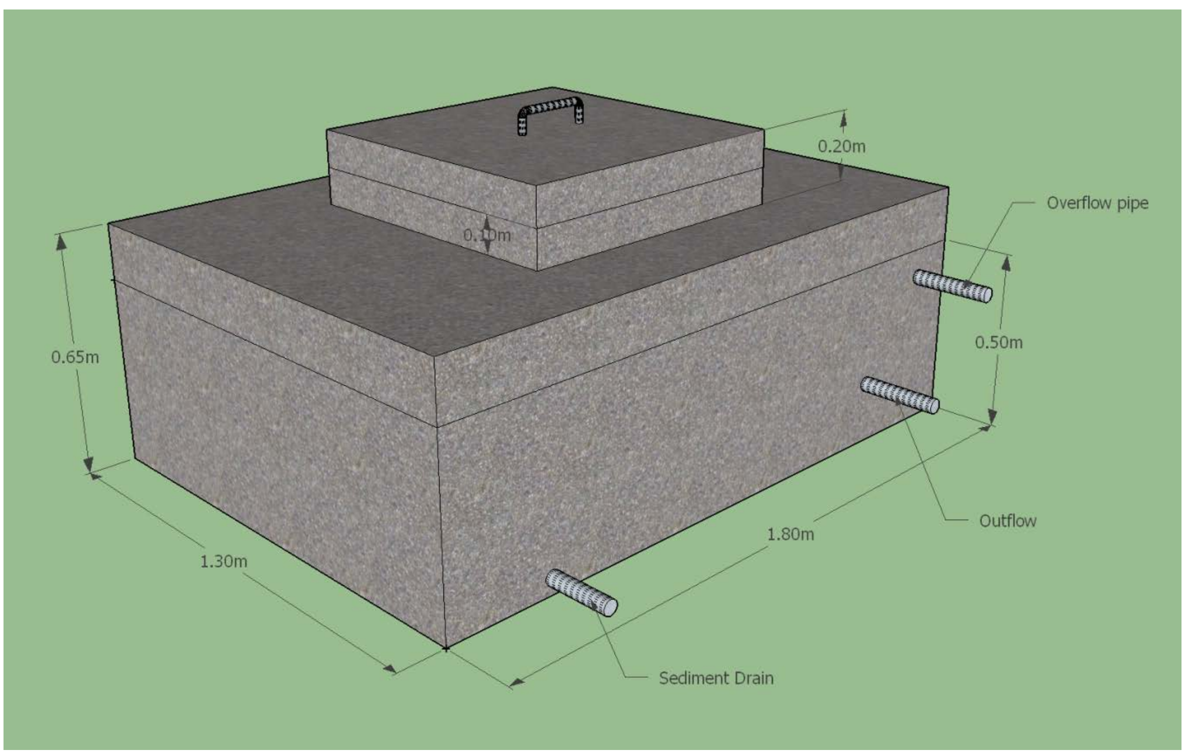


Figure 13: Spring box schematic overall dimensions

4.2.3 Construction and Maintenance

Construction of the spring box will present some difficulties, mostly due to the location of the spring, which is on a steep hill in the middle of the rain forest. However, the community members are familiar with construction on this terrain, so they will have the best idea for a method to complete this project. The team has compiled the following steps as guidelines for the construction process (based on *Water for the World* technical manual's recommendations) [6]:

1. Dig out sediments from the spring pool and clean the area around the spring to ensure good flow. Ideally, one should dig down to a clay layer to ensure maximum flow. Also, dig back into side of the hill open to the box to remove debris.
2. Pile gravel on the uphill side of the spring and hold in place with large stones (approximately 0.25m high). Also pile large stones against the spring for support and foundation, and line the bottom of the spring with gravel.
3. Dig a trench about 8m uphill of the spring to divert surface flow away from the spring. Make it large enough to handle heavy rains, and line with stones.
4. Build wooden forms on site given the *outside* dimensions of the spring. Then use the 0.15m wall thickness to construct forms for the inside of the walls.
    a. Build a form for the spring box top and cover off-site but nearby. Given knowledge of the terrain, a location just uphill of the spring with a relatively flat surface would be best. Do not construct a bottom for any of the forms, except for the top and cover.
5. Be sure the forms are well secured and braced before pouring concrete. Braces can be made by tying wires between the two sides of the brace, nailing boards across the top of the two sides of the brace (be sure to leave open spaces to allow concrete to be poured in), and by nailing boards at an angle to the walls and bracing them in the ground (recommended inside the spring box).
6. Drill holes in the forms at the location of each of the pipe outlets (sediment drain, overflow, and conduction line outflow). Insert section of pipe to be used for these outflows into frame.
    a. Be sure to secure a screen on the overflow pipe to prevent anything from entering the box via this opening.
7. Be sure that no water reaches forms by constructing additional diversion ditches if necessary.
8. Oil the forms with vegetable oil so concrete will not stick to them.
9. Prepare reinforcing rods (shown in Appendix E), and tie together with wire. Handles for the cover (two recommended) can be made using bent rebar, pipe, or other available material. Grids should then be placed in the forms.
10. Mix concrete (recommended one part cement to 2 parts sand and 3 parts gravel, if available. If not, 5 parts sand) and add enough water to form a thick paste (do not add too much water).
11. Pour concrete into the forms and tamp concrete to be sure that the forms are filled completely, with no air pockets. Smooth surfaces.
    a. Top: slope concrete slightly towards the front so rainwater will run off. The top form should also include pieces to create the opening as well as the ridge around the opening. The ridge can be created by adding an extra mold piece and filling, after the main part has been poured.
    b. Insert handles into wet concrete on each end of the cover.

12. Cover with plastic bags to prevent loss of moisture, and be sure to wet the concrete at least daily while it is curing, as if it dries it could crack. Curing should last seven days.
13. After curing, the top piece can be placed on the standing walls and sealed with mortar or wet concrete (be sure to allow for curing of this new concrete). The cover should be placed on top of the box, and the box can then be installed.

Proper maintenance of the spring box will be important to ensuring it stays functional and properly protects the spring water. As per the recommendations of Fry (2004) in her report on spring box construction, a regular maintenance schedule has been compiled in Table 5 [7].

Table 5: Maintenance schedule for spring box [7]

Occurrence	**Activity**
Monthly or more	Cleaning around site (i.e. removing leaves and debris from spring box and drainage canal, clearing brush from trail, etc.)
Every six months (or when water is not clean)	Open spring box and clean walls and floor, wash with bleach. Clear any debris or sediment accumulation.
Unexpected maintenance	Replace broken pipes, repair cracks and leaks.

4.3 Tap Protection

Along with “start of the line” protection from the spring box, “end of the line” protection at the taps is also important. The team observed that the ½” pipes that run into the houses for the taps are exposed to damage from animals and people. A simple tap stand would provide support and protection for the small pipes and reduce the costs associated with replacing these pipes when they are damaged.

There are many options that could be used to construct a tap stand, such as iron pipe, wood, stone, or concrete. However, given the availability of resources in this community, wood seems to be the most reasonable for availability and cost. Concrete and stone would be excessive given that these are not high-use, public taps.

A simple tap stand could be constructed by connecting 2’ x 4’ wood boards in the square pattern shown in Figure 14 below. The figure also shows that metal staples will hold the pipe in place on one of the boards, and a hole can be drilled through this board for the tap to exit. The height of the tap stand would vary depending on the length of pipe up to the house. Overall, the design uses material readily available in the community and a simple design to provide protection for the tap pipes.

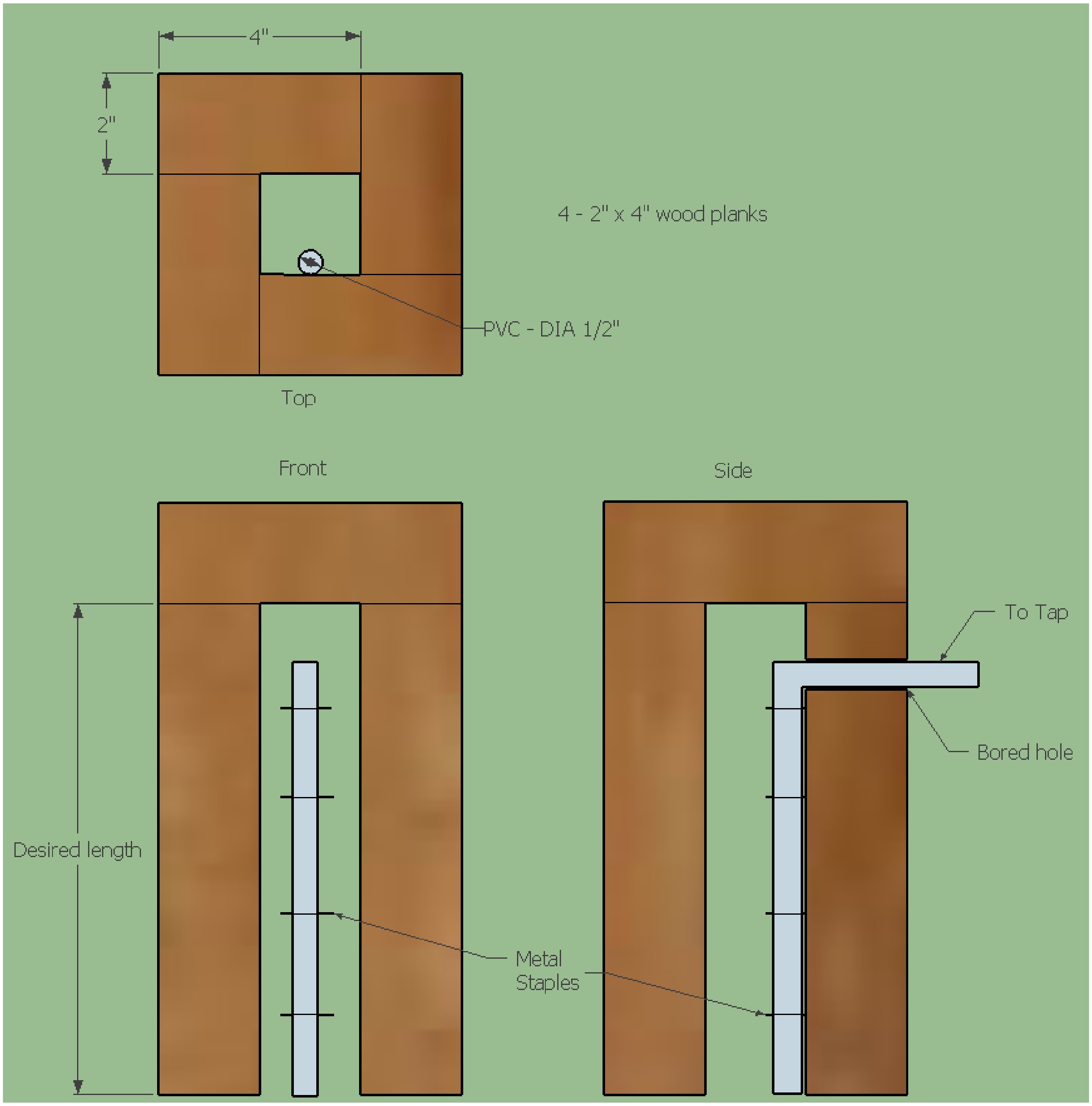


Figure 14: Tap stand schematic drawing

4.4 Aqueduct Expansion

4.4.1 Current Aqueduct System

Valle Escondido currently has an aqueduct system comprised of approximately 1.07 miles of PVC piping in various sizes. Currently, the piping carrying the water from the spring source to the storage tanks is 2” and 1” in diameter, and the piping from the storage tank to the community is 1.5”, reducing to 0.5” at the houses. The elevation change from source to tank is 171 feet, while the elevation change from the tank to the end of the community, where the aqueduct terminates, is 28 feet (Appendix C). There is 0.52 miles of pipe carrying the water from the source to the tank and 0.55 miles of main distribution line carrying the water from the storage tanks to the 17 homes serviced by the aqueduct. The branched segments from the main line to each home are estimated at another 0.21 miles of pipe.

Utilizing data collected from the community and Peace Corps Volunteer (PCV), the monthly water usage for all homes was estimated. The average household consists of 7-10 people, an average of 26 gallons of water per household is being consumed daily. The 17 homes currently connected to the aqueduct system, 180 gallons of water is required weekly for each family. The water use was tabulated below in Table 6.

Table 6: Community water use breakdown

Item	**Water Use (gal/week/family)**
Laundry	90
Meals	83
Drinking	7
Total	180

4.4.2 Proposed Aqueduct System

Using EPANET, a pipe network modeling software, 13 additional homes were added to the existing pipe network system [8]. It was determined that without adjusting any pipe sizes, the additional 13 houses could be added to the water line without the issues of back flow or suction in the pipes. Table 6 tabulates the current water demand per family per week as 180 gallons, however this number is very small, therefore the aqueduct system will be designed for a water usage of 30 gallons per person per day. This demand was modeled with the hourly use pattern shown in Figure 15:

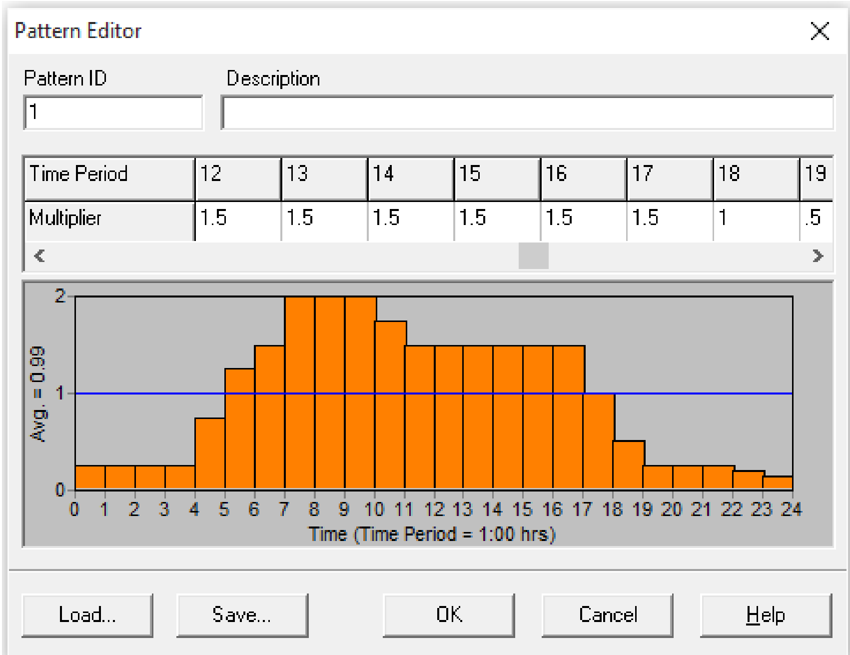


Figure 15: Time varying water demand

The water demand for each household varies with time; there will be more water used in the morning when everyone is awake versus night time when there is minimal water use. The base demand, mentioned above, of 30 gallons per day per person was multiplied by a factor depending on the time of day to complete Figure 15. It is important to note that the base demand used is higher than that of the current base demand. This is to account for an increase in water use due to increased water availability. This time varying water demand was used to determine the average hourly flow rates through the community in Figure 16.

Network Table - Links at 1:00 Hrs

Link ID	Flow GPM	Velocity fps	Unit Headloss ft/Kft	Friction Factor	Reaction Rate mg/L/d	Quality	Status
Pipe 28	0.67	0.28	0.43	0.031	0.00	0.00	Open
Pipe 29	0.67	0.28	0.43	0.031	0.00	0.00	Open
Pipe 30	0.65	0.27	0.42	0.032	0.00	0.00	Open
Pipe 31	0.65	0.27	0.42	0.032	0.00	0.00	Open
Pipe 32	0.64	0.26	0.41	0.033	0.00	0.00	Open
Pipe 33	0.62	0.25	0.40	0.034	0.00	0.00	Open
Pipe 34	0.60	0.24	0.38	0.035	0.00	0.00	Open
Pipe 35	0.58	0.24	0.37	0.036	0.00	0.00	Open
Pipe 36	0.56	0.23	0.36	0.037	0.00	0.00	Open
Pipe 37	0.54	0.22	0.35	0.038	0.00	0.00	Open
Pipe 38	0.52	0.21	0.33	0.040	0.00	0.00	Open
Pipe 39	0.50	0.20	0.32	0.041	0.00	0.00	Open
Pipe 40	0.50	0.20	0.32	0.041	0.00	0.00	Open
Pipe 41	0.50	0.20	0.32	0.041	0.00	0.00	Open

Figure 16: Descending pipe flows in the community

Currently, 1.5'' diameter piping is used for the main water line in the community; using the EPANET model it was determined that replacing this piping with a smaller diameter piping would lead to negative pressure in the system. The water line would then branch off into 0.5'' piping to the houses. Furthermore, the water line from the spring sources to the concrete collection tank is not consistent, with the piping diameter changing from 2'' to 1''. Standardizing this water line to all 2'' piping will allow greater volumes of water to be carried to the collection tanks. There will be less head loss going from the source to tank increasing pressure and flow in the water line.

Furthermore, it was determined that the additional 13 homes would not have much effect on the water level in the collection tanks. In fact, the water levels in the tanks are remaining at full volume, even during peak usage hours. This can be attributed to the standardization of the waterline from the spring sources to the tanks, as mentioned previously. Pressure in the community water line is adequate ranging from 2-3 psi from the top of the tanks to 7-13 psi through the middle to bottom of the community. Survey data for pipe lengths are tabulated below in Table 7. These were also used to calculate the cost estimate:

Table 7: Pipe Length Estimations

Sample Pipe Size	Length (ft)	15% Additional (ft)
0.5''	1969	2264
1.5''	4436	5101
2.0''	2937	3377
Total	9341	10741

4.5 Aqueduct Storage & Treatment Improvements

4.5.1 Water Treatment

Additionally, Todo Debe recommends that an in-line chlorinator, constructed from PVC, be added as the water line approaches the storage tanks as shown below in Figure 17. Currently, the water is chlorinated by removing the tank door and adding the appropriate amount of household bleach. The addition of this chlorinator will reduce the frequency of maintenance required of the system operator. The water entering the in-line chlorinator passes through a capped tee fitting holding chlorine tablets, into the storage tank, offering enough time for sufficient treatment. These tablets are available locally at a cost of $2 each. It is estimated that two tablets will be needed each week for treatment, as estimated in the User Field Guide. A chlorine concentration of 0.20 mg/L is recommended in the User Field Guide for MINSA's In-Line Chlorinator, per tests conducted in another region of Panama using the same chlorinator. A contact time for the 1,250 gallon tanks was calculated to be 93 minutes to treat the typical pathogens listed by Panama's Ministry of Health, with the highest contact time requirement being 35 min-mg/L, as listed in Table 8 [9]. Appendix F details the calculation for contact time.

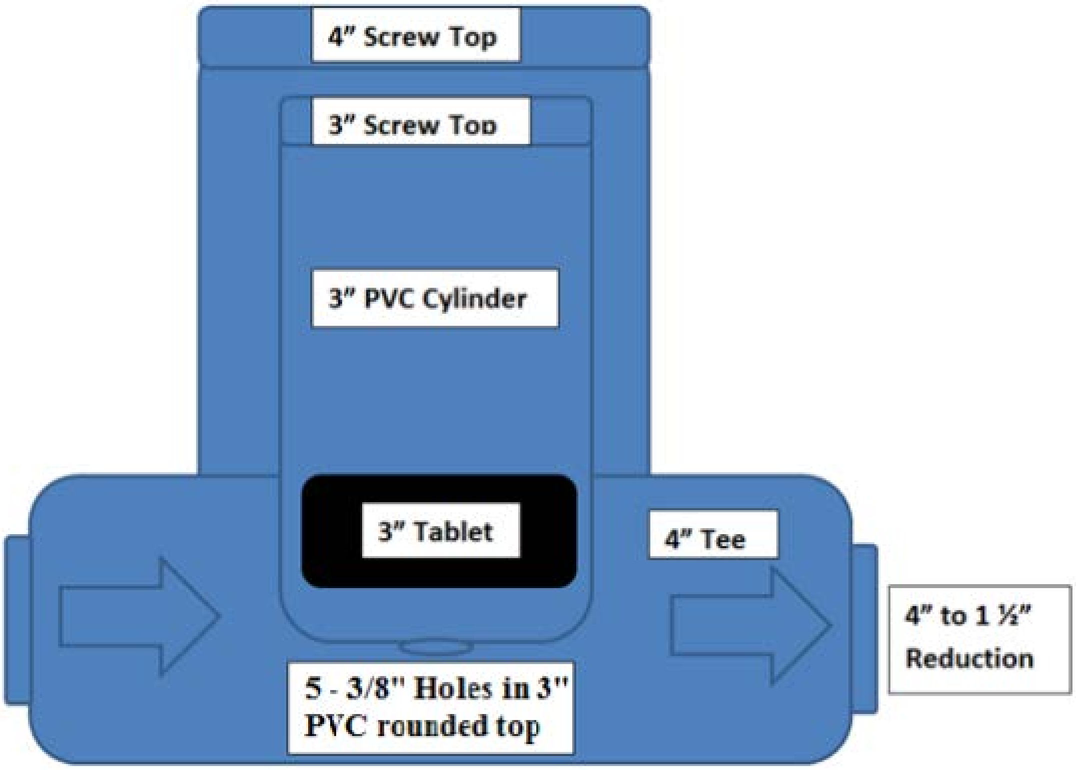


Figure 17: MINSA In-Line Chlorinator

Table 8: Concentration - Contact Time Required per Pathogen (Adapted from CDC, 2013)

Pathogen	Ct Requirement (min-mg/L Cl_2)	Temperature (C^o)	pH
Salmonella typhi	1	20-25	7
Hepatitis A	0.41	25	8
Giardia lamblia	15	25	7
E. coli	0.25	23	7
E. Histolytica	35	27-30	7
Vibrio cholerae	0.5	20	7
Rotavirus	0.05	4	7

4.5.2 Storage Recommendations

Currently, the community possesses one 500 gallon concrete tank, as well as three 1,250 gallon plastic tanks. The three larger tanks are plumbed in-series, but are seldom used as a result of poor experiences in the past. Previously, these larger tanks were filled and then left sitting stagnant while the 500 gallon tank served the community. This stagnancy caused poor water quality and led to the continued disuse of the 4,250 gallons of total storage. Todo Debe recommends that these tanks be piped in series so that all of the storage can be utilized. As mentioned above, the current estimate for water demand, provided by the PCV, is less than 1300 gallons per month. However, Todo Debe believes this to be a very low estimate and also anticipates that the usage of the system will increase greatly once the recommended improvements have been made, wherein the full storage amount will be useful. The problem of stagnancy will be remedied with the proposed chlorinator detailed above. The proposed system, featuring the 1,250 gallon tanks, are to be fed directly from the source after which the water will flow to the 500 gallon cement tank where the outflow pipe to the community is installed. The chlorinator is to be placed before the water from the source enters the 1,250 gallon tanks, as the required contact time is calculated based on the total volume of all the tanks.

5. Scheduling

A simple construction timeline was compiled for each design proposal in order to organize the tasks and also to give those involved with the construction an idea of the commitment and work required. These estimates are based on reasonable considerations for human labor, as well as knowledge of this specific community's work practices. Table 9 displays a general schedule for constructing the rainwater catchment system. Values in yellow must specifically be finished within the time frame, as they are time sensitive. Other tasks are less time sensitive to complete. No labor costs have been associated with the tasks, because there is no need for skilled labor to be hired out. It is assumed homeowners will construct their own tanks and systems, with supervision by the PCV.

Table 9: Schedule Estimates for rainwater catchment system construction

Task	**Time (days)**	
	Min	**Max**
Boat transport	1	1
Construct & cure rainwater tank	8	10
Construct wooden stand	1	2
Install PVC gutters	1	3
Connect first flush & mesh between gutters & tank	1	2
Totals	11	16

Table 10 was assembled for the spring box construction, assuming that 3 community members will assist with construction on this project. Since professional laborers or construction crews will not be hired, many of these times are flexible. However, those few tasks that have a strict time frame are highlighted in yellow.

Table 10: Schedule Estimates for Spring Box Construction

Task	Time (days)	
	Min	Max
Materials pick up with boat	1	1
Build forms	2	4
Place, brace, and oil forms	2	3
Dig Trenches	1	2
Prepare rebar	3	5
Carry Materials to site	1	2
Mix and pour concrete	1	1
Curing and wetting	7	8
Installation of spring box	1	1
Totals	19	27

An estimated construction schedule for aqueduct replacement and expansion is detailed below in Table 11. Digging the pipe trench for a 15' section, and material pick up have the greatest variability between the minimum and maximum time due to uncontrollable factors. Weather may extend the time needed to complete a task; another thing to note is that Todo Debe included the total time to complete a 15' section. The reason for this is because it is more likely that the community of Valle Escondido will complete the aqueduct replacement and expansion in sections rather than as a whole. The total time to complete a 15' section is 3.6 hours to 7.7 hours. The difference, as mentioned previously, is to account for changing conditions such as weather or variability in terrain. Additionally, the total time to complete the whole aqueduct system is 2577.84 hours (107.4 days) to 5513.71 hours (229.74 days). These values were determined by the time for a 15' section and multiplying this number by the number of 15' sections in the aqueduct system, see Appendix H for example calculations. It is important to note that task labeled "materials pick up with boat" is a singular task and is independent from the tasks associated with pipe replacement. Additionally, the schedule to complete the aqueduct assumes only one person, if there is additional support from community members then the schedule to replace and expand the aqueduct will be shorter.

Table 11: Estimated schedule for aqueduct expansion and replacement

Task	Time (hrs)	
	Min	**Max**
Materials pick up with boat	24	48
Dig Pipe Trench Section	3	6
Install Piping Section	0.1	0.2
Bury Piping Section	0.5	1.5
Total Time for 15' Section	3.6	7.7
Total Time for whole system	2577.84	5513.71

6. Materials/Cost

The overall cost of improvements and supplements to the system in Valle Escondido is estimated to be $9302.35. The majority of the cost is in the replacement and expansion of the existing aqueduct, at $4552, with the second largest cost being the individual rainwater catchment tanks for each home totaling $4271. The chlorinator comprises a very small portion of the overall cost. The costs listed in the tables below are based on both material costs obtained while in-country, and from online research. It should be noted that labor is not an item, as none of the labor for the proposed design is 'skilled' and therefore does not require outside assistance and associated labor costs. It should also be noted that for the rainwater catchment estimate, the transportation cost (boat pick-up with gas) of $20 is included with each family's tank, as we cannot assume they will all be constructed at once. Lastly, the chlorinator pricing does not include the weekly addition of chlorine tablets.

A summation of the costs for each individual aspect is shown in Table 12 below.

Table 12: Sum of estimated costs

Item	Description	Estimated Quantity	Unit	Unit Cost	Total Cost
1	Spring box	3	Individual	$153.50	$460.50
2	Aqueduct Expansion	1	Individual	$4552.00	$4552.00
3	Chlorinator	1	Individual	$19.15	$19.15
4	Rainwater Catchment	30	Individual	$142.00	$4271.00
				Total:	**$9302**

5.1 Rainwater Harvesting

Materials needed for an individual rainwater catchment system are shown in Table 13. The material quantities and cost were given by the PCV based on the prototype she constructed [10]. Constructing the catchment tank requires 1-2 days for the mixing of cement and sand to create ferrocement. The tanks will be framed with rebar and chicken wire and covered in ferrocement, alternating layers of chicken wire and ferrocement to create the cylindrical shape. Curing the tank consists of maintaining moisture within the tank by wrapping the tank with trash bags, and watered daily for 7-8 to prevent cracks or chipping. The tank will sit on a wooden stand, made of 2x4 boards constructed locally. Water enters the tank through PVC piping from the roof, through a mesh screen filter, and first flush system to reduce the amount of particles, sediment, and other undesirables entering the tank. All materials can be found either on Isla Cristobal or in the nearby city of Almirante in Bocas Del Toro. Final estimates for an individual catchment system were made, and multiplied by a factor of 30 to account for all current homes within the community to calculate the cost for all members to own a rainwater harvesting system.

Table 13: Cost estimates for rainwater catchment system materials

Item	Description	Estimated Quantity	Unit	Unit Cost	Total Cost
1	Cement Sack	1	1 Sack (94 lbs)	$ 9.50	$ 9.50
2	Bags of Sand	1	6 Bags	$ 11.50	$ 11.50
3	Box of Trash Bags	0.16	25 Pack of bags	$ 4.50	$ 0.72
4	Chicken Wire	1	60 ft	$ 24.00	$ 24.00
5	#4 Rebar	1	1 lb	$ 0.95	$ 0.95
6	Wood	4	2x4 Boards	$ 8.00	$ 32.00
7	PVC 2" Pipe	4	15 ft pipe	$ 7.50	$ 30.00
8	PVC 2" Elbow	1	Individual	$ 0.75	$ 0.75
9	PVC Connection	1	Individual	$ 0.45	$ 0.45
10	Plastic Ball	1	2" Diameter	$ 5.00	$ 5.00
11	Mesh	0.1	Square foot section	$ 75.00	$ 7.50
12	Boat Transport	1	Boat ride, gas, transport	$ 20.00	$ 20.00
			Total (Individual Home)		$ 142
			Total (Community of 30)		**$ 4,300**

5.2 Spring Box

Cost is an important consideration for this project since funds are limited in the community. Since it is assumed that there will be no labor costs, the only costs for the spring box will come from the materials. The costs of many materials was known from the cost breakdown given by the PCV for the rainwater catchment tank [10]. In order to determine the amount of cement and aggregate needed, the volume of concrete required to make the spring box needed to be calculated (see Appendix G for calculations). Assuming a cement to aggregate ratio of 1:5, it can be assumed that one 100lb bag of cement will produce 4.5ft^3 of concrete, which is approximately 0.127m^3 [11]. Based on this, and a concrete volume of approximately 0.753m^3, the spring box will require 6 bags of cement and therefore 30 bags of sand (ideally some of which will be gravel, if available). Table 14 summarizes materials necessary for the spring box, as well as the total costs of these.

Table 14: Cost Estimate for spring box materials

Item	Description	Estimated Quantity	Unit	Cost Per Unit	Total Cost
1	Cement	6	sack	$9.50	$57.00
2	Sand/Gravel	30	bag	$1.92	$57.60
3	Trash bags (25/box)	1	box	$4.50	$4.50
4	6mm rebar	9	20ft sections	$1.60	$14.40
5	Boat pick-up (gas and rental)	1	each	$20	$20
				Total =	$153.50

Another important part of concrete construction is the reinforcement. 6mm rebar was determined to be a reasonable and available type of rebar from previous spring box projects in Panama [12]. A grid pattern with approximately 0.15m spacing was designed for the top and cover of the spring box, since these pieces would be affected by sag as well as people standing on them. The side walls had much simpler reinforcing, since they would not have as much pressure being exerted on them and therefore required much less rebar. In order to ensure the rebar would not extend outside of the concrete but still provide maximal reinforcement, the length of each piece of rebar is to be 0.05m less than the outside dimensions of the spring box. A schematic of each rebar configuration is shown in Appendix E. Given these designs, the length and number of bars is given in Table 13, and the total length of rebar is calculated to 45.05m. One meter of rebar was added to create a handle for the cover, and then this value was increased by 15% to account for laps and cutoffs. Since rebar is sold in 20ft (6m) sections, it was determined that approximately 9 sections of rebar would be required. The total cost of this rebar is given in Table 15.

Table 15: Rebar dimensions and total length/weight estimates

Piece	Dimension	Value (m)	# of bars	Length of bar (m)	Total length (m)
Lid	Length	1.8	4	1.75	7
	(around hole)	0.6	8	0.55	4.4
	Width	1.3	8	1.25	10
	(around hole)	0.35	8	0.3	2.4
Cover	Length	0.6	3	0.55	1.65
	Width	0.6	3	0.55	1.65
Front	Length	1.8	2	1.75	3.5
	Height	0.5	5	0.45	2.25
Left Side	Width	1.3	2	1.25	2.5
	Height	0.5	3	0.45	1.35
Right Side	Width	1.3	2	1.25	2.5
	Height	0.5	3	0.45	1.35
Back	Length	1.8	2	1.75	3.5
	Back Height	0.25	5	0.2	1
				Total =	45.05 m
				add 1m for handle	46.05 m
				15% increase for laps and cutoffs	53 m

The other items shown in Table 15 include plastic trash bags, used to cover the concrete while it cures, and the cost of the boat trip in order to pick up materials. Both were given in the rainwater tank breakdown, and it was estimated that one box of trash bags would be sufficient for one spring box. It is assumed that all the materials would be carried over to Isla San Cristobal in one boat trip.

5.3 Aqueduct Expansion and Replacement

Conservative estimates for the costs of replacing and expanding the current aqueduct system are tabulated below in Table 16. The estimated amount of piping includes 15% extra in order to account for unforeseen circumstances such as breakages. It is important to note that the unit costs for the 0.5'' piping and 2.0'' piping were obtained from the Peace Corps volunteer, while the other unit cost estimates were obtained from a past iDesign report [12].

Table 16: Cost Estimate for aqueduct expansion and replacement

Item	Description	Estimated Quantity	Unit	Unit Cost	Total Cost
1	0.5'' SDR 26 PVC	2264	15'	$2.95	$446
2	1.5'' SDR 26 PVC	5101	15'	$6.50	$2,210
3	2.0'' SDR 26 PVC	3377	15'	$7.50	$1,689
4	SDR 26 PVC TEE 1.5'', 1.5'' - 0.5''	35	Individual	$4.00	$140
5	SDR 26 PVC TEE 2'', 2''- 2''	6	Individual	$4.50	$27
6	Transportation	2	Individual	$20.00	$40
				Total:	**$4552**

The piping, with the 15% excess, will cost approximately $4,552. Furthermore, it is recommended that the piping, where feasible, be buried. While this may be more difficult near the spring box due to difficult terrain and hard soil. As the pipeline enters areas inhabited by both humans and animals, it is very crucial that the pipe be buried to prevent potential damage and contamination. In areas where burying the pipe is not feasible, it is recommended that the piping be encased in another, larger diameter, PVC pipe to offer some protection. Todo Debe recommends a minimum burial depth of 1 foot.

The in-line chlorinator used to improve the water quality will have minimal cost compared to the other projects. Table 17 shows a breakdown of the chlorinator components and their cost.

Table 17: Cost Estimate for in-line chlorinator

Item	Description	Estimated Quantity	Unit	Unit Cost	Total Cost
1	4" PVC Tee	1	Individual	$5.00	$5.00
2	4" PVC Cap	1	Individual	$2.15	$2.15
3	1" - 4" Reducer	2	Individual	$3.00	$6.00
				Total:	**$19.15**

6. Conclusion

Todo Debe Engineering makes a number of recommendations and respective calculations regarding modifications to the water resources that exist in the community of Valle Escondido. Implementing rainwater catchment systems consisting of PVC gutters, mesh screen, a first flush system, ferrocement tank, and wooden stand will ensure clean drinking water to homeowners. An integrated open bottom and open side spring box will protect the source of the aqueduct water that is distributed to the community. Providing tap stands to individual homes will protect the water from accidental breakage. Expanding and updating the current aqueduct system will also contribute to more sanitary drinking water for the entire community. Utilization of the current storage tanks will increase the amount of water available for use, and providing a chlorination treatment system will inactivate pathogens and bacteria present in the water. Todo Debe Engineering believes each of the proposed solutions offers increased water security and quality, therefore improving the overall health and well-being of community members.

7. Acknowledgements

Todo Debe Engineering would like to acknowledge Dr. Dave Watkins, Mike Drewyor and PCV Katie Ahern for their assistance in the formulation of these conclusions for Valle Escondido.

8. References

[1] 3M Petrifilm E.coli/Coliform Count Interpretation Guide, *3M Food Safety,* AOAC INTERNATIONAL (2014)

[2] "Historical Climate Data." *Hidrometeorología*. ETESA, n.d. Web. <http://www.hidromet.com.pa/clima_historicos.php>. Accessed: 9 Sept. 2015.

[3] Mihelcic, James R. et al. "Rainwater Harvesting." Field Guide to Environmental Engineering for Development Workers: Water, Sanitation, and Indoor Air. Reston, VA: ASCE, 2009. 318-30.

[4] "Downpipe First Flush Diverters." Rain Harvesting. Rain Harvesting, 2010. Web. <http://rainharvesting.com.au/product/downpipe-first-flush-diverters/>. Accessed: 14 Oct. 2015.

[5] Arkitrek. "First-Flush Diverter." Arkitrek. Arkitrek, 1 Apr. 2013. <http://arkitrek.com/http:/arkitrek.com/first-flush-diverter/>. Web. Accessed: 14 Oct. 2015.

[6] "Water for the World", Constructing Structures for Springs, *Technical Note No. RWS. 1.C.1*

[7] Fry, L., "Spring Box Design and Construction", CE 5993 Michigan Technological University Department of Civil & Environmental Engineering

[8] L. A. Rossman, "EPANET 2: User's Manual," Environmental Protection Agency, September 2000. [Online]. Available: nepis.epa.gov/Adobe/PDF/P1007WWU.pdf. [Accessed 16 October 2015].

[9] B. Yoakum., "User Field Guide for MINSA's In-Line Chlorinator." U.S. Peace Corps. August, 2013.

[10] K. Ahern, 'Data collection interview for Valle Escondido', Valle Escondido, Isla San Cristobal, Bocas del Toro, Panamá. 16 Aug. 2015

[11] Portland Cement, SAKRETE, cpmproducts.com/docs/Cement.pdf Accessed: 17 Nov. 2015

[12] J. Ammerman, V. Leveille, J. Robinson, and N. Zgnilec, "Providing safe drinking water to the Quebrada Arena Community of Panama", *Michigan Technological University*, Dec. 2013

APPENDICES

APPENDIX A

Drinking water quality test locations

Figure A1: Drinking water Well (Pozo) 1

Figure A2: Drinking water Well (Pozo) 2

Figure A3: Drinking water Well (Pozo) 3

Figure A4: Drinking water Well (Pozo) 4

Figure A5: Aqueduct spring currently in operation (Ojo viejo)

APPENDIX B

3M petrifilm count plate results

***Note: Red dots indicate coliform bacteria colonies while blue dots are E.coli colonies.**

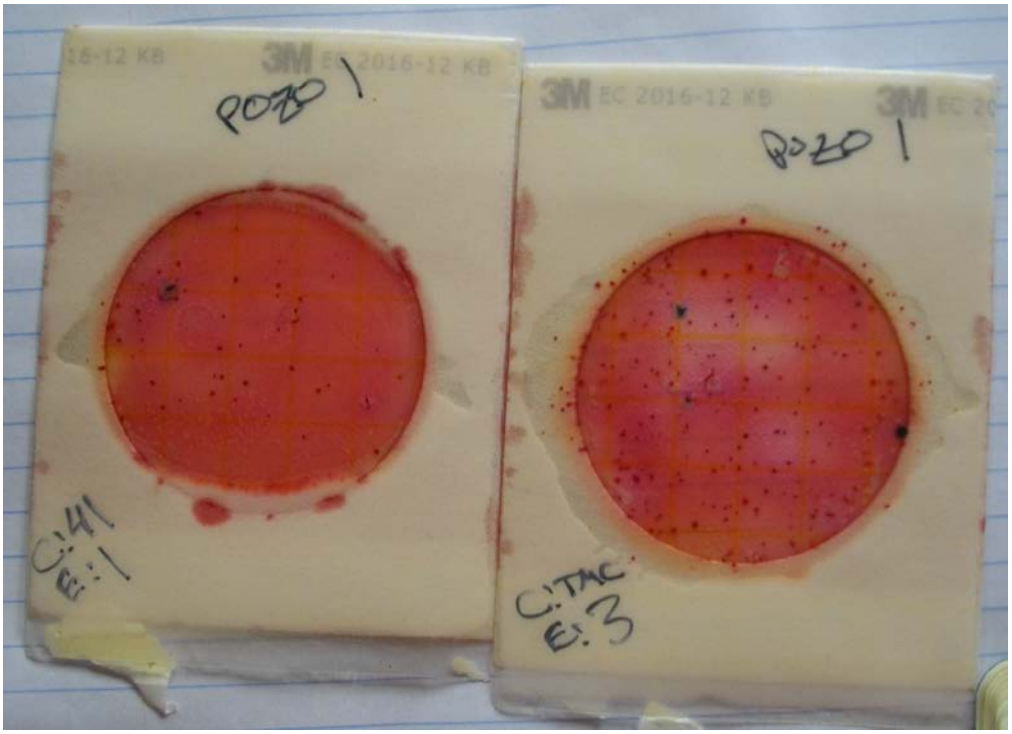


Figure B1: E.coli/Coliform Count Plates for Well 1

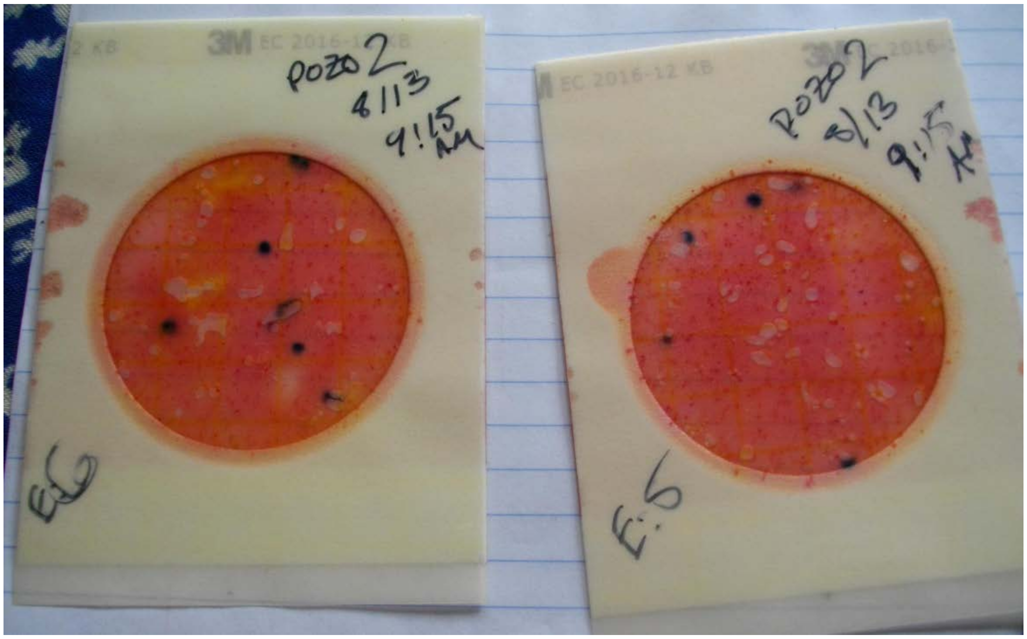


Figure B2: E.coli/Coliform count plates for Well 2

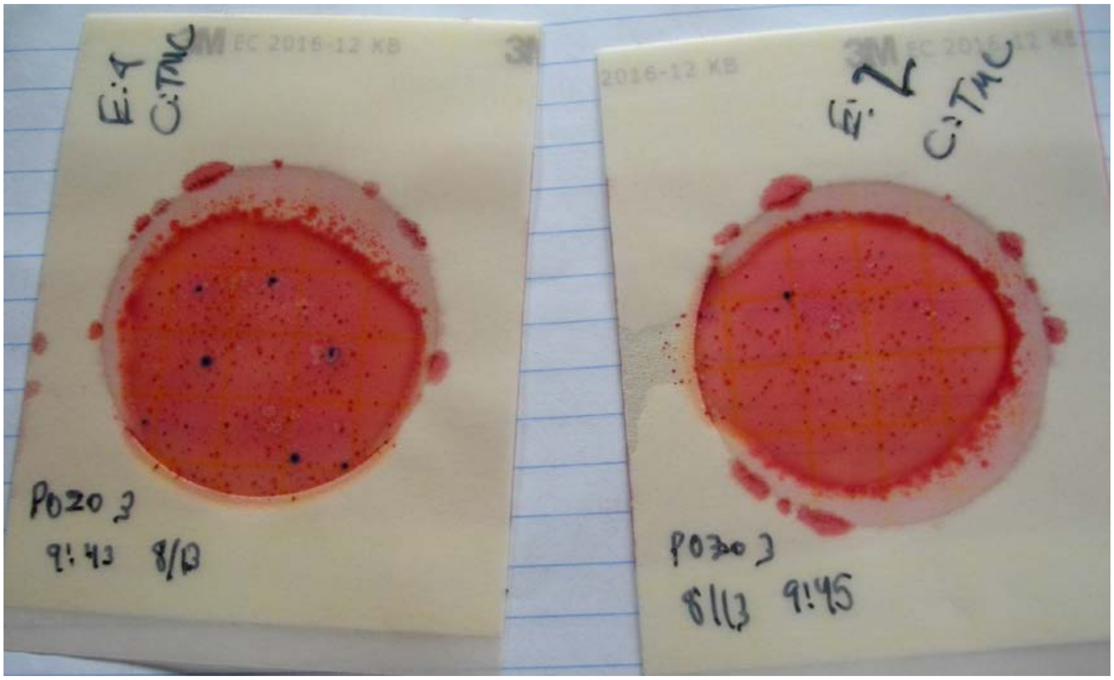


Figure B3: E.coli/Coliform count plates for Well 3

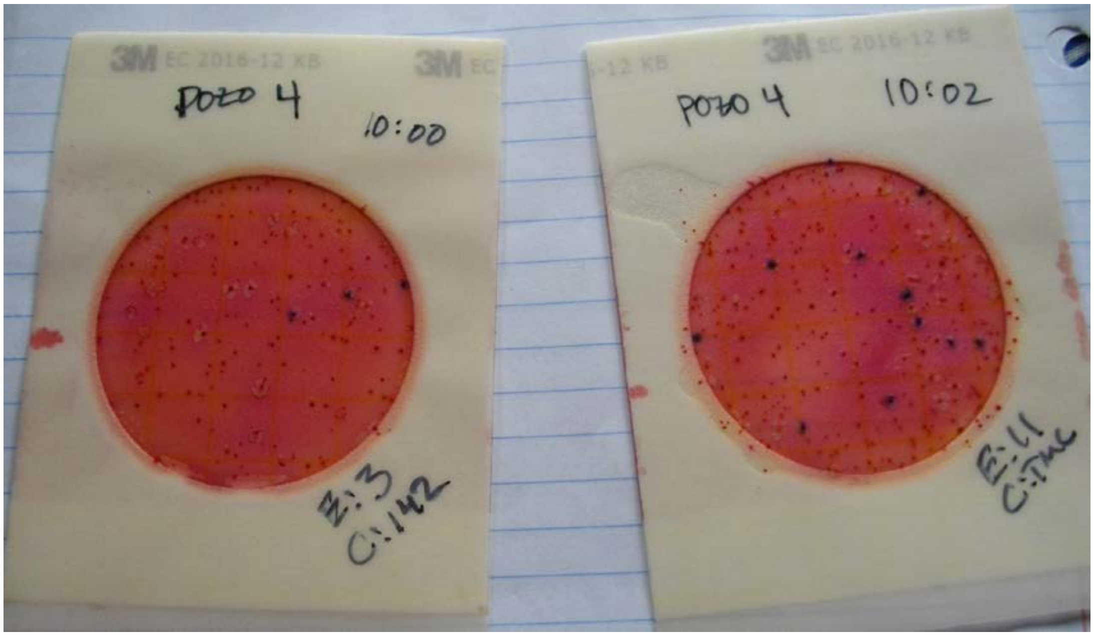


Figure B4: E.coli/Coliform count plates for Well 4

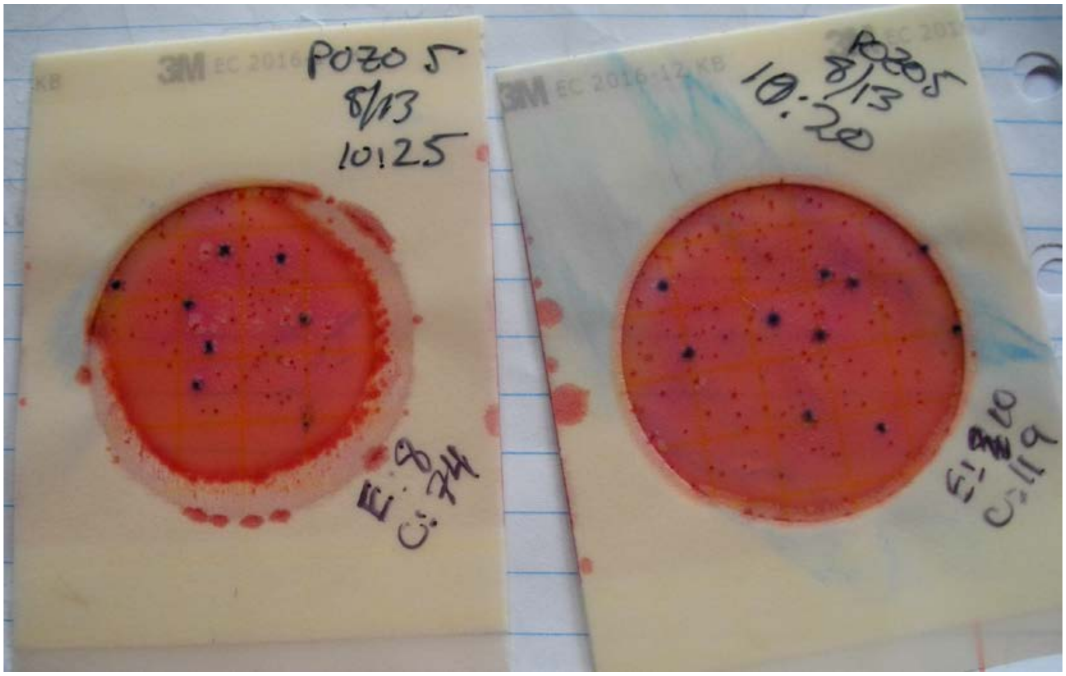


Figure B5: E.coli/Coliform count plates for Well 5

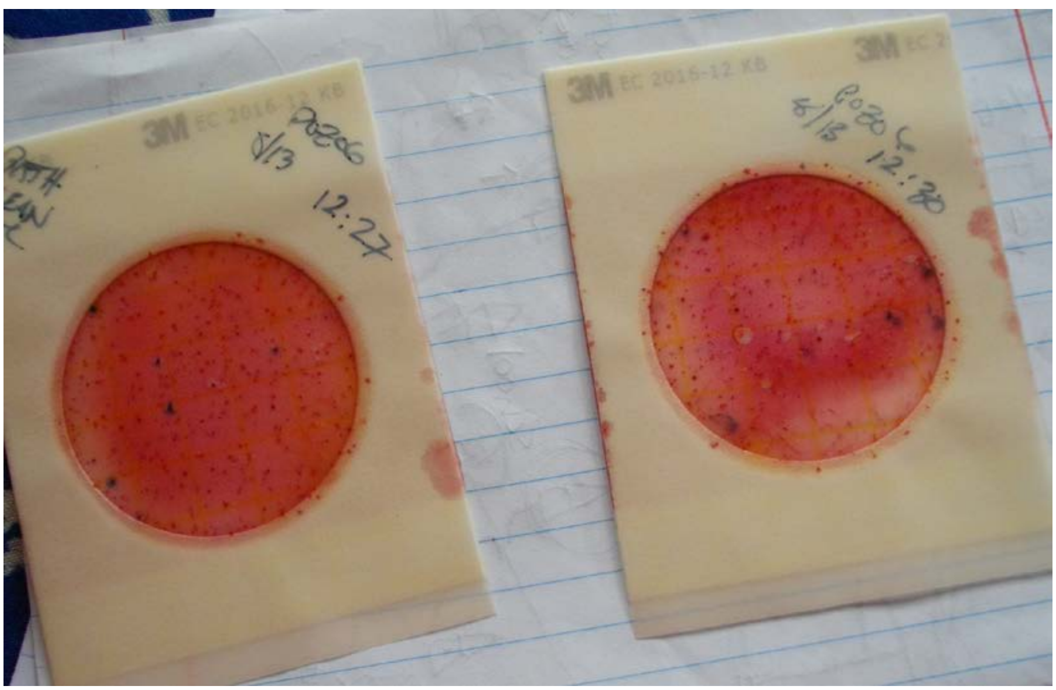


Figure B6: E.coli/Coliform count plates for Well 6 (bathing and laundry area)

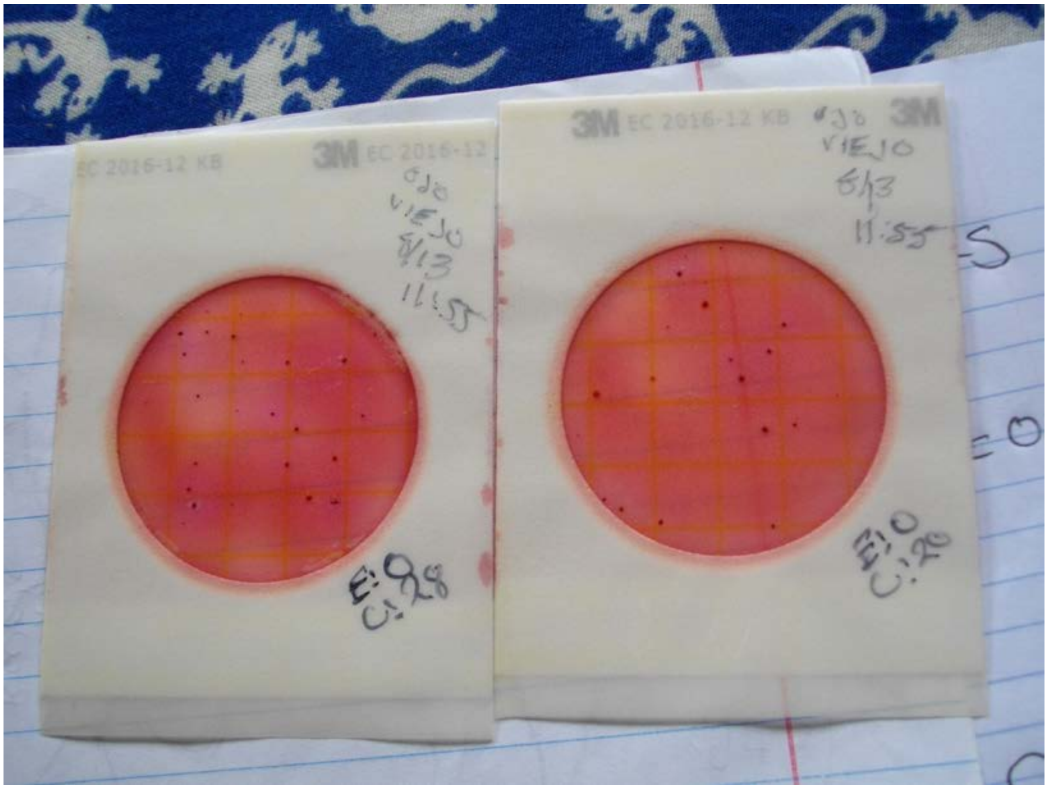


Figure B7: E.coli/Coliform count plate for the Old Spring (Aqueduct source)

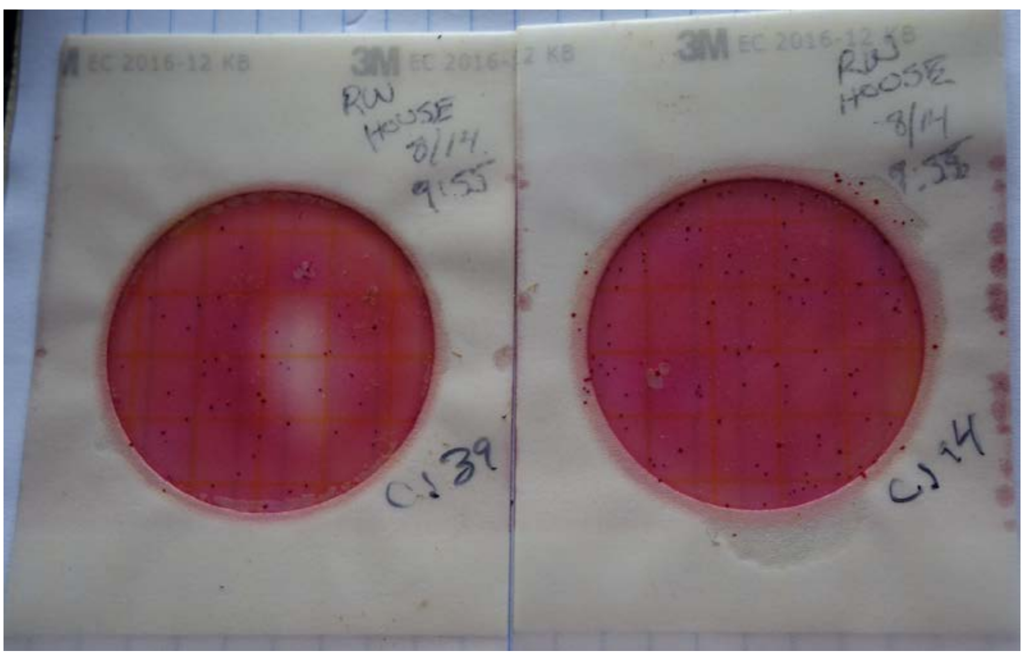


Figure B8: E.coli/Coliform count plate for roof rainwater sample

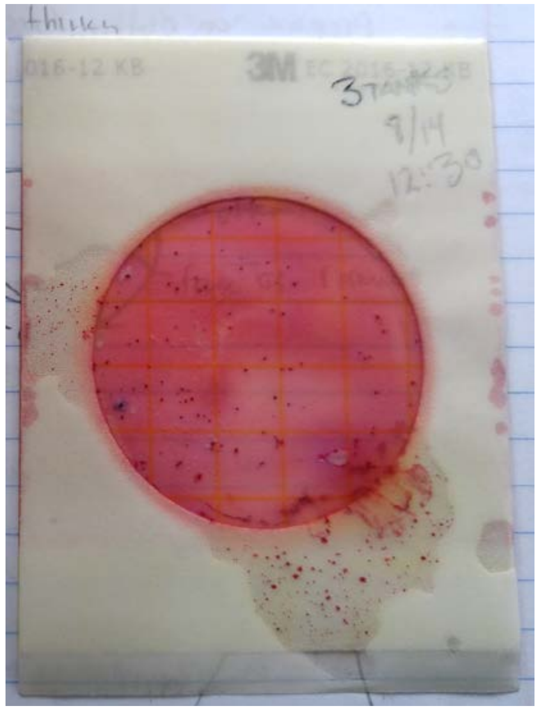


Figure B9: E.coli/Coliform count plate for the three large storage tanks

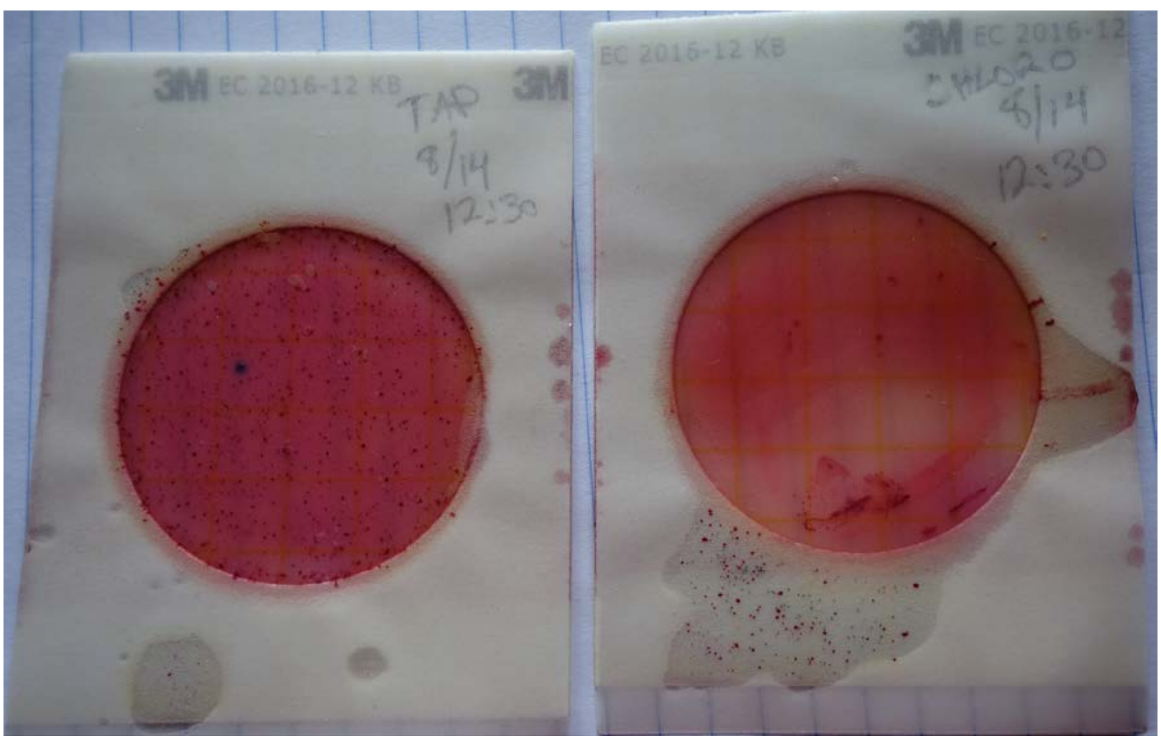


Figure B10: E.coli/Coliform count plates for untreated tap water and chlorinated tap water

APPENDIX C

Aqueduct elevation profiles

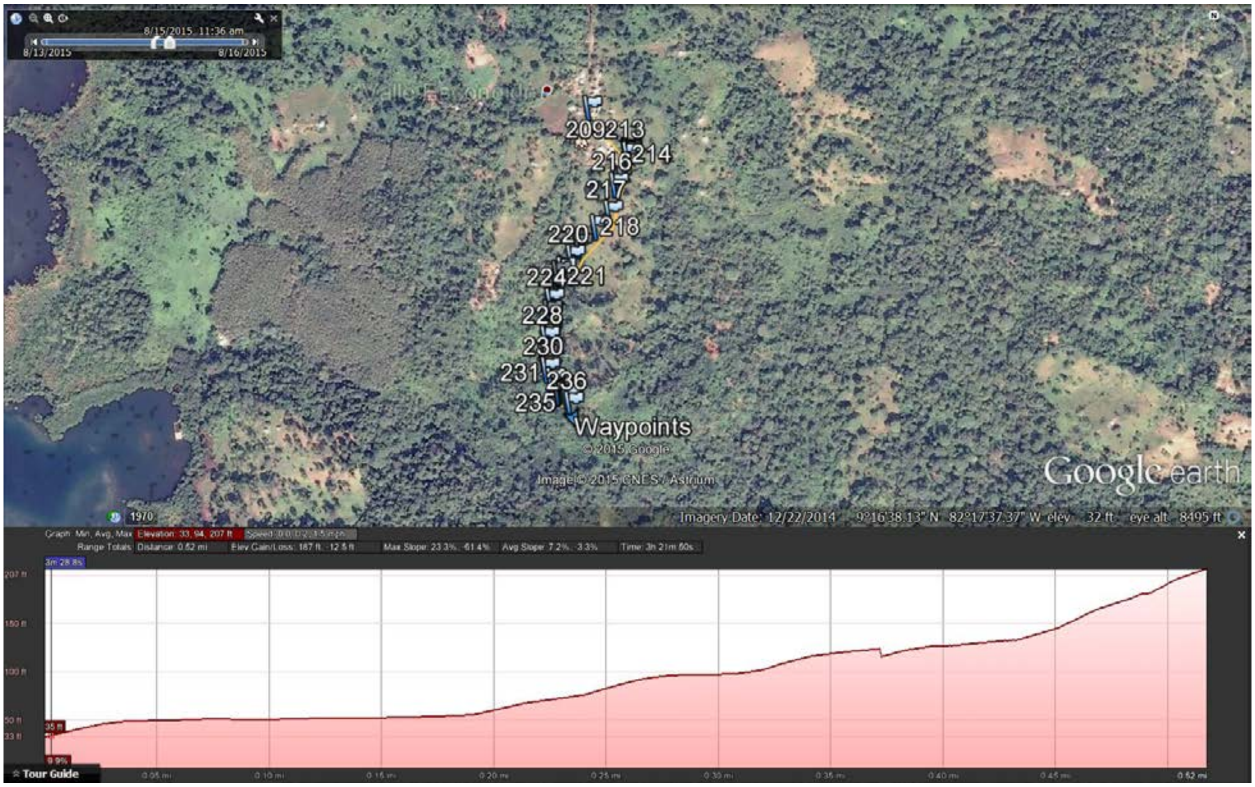


Figure E1: Elevation profile for source to tank water line

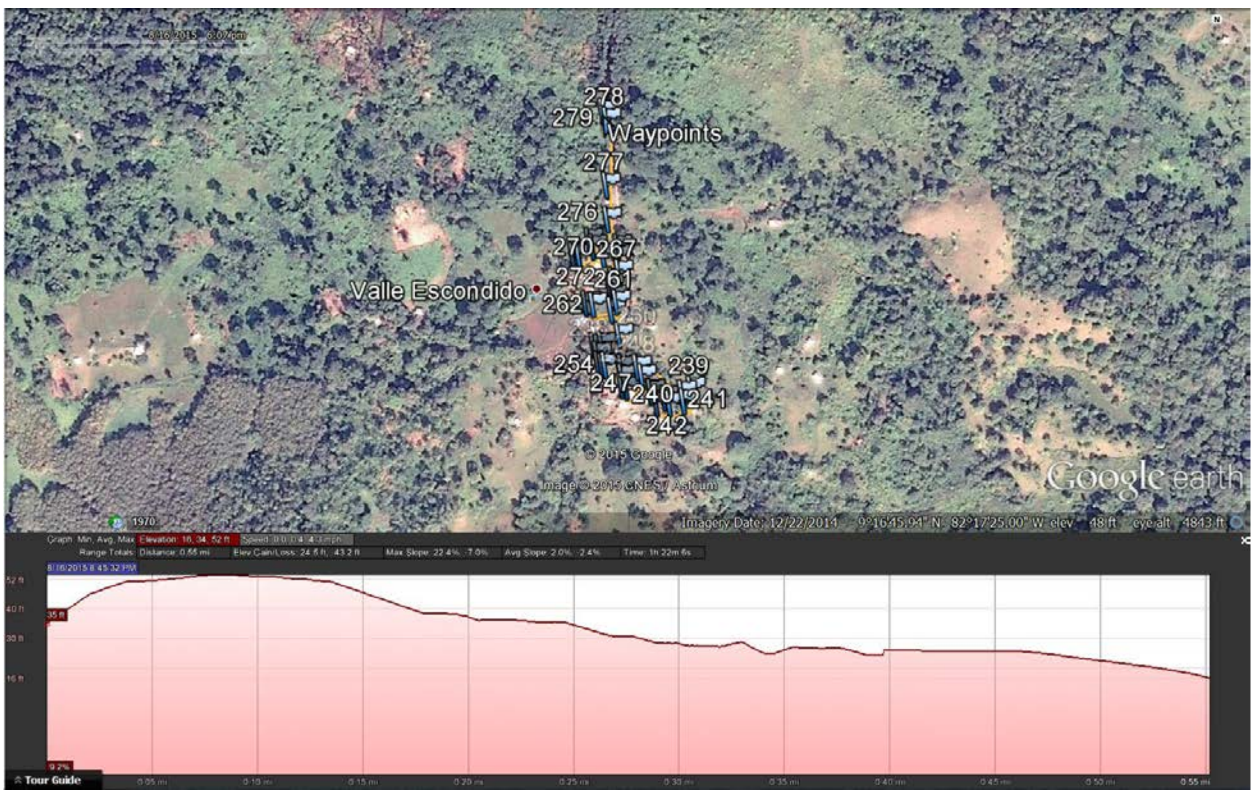


Figure E2: Elevation profile for tank to community water line

APPENDIX D

Rainwater supply for average community house

Table D1: Area of Current Homes and Possible Rainwater Supply

	January	February	March	April	May	June	July	August	September	October	November	December
Average Monthly Precipitation (mm/month)	241	148	148	194	225	205	290	205	107	138	267	345
Supply (L) of various home sizes given average monthly precipitation												
PCV House	1686	1032	1037	1353	1571	1432	2027	1435	745	963	1867	2407
Home doubled width	3115	1907	1915	2499	2901	2644	3745	2650	1377	1780	3449	4447
Home tripled width	4597	2814	2826	3688	4282	3903	5527	3911	2032	2627	5091	6563

APPENDIX E

Schematics for rebar concrete reinforcement for spring box

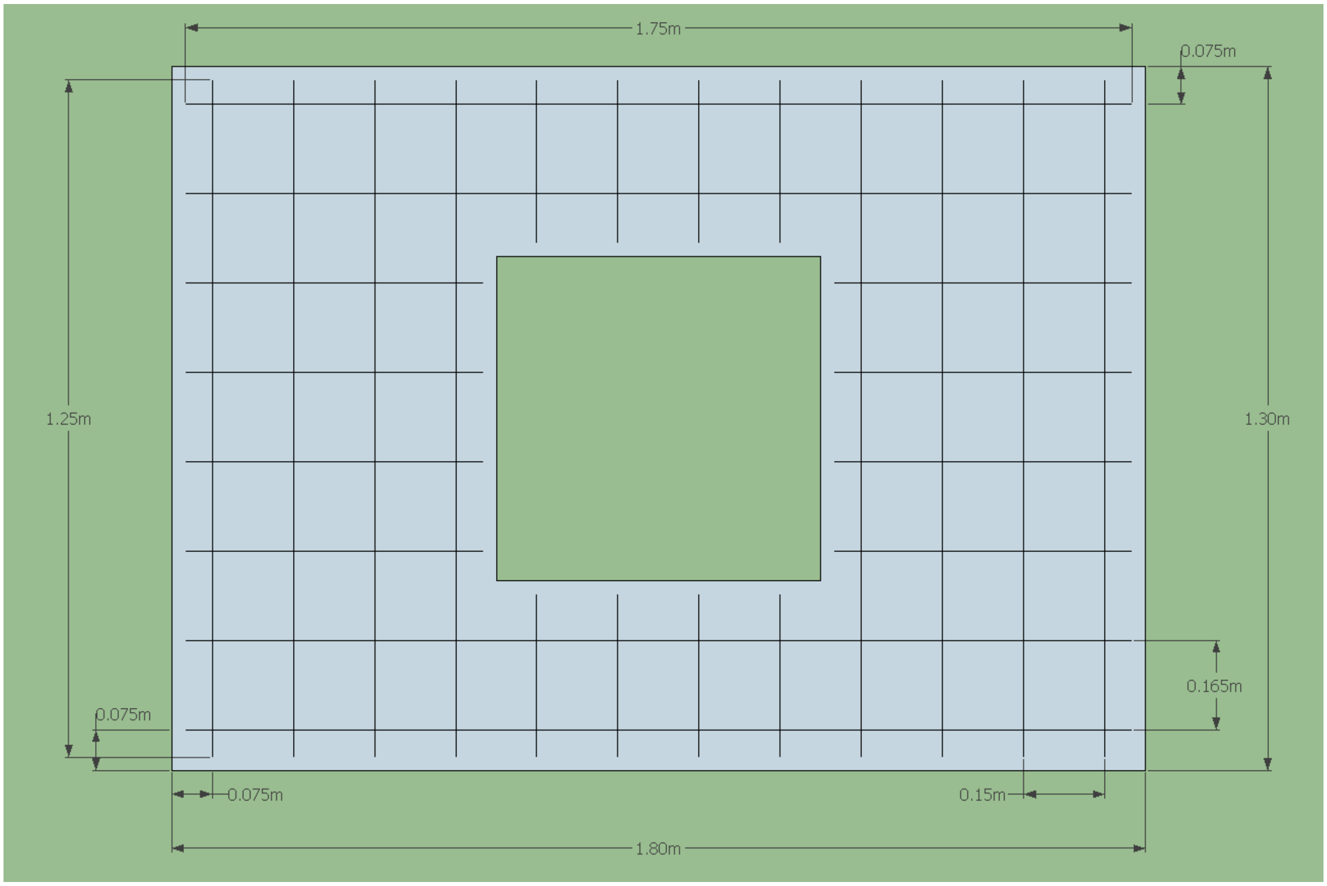


Figure E1: Rebar schematic for top side of spring box

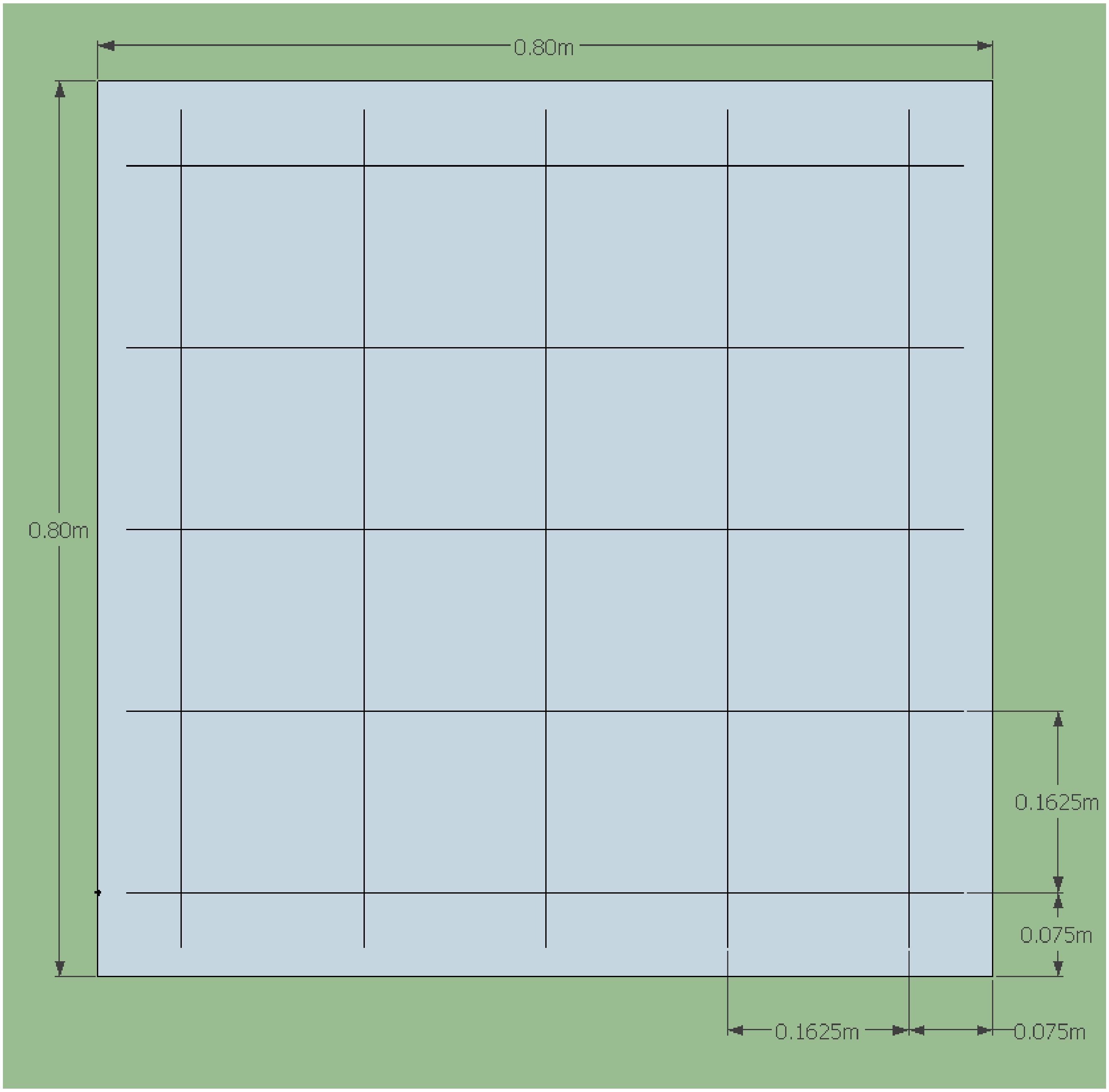


Figure E2: Rebar schematic for cover of spring box

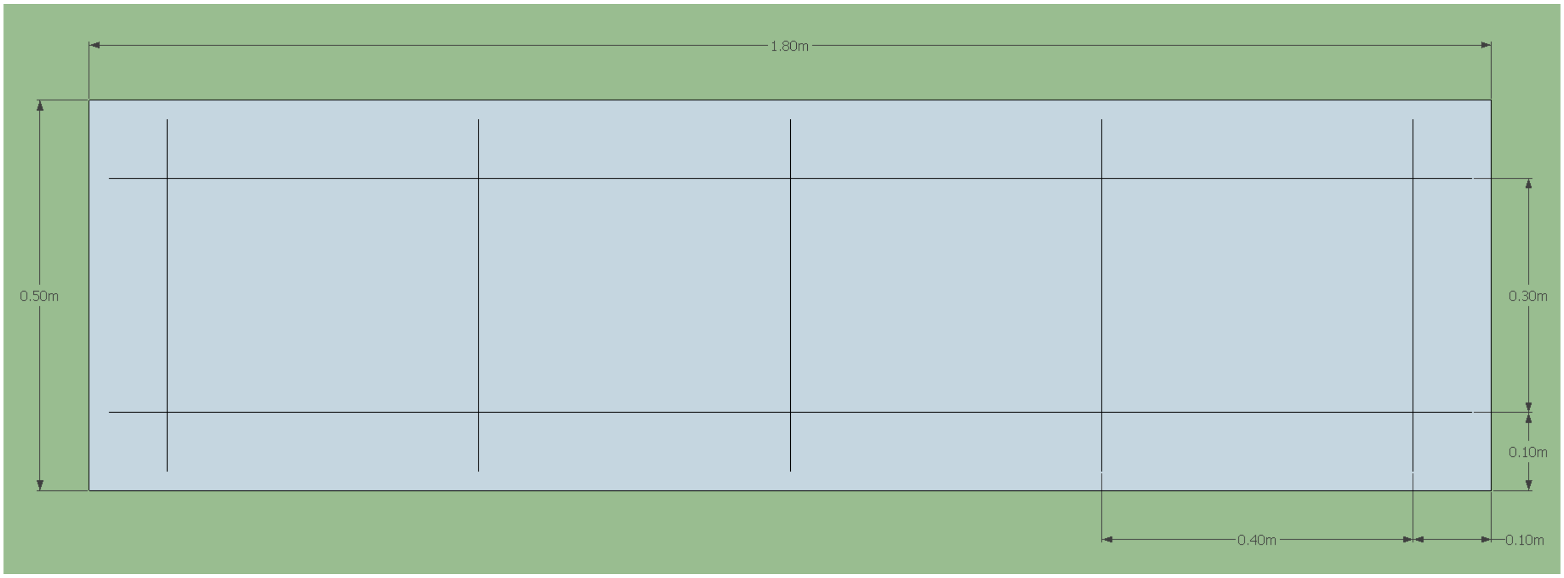


Figure E3: Rebar schematic for front side of spring box

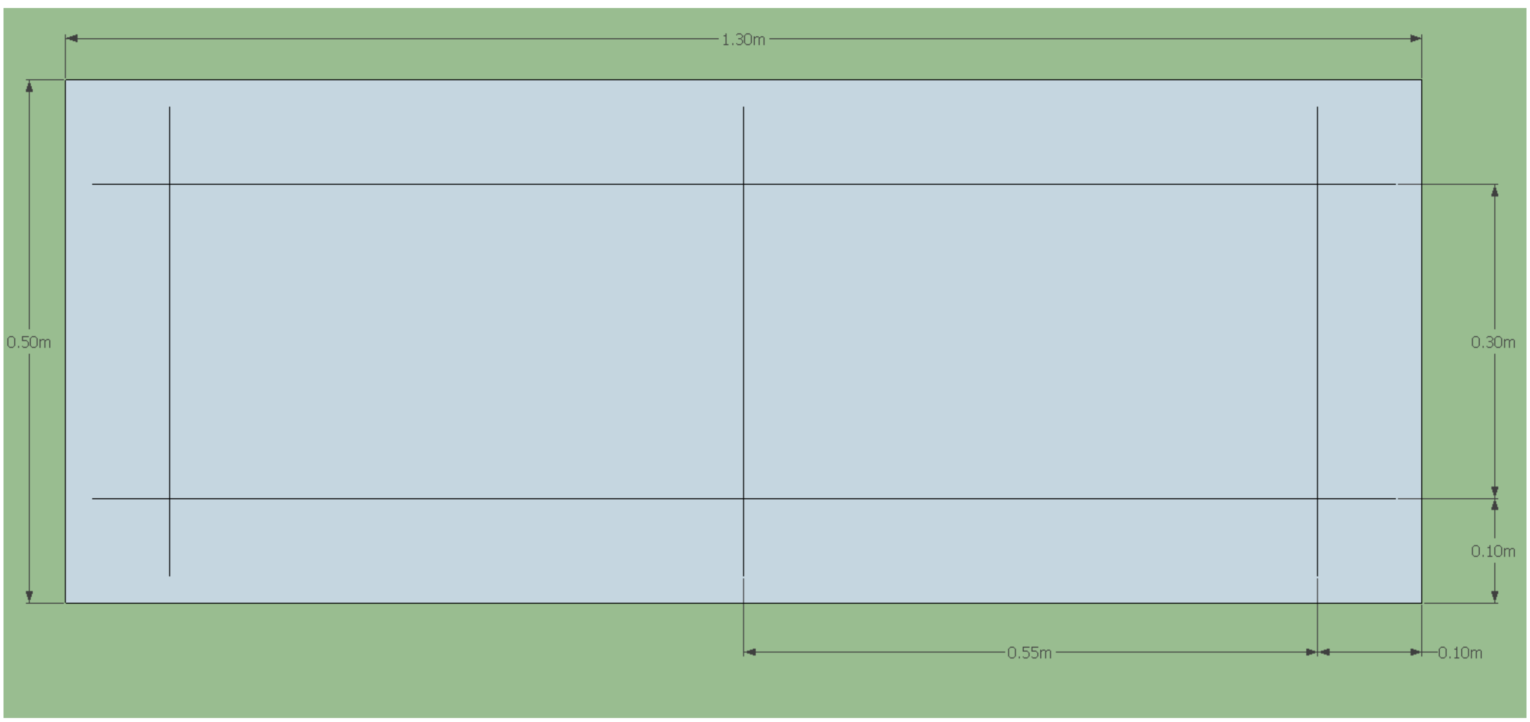


Figure E4: Rebar schematic for left and right side of spring box

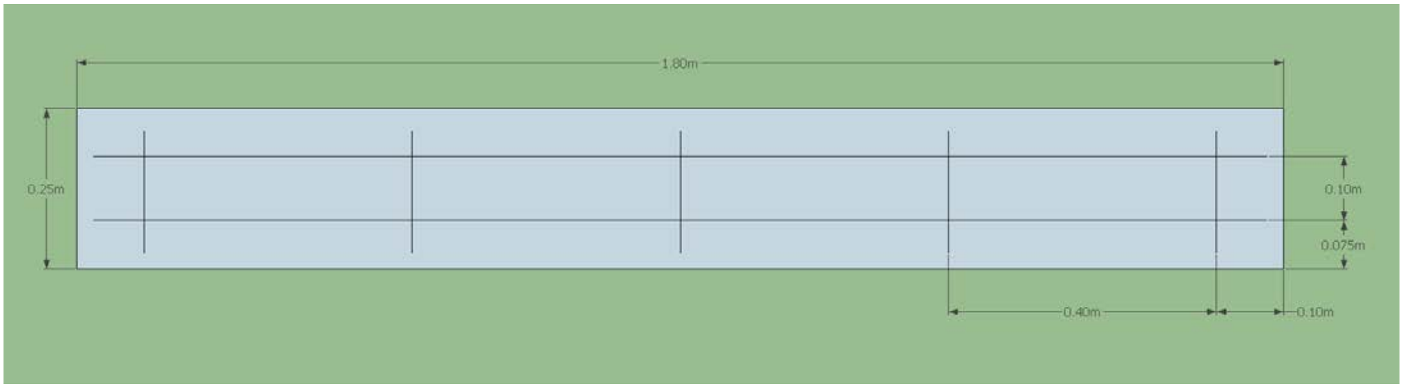


Figure E5: Rebar Schematic for back side of springbox

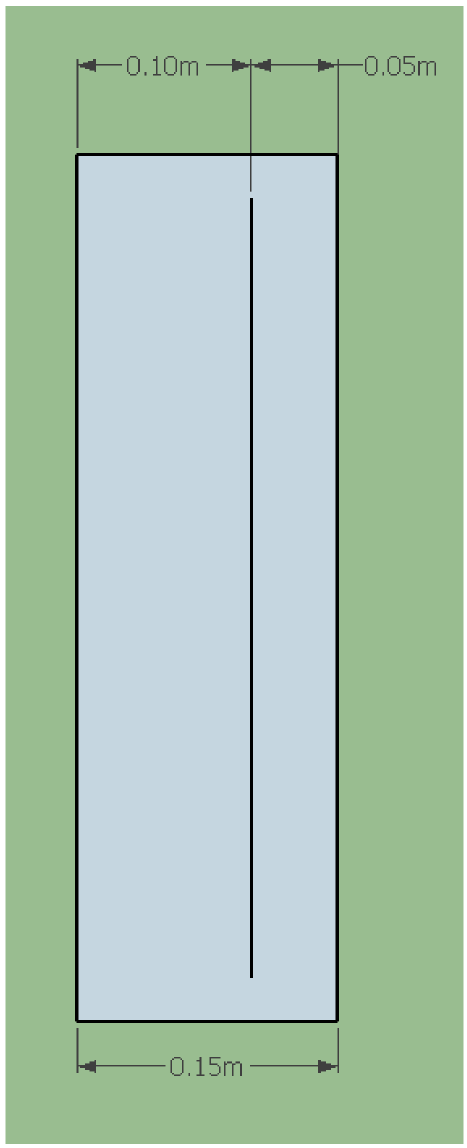


Figure E6: Profile view for rebar placement in all side of springbox

APPENDIX F

Chlorinator contact time and related calculations

Target Ct Value=40 min-mg/L

Minimum free chlorine concentration = 0.2 mg/L

Assume 30% baffling factor in tank=0.3

Contact Time in 1,250 gallon tank (min)=(1250 gallons/13.4 (gallons/min))*0.3=93 minutes

APPENDIX G

Spring box volume and multiplication factor calculations

Total void volume: 1.5m x 1m x 0.5m = 0.75m^3

Concrete volume calculations:

Separate four walls and lid and calculate volumes:

front wall → 1.8m (long) x 0.5m (high) x 0.15m (thick) = 0.135m^3

left wall → (1m + 0.15m) (wide) x 0.5m (high) x 0.15m (thick) = 0.08625m^3

0.15m thickness to account for thickness on back wall

right wall → same as left wall = 0.08625m^3

back wall → 1.5m (long) x 0.25m (high) x 0.15m (thick) = 0.05625m^3

back wall has half the height to allow for water flow into springbox

1.5m neglects 0.15m thicknesses because accounted for in side walls

lid → [1.8m (long) x 1.3m (wide)]x 0.15m (thick)

+[0.8m x 0.8m] x 0.1m (ridge)

-[0.6m x 0.6m (hole dimensions)] x [0.1m +0.15m] = 0.325m^3

cover → 0.8m x 0.8m x 0.1m (thick) = 0.064m^3

Total concrete volume = 0.135 + 0.08625 + 0.05625 + 0.325 + 0.064 = **0.753m^3**

APPENDIX H

Aqueduct expansion and replacement time estimate calculations

Total time it takes to complete a 15’ section

- Min: 3.6 hours
- Max: 7.7 hours

Total time it takes to complete whole aqueduct system

- Total length of pipe +15% extra: 10741 ft

$$Number\ of\ 15'\ sections\ = \frac{Length\ of\ pipe\ needed}{15}$$
$$Number\ of\ 15'\ sections\ = \frac{10741 ft}{15\ ft}$$

Number of 15’ sections: 716 sections

$$Time = Number\ of\ sections * Time$$
$$Min\ Time = 716\ sections * 3.6\ hours$$
$$Max\ Time = 716\ sections * 7.7\ hours$$

Min time: 2577.84 hours
Max time: 5513.71 hours