Rö Krobu

Michigan Technological University iDesign
Cerro Gallina, Panama

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December 1, 2017

Letter of Intent

December 15, 2017

Peace Corps- Panama

City of Knowledge, Building #104

Clayton, Ancon

P.O. Box 0843-03081

Republic of Panama

To: Sierra Schatz

CC: Dr David Watkins; Mike Drewyor

Dear Sierra:

The two water distribution system designs detailed in this report were developed for the community of Cerro Gallina. The first system is gravity-fed to the neighborhood of Bajo Conejo, including all seven homes. It was designed to be under the government budget of $12,500 for the same location. The second system uses a ram pump to provide water to a family on a mountain ridge, and it is designed to be built and funded by the family.

Work on the gravity-fed system should be completed in the dry season (January to March) and is estimated to cost $5,300 and take 22 work days to complete. Chlorine, provided by the Panamanian government, will be used for disinfection of the system. Implementation is expected to be supported by the Panamanian government and/or Peace Corps, Panama. The ram pump will be built by a family and is estimated to take 48 work days to complete with a total cost of $240.

Both systems are intended to be built in the next year with the support of the Panamanian government and/or Peace Corps, Panama. This document was developed in conjunction with Michigan Technological University's International Senior Design and Peace Corps, Panama. System designs and this document fulfill the senior design requirements for engineering students involved at Michigan Technological University.

Sincerely,

Team Rö Krobu: Matthew Adams, Sasha Drumm, Kira Koboski, Juli Mickle

Enclosures: Disclaimer.

Disclaimer:

All information provided in this report is original unless noted. This report, titled "Water Distribution Systems for Cerro Gallina, Panama" represents the efforts of undergraduate students in the Environmental, Mechanical and Geological Engineering programs at Michigan Technological University. Students worked under the supervision and guidance of associated faculty members, yet contents of this report ***should not*** be considered professional engineering.

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Executive Summary

Provided in this document are system designs, materials lists, cost estimates, implementation schedules, and operation and maintenance plans for two water supply systems in Cerro Gallina, Panama.

One system is a gravity-fed water distribution system servicing seven homes from one spring source, spanning 5500 feet. A storage tank will be placed upstream of the first house. The system will include clean-out valves and air-release valves, as well as a pressure break tank. Each home will have a single spigot. This is a government funded project with a budget of $12,500. It was designed with the intent for implementation to start between January to mid- February 2018 and be completed in 4 weeks. Materials are estimated to cost $4,000. The team recommends labor to be done primarily by the community in Cerro Gallina rather than exclusively government workers, in order to allow for understanding of the system for maintenance purposes and to decrease the cost of system implementation. Using community labor reduces the labor cost by $3,000.

The second system presented in this document is a ram pump system to service a single family. This system pumps water from a lower spring source up the hill to the family's residence. It will be funded and implemented by the family themselves if and when they so choose. It is recommended to start the building process during the dry season. Materials to build the ram pump will cost $240 and can all be purchased locally. Due to the minimal labor resources, it is estimated implementation would take 48 days to complete.

1.0 Background

Cerro Gallina is a community located in the mountains of south-western Panama within the state of Chiriquí, see Figure 1. Ngöbe, the larger subgroup of the Ngöbe-Buglé Comarca, is the indigenous group that resides in Cerro Gallina. The community is comprised of five neighborhoods and 42 houses, 39 of which are occupied all year. They do not have access to electricity, and few houses have access to water at their homes; instead they collect it from nearby streams and springs.

Households typically consist of six to 10 people and can include grandparents, parents and children as well as more extended family. Men are primarily subsistence farmers and women often stay at home to cook and care for children. Some women are artisans, making bags, called *chacara*, which can be made of natural or synthetic fibers, beaded jewelry, sombreros, and *naguas,* women's dresses which are decorated with *dientes* (teeth) or *pinturas* (paints) which represent the mountains. Children attend school, though few graduate high school. A high school diploma is viewed like an Associate's degree would be in the United States, and students are allowed to choose a specialty in the last two years.

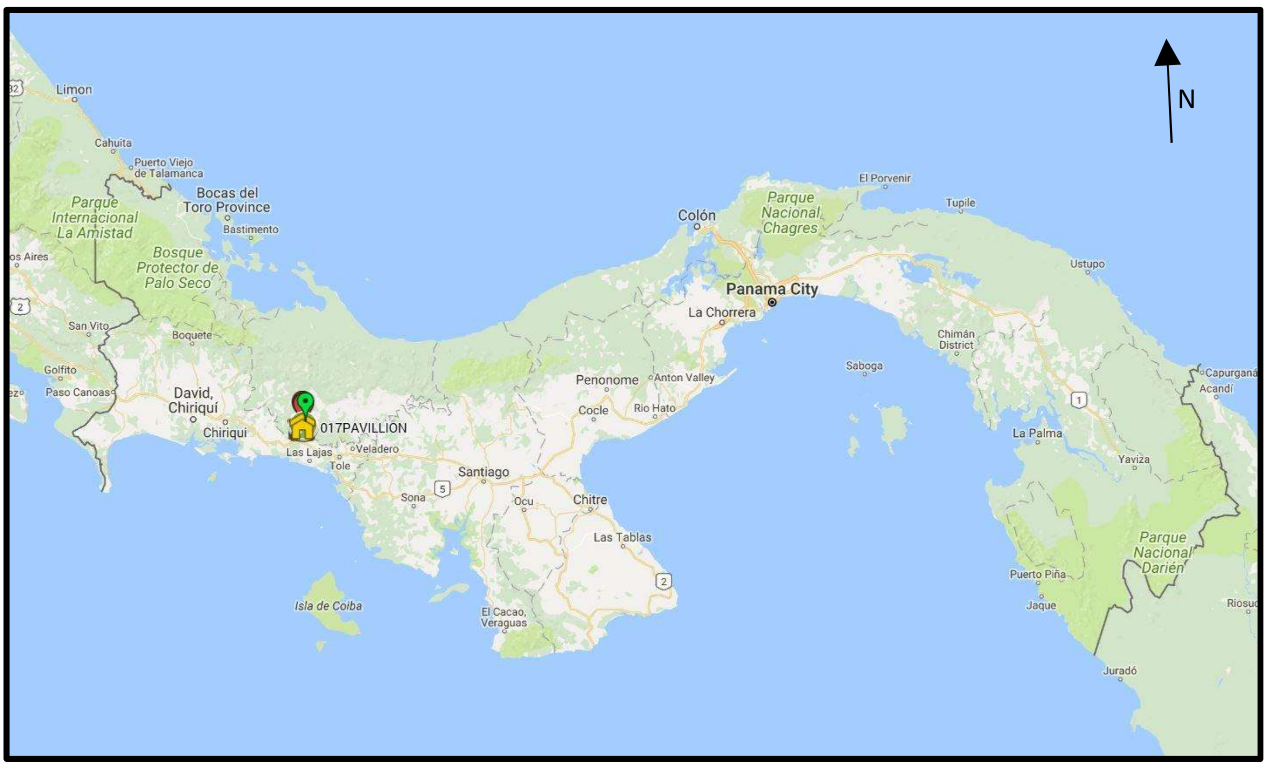

Figure 1: Map indicating the location of the community within Panama.

2.0 Problem Description

Cerro Gallina experiences inadequate access to water, improperly assembled piping, lack of education, and social disputes. Families obtain their water from spring sources found in the valleys between the ridges, whereas their homes are situated on the top of the ridges. Although the distance to obtain water for most families is not far, carrying gallons of water, wet laundry bags, etc., makes the trek up from the spring on the slippery ground dangerous.

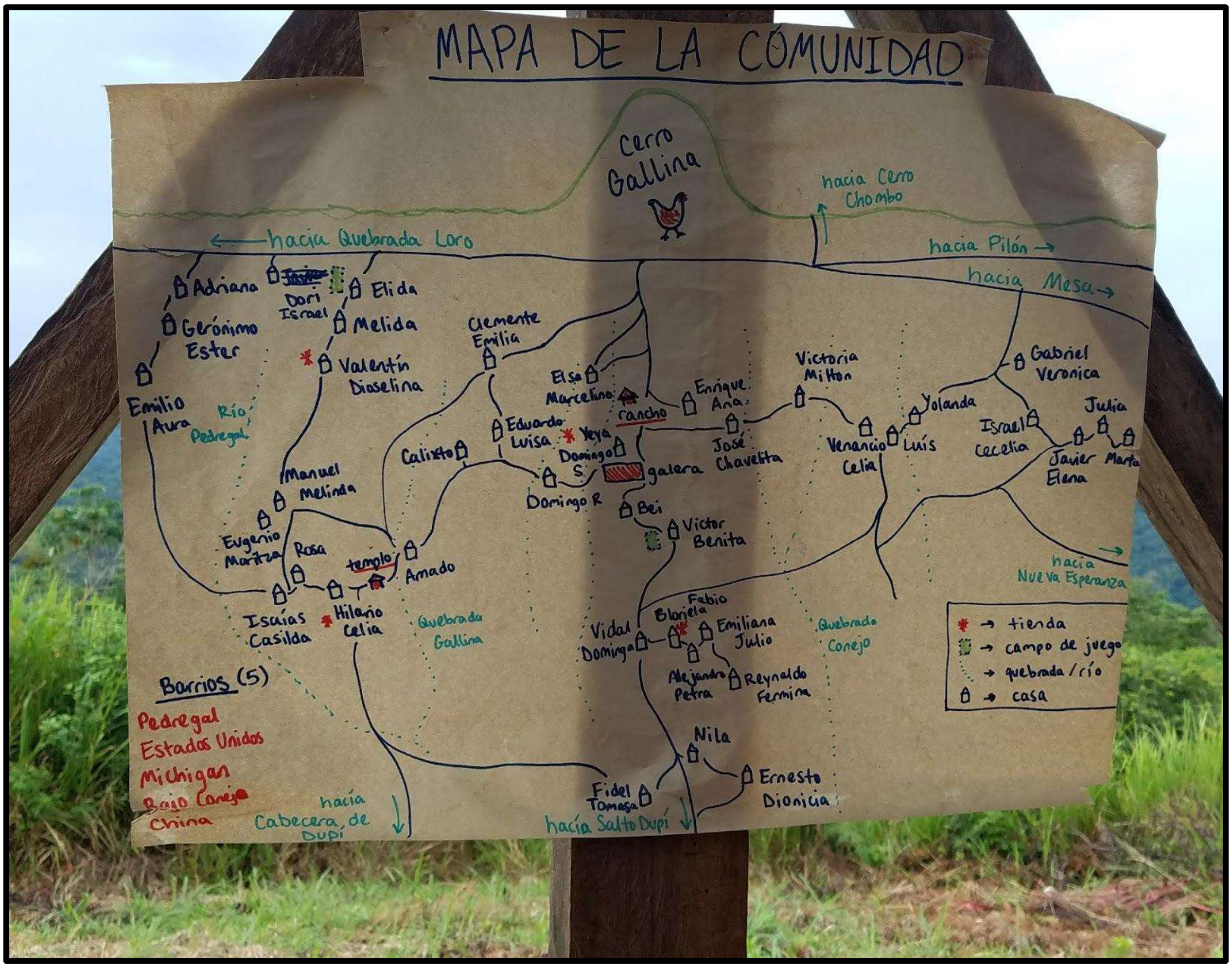

Figure 2: Map of the community created by current Peace Corps volunteer, Sierra Schatz, illustrates how the community is spread out.

There are two distinct seasons in the community: dry and wet. The wet season lasts for eight to nine months, with a three to four-month dry season. During the dry season, typically January-March, many of the streams dry up, depleting the nearby spring sources for the families. Families have to spend more time hiking for water farther away from their homes.

There are existing water pipes in a few areas of the community which bring the water from spring sources to the family's kitchens. However, this source of water is not always reliable. Some families live far up the mountain and do not have access to the current piping system because the water cannot make it up the ridge. Some form of pumping would be required for these families to have close access to water.

The neighborhood of Bajo Conejo has taken it upon themselves to develop a piping system to bring water closer to their homes. There are several issues associated with the current piping structure. Pipes are run above ground from a *toma,* or a spring catchment, to homes in the community. Pipes that are exposed risk being weathered or broken, shortening their lifespan. Additionally, aboveground pipes have a lot of sun exposure resulting in more potential for bacteria growth. These pipes also run along commonly travelled paths, which poses a tripping hazard and more potential for pipe breakage.

Figure 3: (Left) A pipe running above ground on a common path between homes in the community. (Right) A leaking pipe due to improper sealant.

The method used to join the pipes is of great concern. The couplings used to join pipes are not long enough, resulting in the pipes breaking free often. No sealant is used to connect the pipes, resulting in lots of leaks and constant repairs. Additionally, having openings in the pipelines is an access point for contamination within the pipes. Therefore, even if the source is clean, the water could be contaminated during transport to the homes. The community is educated on creating piping systems and knows the proper technique for joining pipes; however, they often do not allocate the money for buying the proper materials.

Families in the Comarca lack basic water, sanitation, and hygiene (or "WASH") education. Very few people understand how contaminants enter a water source. As a result, the spring sources are open to the air, an easy access point for contamination. They are not cleaned regularly, so any contamination that is introduced likely stays deposited on the spring walls. There are at least two families in the community who do clean their spring source daily by removing all the stagnant water to gather fresh water. Currently, this knowledge has not been shared with others in the community.

Figure 4: A common spring used as a single-family drinking water source.

Families gather water using containers that are often not regularly cleaned, potentially contaminating the water before it is consumed. Furthermore, none of the families in the community use water treatment methods such as adding chlorine or boiling.

Most of the families in the community are related. Unfortunately, these close relationships can become acrimonious. Fear of violence causes one of the families to refrain from attending community water meetings to avoid the other side of the family. This family was disconnected from the current piping system when the other side cut their pipes during the night. Prior to being cut off from the system, the family often controlled the water, depleting the resource before it could reach families downstream. The two sides of the family must reach an agreement prior to the creation of an improved water system.

There are also discrepancies in the current government water project. The government water project plan within Cerro Gallina is to service six homes. However, there is a seventh home within the same area which has not been included in the plan. There is no current explanation for why this family has not been included; however, to insure equal access to everyone, the seventh home should be included in the system. Culturally, negotiating with the government who is funding the project is a difficult task and is beyond the scope of this work.

3.0 Design Components

Based on an assessment of alternatives, Rö Krobu has developed a final design for the two systems within the community.

Alternatives for System 1 included a junction box in addition to a storage tank, variations in pipe paths, and materials for the pipes and tank. It was determined that: a junction box will not be necessary because one spring provides sufficient flow; the shortest pipe path will be used because it is the cheapest and allows for less maintenance; all materials will be locally sourced so part replacements are accessible. The alternatives for System 2 included the use of either a bicycle pump or a ram pump. It was determined the ram pump is the cheapest option and contains materials that can be found locally.

System 1 is a gravity-fed system to serve seven homes from a single spring, with one spigot per home, a storage tank, and a pressure break tank. System 2 will serve one home and will be operated with a ram pump. Details of the final design have been divided for each system and are presented below.

3.1 System 1

3.1.1 Summary

During the assessment trip, water at one of the seven homes had E. Coli present, while most others had high potential for E. Coli represented by high total coliform numbers. As a result, it was decided that there will be manual chlorination in the system to prevent contamination.

EPAnet is a common water distribution system modeling program and was used to determine several hydraulic parameters for System 1, pressures at each node, and flow throughout the system. Nodes were determined by points of significant elevation change, spring and spigot locations, as well as potential tank locations. They are correlated with the GPS point data collected during field research and include elevations and surface distance adjusted using rangefinder data. Figure 6 provides a layout of the system within the program. It includes two springs, seven spigots (one at each home), a junction box, a pressure break tank (PBT), and a storage tank. Each system component is described in more detail below.

Construction will be done in the dry season between January and March of 2018. The dry season will provide the best chance for consecutive work days. It will take four weeks to complete the project.

System 1 will be funded by the government with a budget of $12,500. The government has committed to investing in burial of the pipes. Labor cost for the system is almost double the material cost. If labor consists primarily of government workers the cost will be $4,300, while using mostly community members would cost $1,300. Material cost totals to $3,620. Therefore, the total system costs will be $5,000 to $8,000. A complete breakdown of the budget is in Appendix G.

3.1.2 Elevation Profile

Figure 5 is the elevation profile for System 1, with locations for a pressure break tank, storage tank, spigots, and flow reducing disk included. The spring is at the highest elevation (1,492 feet), and Fidel's home at the lowest (1,073 feet). These components will be further discussed.

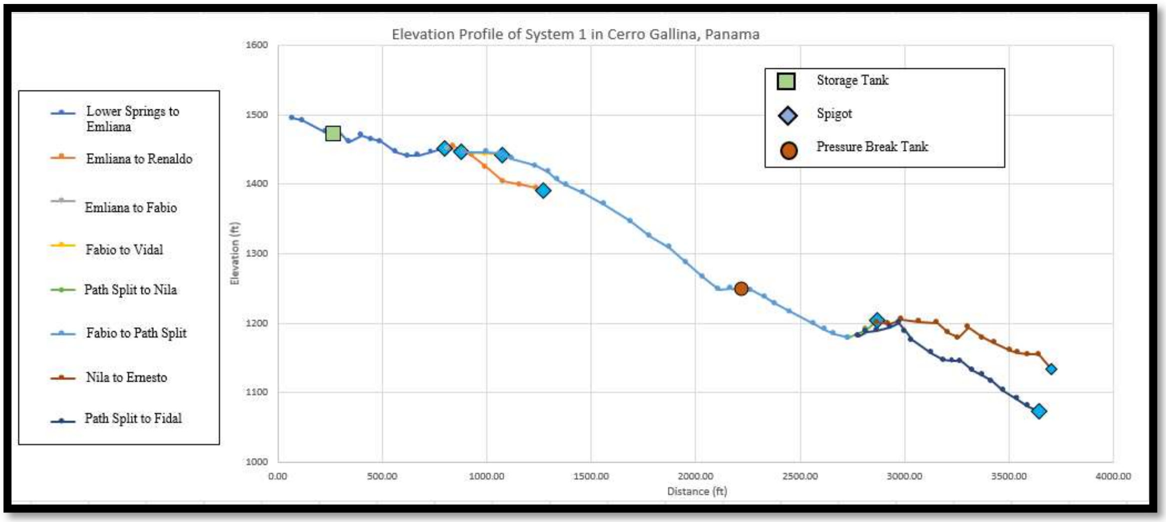

Figure 5: Elevation profile for System 1 including major design criteria.

3.1.3 Pipes and Water Demand

Pipes used in EPAnet modeling only included the main pipeline and had diameters of 1 inch, ½ inch or 1.5 inches. They will be buried during installation. Pipe sizes were distributed so the flow would not be unbalanced at the splits between two paths. For example, water would prefer to flow down the larger diameter pipe which would restrict flow to spigots on the end of the smaller diameter pipeline. Other factors, such as cost of pipe by diameter and the fact pressure is pressure increases with increasing diameters, were considered. The distribution of pipe diameters is shown in Figure 6. Note, the pipe after the reservoir (in red) is ½ inch for modeling purposes. This constricts the input to below the measured spring flow rate which is 4.72 gpm. The largest flow rate from the reservoir in the model is 3.22 gpm; therefore all modeling results are reasonable.

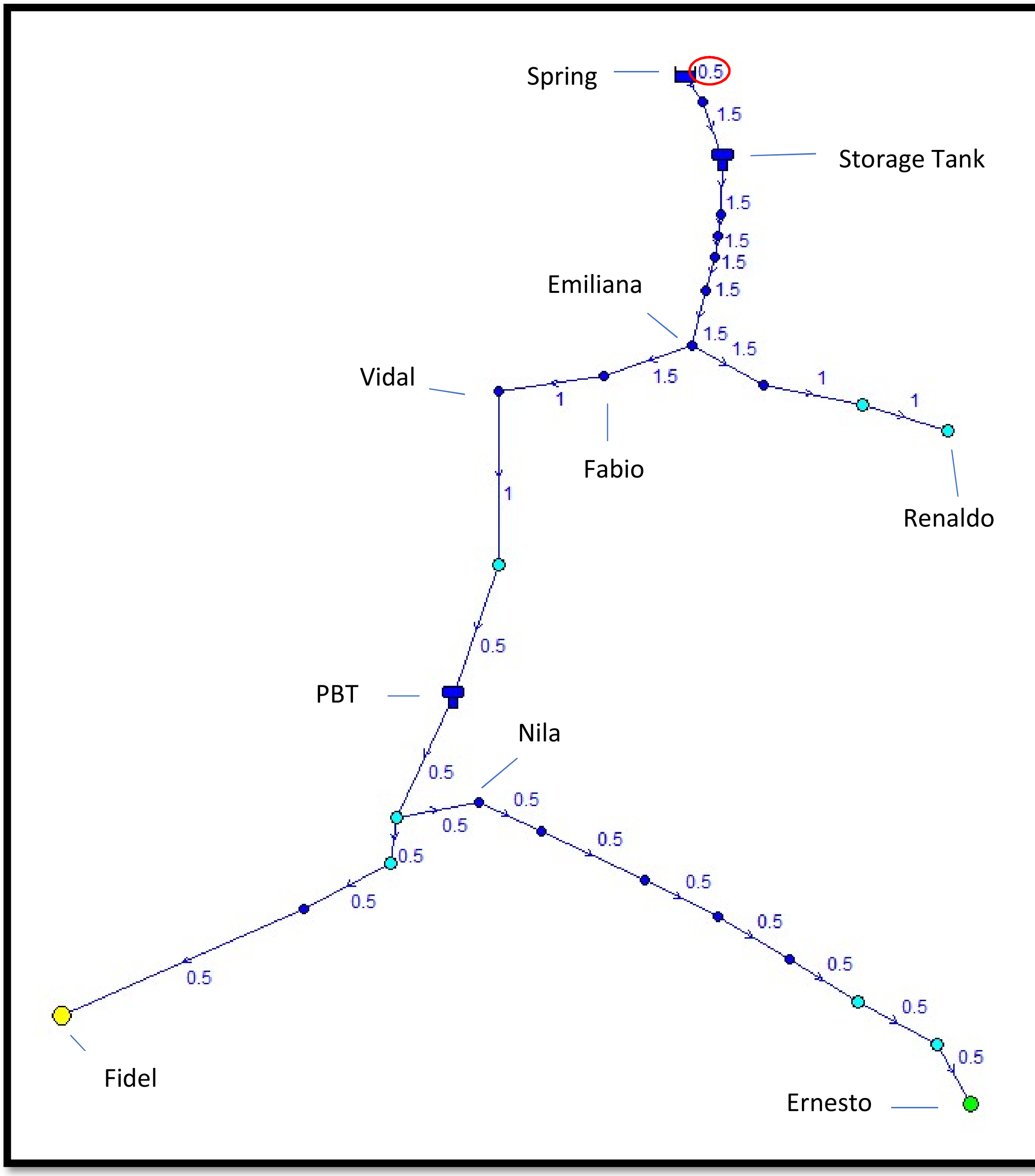

Figure 6: EPAnet water model showing the pipe diameter distribution and locations of the storage tank and PBT.

Demand was determined under the assumption each family uses 180 gallons per day (gpd), which is an average demand of 0.125 gpm per household. The model was run using a time varying pattern over a 24-hour period, with the assumption of an increased water demand during meal times and a decrease overnight, shown in Figure 7.

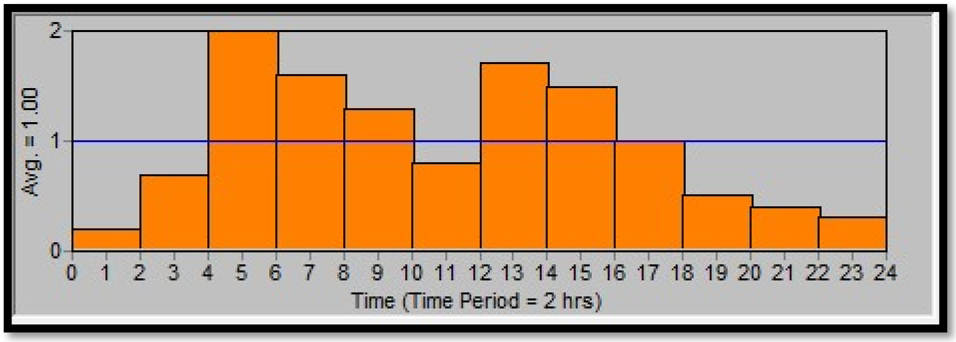

Figure 7: Time pattern for demand over 24 hours.

The results of the model indicate water will successfully reach each of the 7 homes. The lowest pressure is 10.5 psi at Emiliana's, and the largest is 76 psi at Fidel's, the lowest in elevation within the system. To allow for higher pressures at Emiliana's, the tank is placed as close to the spring as possible, accounting for accessibility. The addition of a partially opened valve prior to Fidel's spigot is recommended to adjust the flow and reduce large pressures. The pressure change over time at all homes can be found in Appendix B, Figures B1, B2 and B3.

3.1.4 Spring Box

A low-profile spring box design was selected for this system. A detailed description and construction manual for the spring box can be found in Appendix D. The spring box was sized according to the measurements taken in the field, with natural spring dimensions of 6ft x 5.5ft. The walls of the box should begin at an impermeable layer and expand upward until they are flush with the ground surface. An example of a completed spring box can be seen in Figure 8 below, where only the hatch is above the natural ground surface.

Figure 8: Low-Profile Spring Box from Snyder report in Appendix D.

The box will be built using existing rocks near the spring filled in with mortar. A complete materials list can be found in Appendix G. Construction of the spring box will follow the general design shown in Figure 9, which is detailed in Appendix I (Snyder).

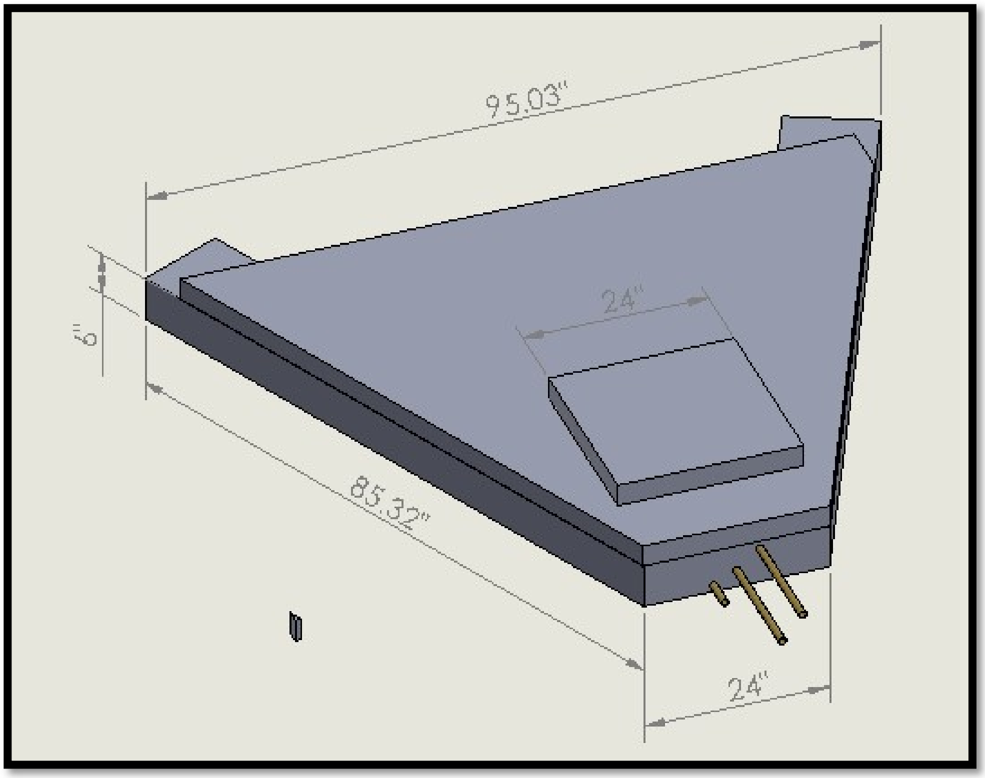

Figure 9: Spring box diagram.

3.1.5 Chlorination

The Panamanian government freely provides both chlorine tablets and an applicator to officially established water committees for disinfection. Bajo Conejo, of Cerro Gallina, is currently in the process of filing for a water committee that will soon be officially recognized by the government.

Disinfection will be done using this chlorine tablet system. One chlorine tablet will be inserted into the system upstream of the storage tank on a bi-weekly basis. A contact time of 3 hours with a full tank was calculated based on the storage tank volume and the maximum flow rate, then multiplied by a baffling factor of 0.3 since no baffles will be present (Orner, 2011). The chlorine tablets have a diameter of 3 inches, weigh 200 grams, are made of calcium hypochlorite and have a chlorine concentration of 60 to 70 percent.

The tablets will be less effective if they were packaged improperly and therefore exposed to the environment. The design follows Figure 9.

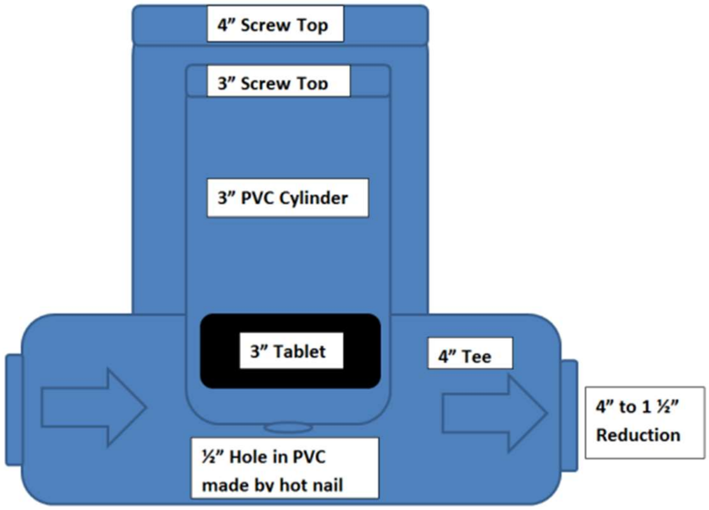

Figure 10: Design of the Panama Ministry of Environmental Health's In-Line PVC Chlorinator (Orner, 2011).

3.1.6 Storage Tank

The storage tank was placed between Emiliana's house and the spring, as requested by the community, and was sized based on the demand for 7 homes.

Prior to constructing the tank, the soil must be manually compacted using the pour and drain water method to speed up natural compaction processes. It is likely that a concrete slab stamp with a handle will be constructed on site to assist in manual compaction.

The tank will be rectangular, constructed of 6" CMU blocks, mortar, cement, and steel reinforcement. Detailed drawings for all tank components can be found in Appendix I. The foundation of the tank, the base, will be a rectangular concrete slab measuring 126 inches x 110 inches. It will extend 10 cm, or approximately 4 inches, past the tank wall on each side to provide more protection against possible erosion on the edges of the slab. The base slab will be 6 inches thick with ⅜-inch rebar spaced every 10 inches across the long side and 11 inches across the short side. All rebar will be 3 inches from the edges of the slab and 1.5 inches above the base of the slab. A timber frame will be constructed for pouring the base, and the rebar will be laid on rocks spaced every 2 feet. The concrete used for the entire tank design will have a mixing ratio of 1:2:3 parts cement, sand, and gravel, respectively. It will be poured into the frame, the surface leveled, and allowed to cure under wet conditions for 7 days.

The walls of the tank will be constructed of 6-inch hollow CMU blocks placed together with ⅜-inch thickness of mortar. See Figure 10 for block dimensions. Nominal CMU dimensions were used in calculations which account for the addition of the ⅜ inch mortar.

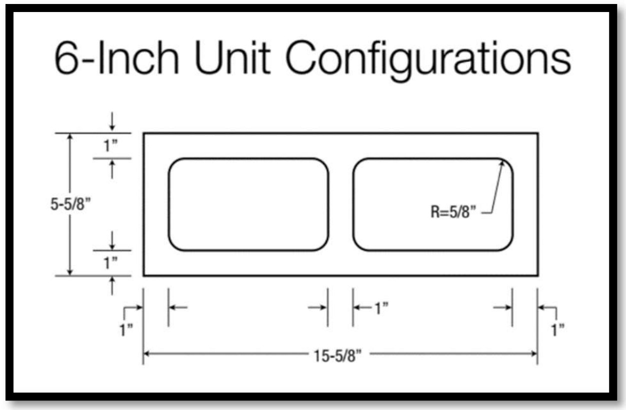

Figure 11: Configuration of CMU for storage tank.

The mortar will have a 1:3 mixing ratio of cement to sand. A 3/8" thick layer of mortar should be used to connect the first layer of blocks to the base of the tank. Rebar will be placed in the center of the hollow CMU blocks spaced 16 inches apart; this translates to one piece of rebar per block. See Figure 11 for a visual of wall construction. The rebar will extend from the base of the tank to the top of the wall, totaling four feet. The holes will be filled in with concrete using the same mixing ratio as that for the base. The wall outside dimensions are 118 inches x 102 inches, with internal dimensions of 106 inches x 90 inches. The design was based on a family demand of 180 gallons per day, with a goal to store enough water for all seven families for at least one day. The design accounts for thirty percent additional water storage as a safety factor. This tank will store 265 cubic feet of water, which translates to 1982 gallons.

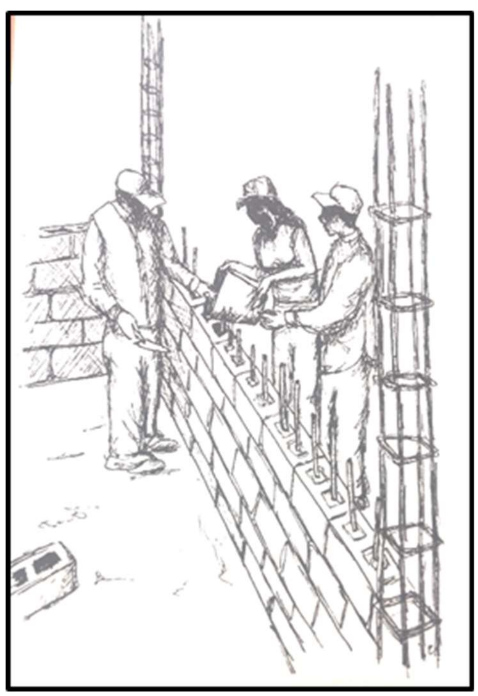

Figure 12: Concrete block over vertical rebar installation (Mihelcic 2009).

A 31- inch piece of 1.5” galvanized piping should be installed in one CMU block on the eighth layer (at the top of the wall) as the overflow pipe. This pipe should on the opposite wall of the inlet pipe and extend approximately, 23 inches beyond the outer edge of the block. This placement is to ensure that the overflow water is directed away from the tank to prevent erosion. A piece of mesh of fabric should be secured to the end of the pipe to prevent wildlife or contamination from entering. Gravel should be poured below the overflow outlet area to further prevent erosion.

The tank cover will be a 6.5-inch thick reinforced concrete slab with ⅜-inch rebar spaced every 14 inches on the long side and 14.5 inches on the short side. The cover of the tank will overhang the tank walls by 10 cm, approximately 4 inches, on each side, with final dimensions of 126 inches x 110 inches. A timber hatch measuring 3ft x 2ft will be installed on the cover to allow for water quality tests and cleaning. It is very important that there is a good seal between the hatch and the tank cover to prevent contaimination from entering the tank. For visual purposes, Figure 13 below shows the hatch slightly above the cover. However, timber blocks should be used as forms when pouring the cover as a place holder for the hatch notches to sit into. Timber forms will also be required for pouring of the cover slab to support the concrete as it cures. Detailed drawings can be found in Appendix I.

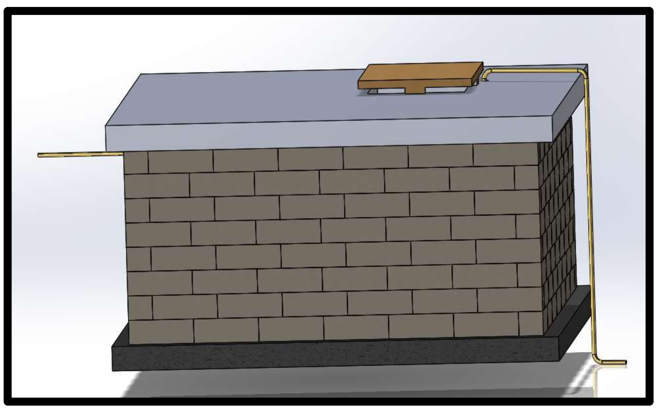

Figure 13: Model view of the completed tank design.

More extensive calculations for the tank base, walls, and cover can be found in Appendix A.

<u>3.1.7 Pressure Break Tank (PBT)</u>

Pressure can build up in water distribution systems that transverse large elevation differences. A PBT should be placed every 328 feet (100 meters) of elevation difference (Mihelcic et al., 2009). System 1 has a 400-foot elevation difference between the storage tank and the lowest point, resulting in the high pressures within the system, shown in red in Appendix B, Figure B4. A PBT was placed at the node previously labeled VR9, which is along the main walking path between Nila’s and Vidal’s homes. This spot was chosen because it is the closest the tank can get to the tee between Fidel’s and Ernesto’s, which are points of high pressures, without causing negative pressures in the upper part of the system. The elevation difference between the storage tank and the PBT is 224 feet, while it is 175 feet to Fidel's house from the PBT, which is the lowest point in the system.

The tank is sized at two feet tall, with a one-and-a-half-foot square base, which allows for pressure equalization, 3 pipes (inlet, outlet, and overflow), as well as room to use tools when working in it. The design of which is shown below (Figure 13) and the details can be found in Appendix I.

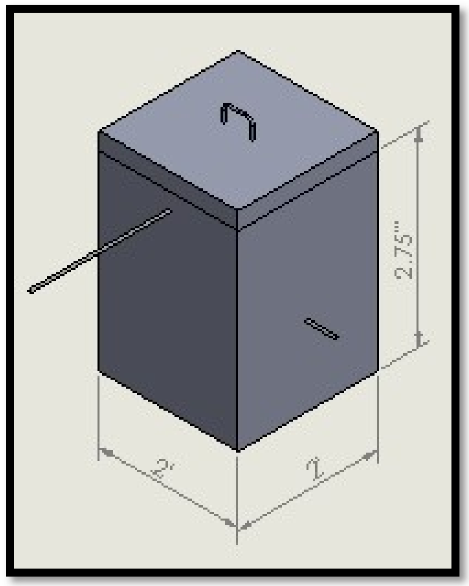

Figure 14: Model view of the PBT.

3.1.8 Spigots

Tap stands will be built for each spigot to protect the water outlets. Using a diagram from Mihelcic (2009), shown in Figure 14, the spigots were designed using PVC and galvanized piping, rebar, couplings and concrete. It also includes two elbow joints and two control valves. Pipes will be run two-feet underground and the spigots will protrude three feet above ground, so the vertical portion will total to 5-feet in length. Spigots will all be made of half-inch piping, and surrounded by a 4-inch concrete column supported with rebar. One control valve will be at the outlet for outflow control, and the other will be included at the inlet of the structure for maintenance purposes. The maintenance valve will be encased in a concrete box with dimensions of 1.5 feet by 1.5 feet and 2feet tall. More details on materials and dimensions can be found Appendix C.

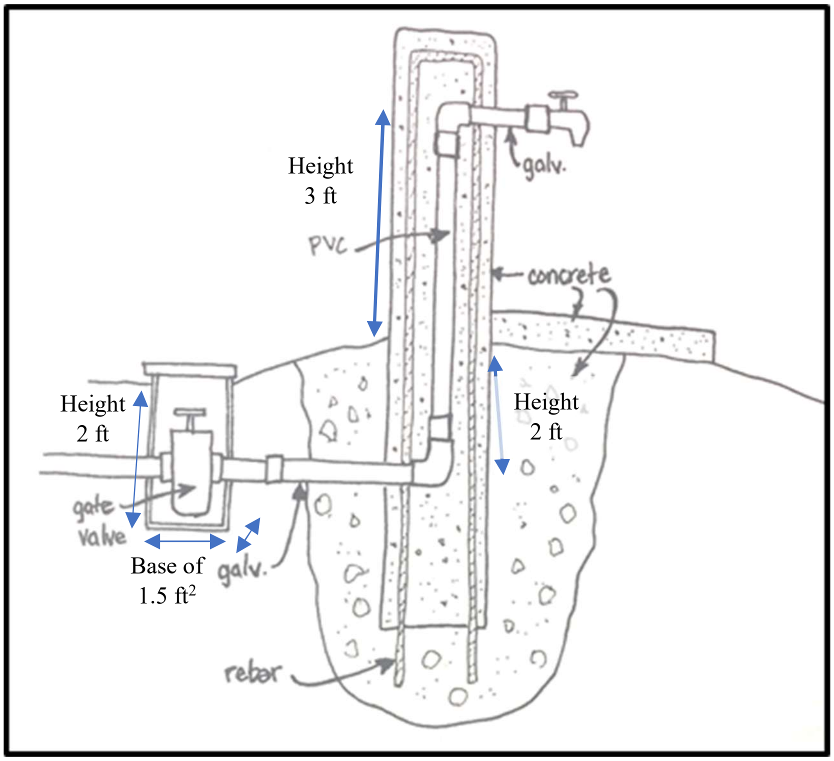

Figure 15: Typical tap stand design for spigots (Mihelcic, 2009).

3.1.9 Clean-Out and Air-Release Valves

Clean-out valves are control valves that deliberately allow for water to flow out of a system, which flushes out loose sediment or grime. Such valves are necessary at each of the spigots, the spring box, and two low points (circles marked in Figure 15) where sediment is the most likely to settle out. The low point marked in the box is assumed not to accumulate excess sediment due to the PBT capturing much of it upstream.

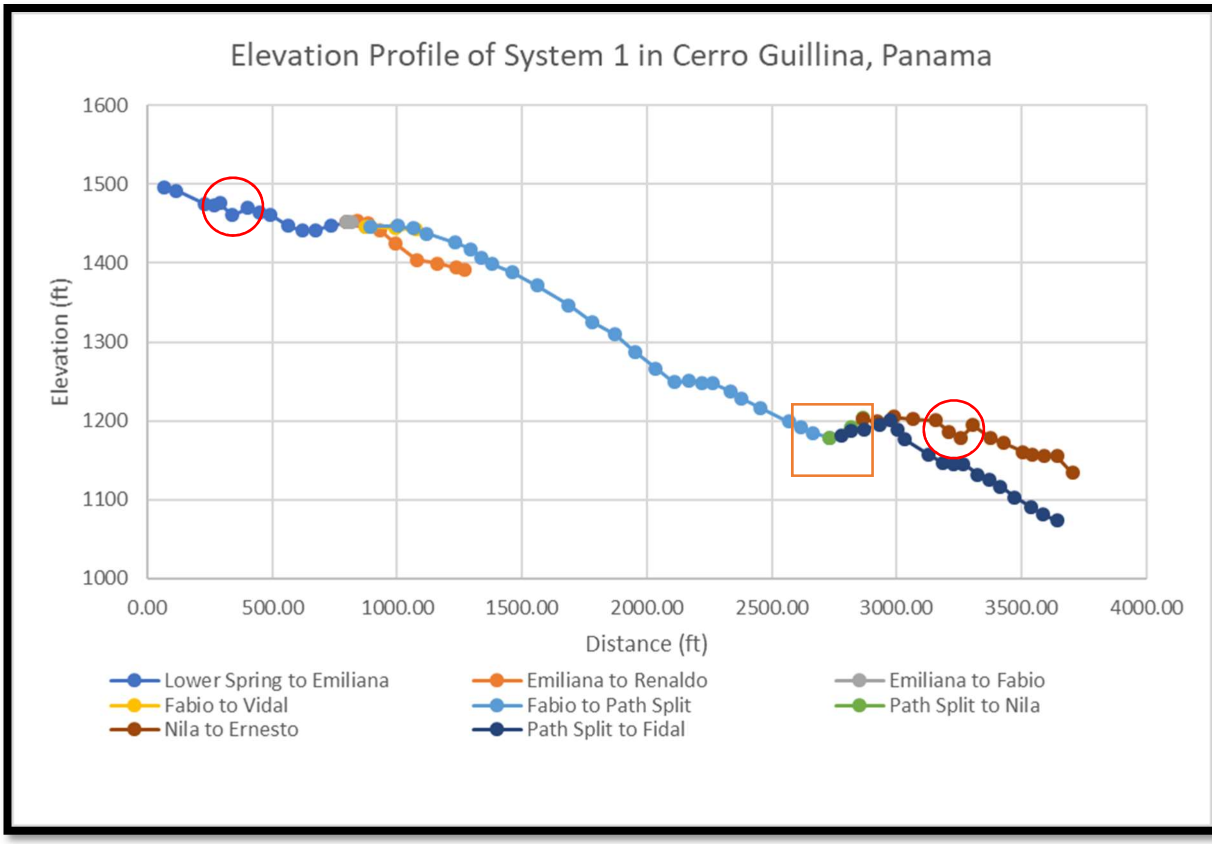

Figure 16: Elevation profile of System 1 including the suggested areas for air-release and clean-out valves.

The two low points in the system are also preceded by high points that have the potential to trap air. Installing air-release valves at these spots will ensure proper flow. Figures 16 and 17 show the basic designs and for a functional air-release valve and clean-out valve, respectively.

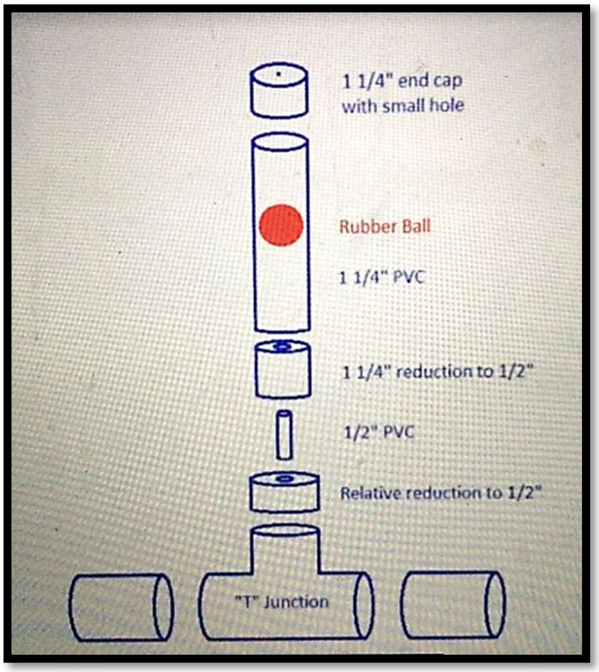

Figure 17: Design of an air-release valve (Sierra Schatz, 2017).

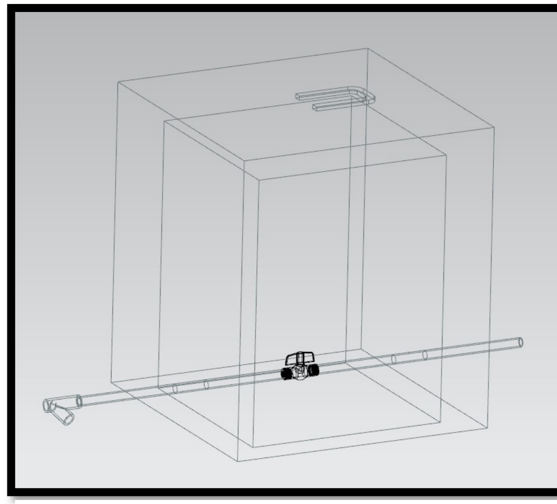

Figure 18: Design of a clean-out valve and containment.

Both valve types will be buried and encased by a concrete box, as shown in Figure 17, for protection and ease of access. These boxes will be 2ft x 2ft x 2ft with ⅜" rebar every 12 inches on the top slab. Note, the bottom of the boxes will not be concrete, but gravel to allow for proper drainage.

3.2 System 2

3.2.1 Summary

The final design for system two is a water system powered by a homemade ram pump. The main reason that the ram pump was decided upon was due to availability and cost. The other option that was being considered included a bike, a water pump, and a bike stand. These materials were not only expensive, but also not as available as the materials needed to construct the ram pump. The homemade ram pump is made from materials that are available at any hardware store. Figure 18 shows a model of a constructed ram pump. The parts for the ram pump are shown in Figure 19. There will also be a wooden pump cover to protect the pump, shown in Figure 20. All parts are listed in the materials list located in Appendix G. Detailed drawings of the ram pump and its cover can be found in Appendix I.

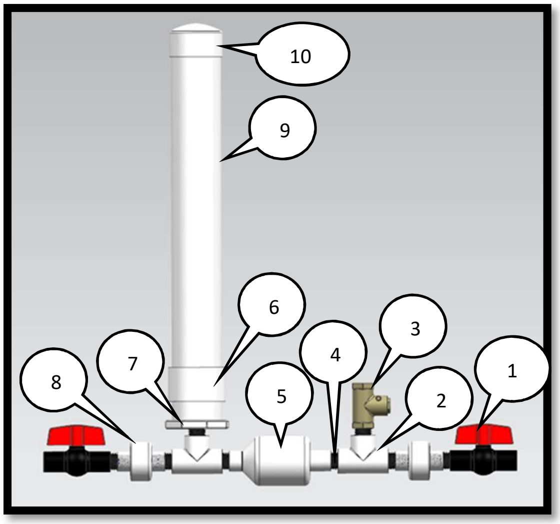

Figure 19: Ram pump ballooned model.

Table 1: Ram pump parts list

#	Part Name	Quantity
1	½" Threaded PVC Control Valve	2
2	½" Threaded PVC T Joint	2
3	½" Threaded Brass Swing Check Valve	1
4	½" Short Threaded PVC Nipple	8
5	½" PVC Check Valve	1
6	2" Coupling	1
7	½" x 2" PVC Pressure Reducer	1
8	½" Threaded PVC Union	2
9	2" PVC Pipe	1
10	2" PVC Cap	1

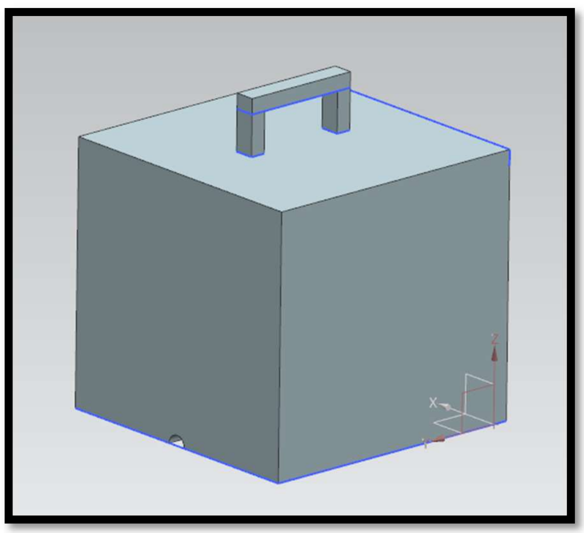

Figure 20: Ram pump cover.

The ram pump will be located 10 feet below the spring source. There will be a ½-inch PVC pipe that transfers the water from the spring down to the location of the ram pump. This will give the water a velocity that the ram pump can convert into stored energy to push the water up the hill through a ½-inch PVC pipe to Javier's house. Once it reaches the house it will be fed into a 55-gallon drum so that the water can be stored until the family is ready to use the water. The elevation profile and the schematic of the system can be found in Figures 21 and 22.

The ram pump needs water velocity to function. That is why there is a ten foot drop from the spring source down to the pump. The pump uses that water velocity to build up pressure in the tank. The tank then uses that pressure to propel the water up the hill to overcome the 52-foot elevation difference.

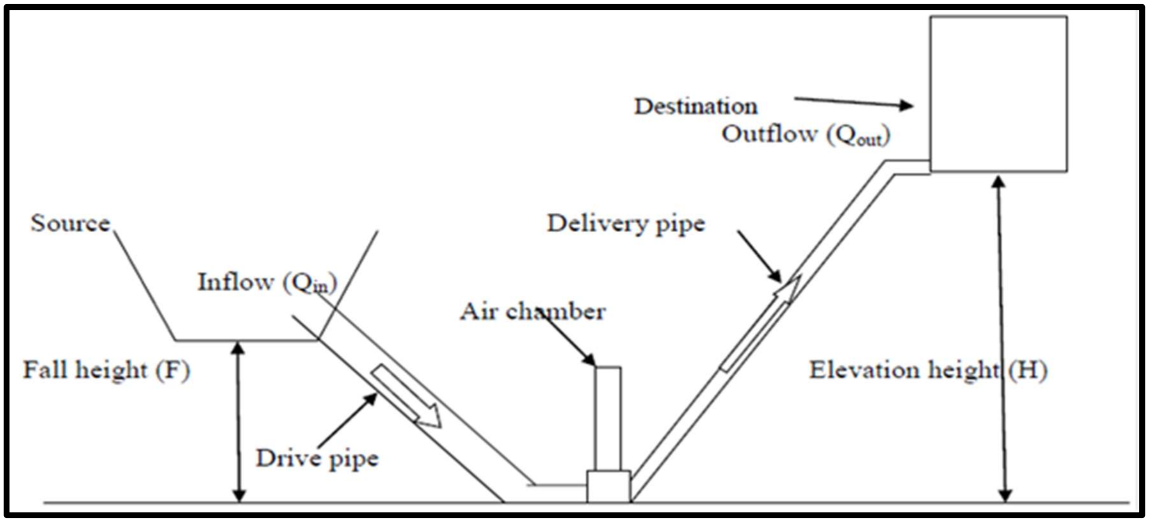

Figure 21: System 2 schematic.

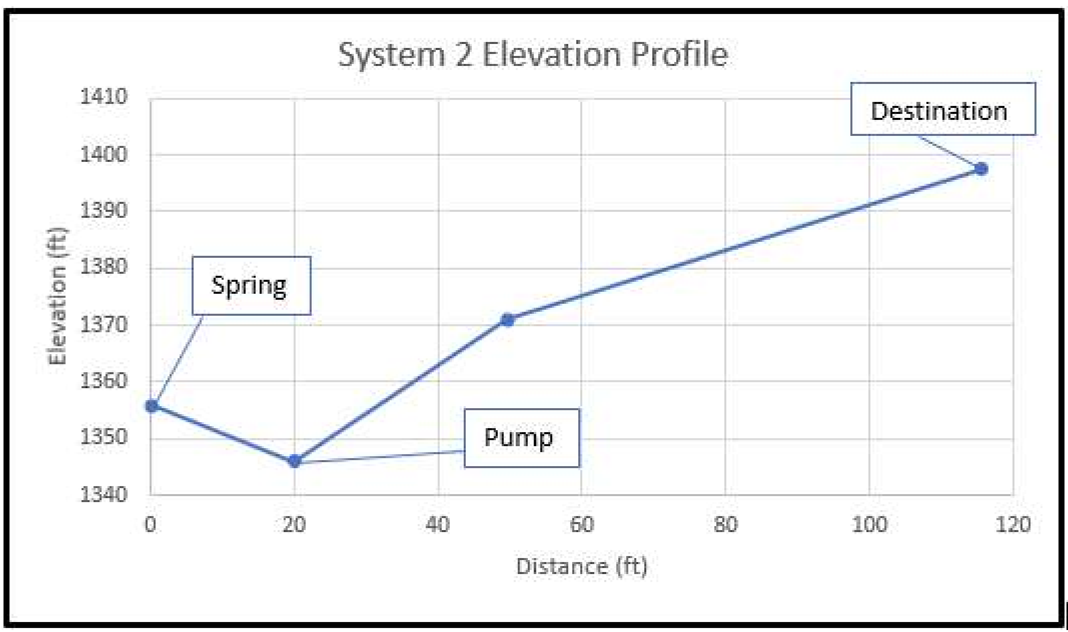

Figure 22: System 2 elevation profile including design locations.

This system will also include a low-profile spring box (Appendices D & I) which is built using the natural curvature of the land around the spring. This spring will use using existing rocks near the spring filled in with mortar for the walls and will have a concrete cover with a hatch for access. There are three pipes that will be coming out of the spring box: an overflow pipe, a transmission pipe, and a cleanout pipe. Chlorination will not be integrated in this system as this home has the cleanest water source. The family cleans the spring source daily to ensure any contamination is removed. The total price of this system including the tank is $240.

3.2.2 Flowrate and Design Validation

The two biggest challenges to overcome for System 2 were the elevation difference and still having a sufficient flow rate for the family at the top of the hill. The flowrate at the spring source was 0.09 liters per second, which equates to 1.43 gallons per minute**.** One of the biggest disadvantages of the ram pump design is that only about 15 percent of the flow rate going into the pump will reach the top of the hill. The flow rate at the top of the hill was calculated to be 0.23 gallons per minute using the formula below. The calculated flowrate was validated in two ways. This flowrate was first validated by multiplying the flowrate at the spring by 15 percent which produced a flowrate of 0.21 gpm. The flowrate that was calculated was also compared to homemade ram pump tests that had been run by Clemson University. These tests are shown in Figure 23. Both validations show a similar flowrate to the 0.23 gpm that was calculated.

Calculations for flowrate (Jordan, 1982).

$$Qp = \frac{2 * Hd * Qd}{3 * Hp}$$

Q_p =	Flow rate at the top of the hill (gallons per minute)	= .023 gpm
H_d =	Falling Head (meters)	= 3.05 m
H_p =	Lifting Head (meters)	= 12.80 m
Q_d =	Falling flow from spring (gallons per minute)	= 1.43 gpm

Table 2: Flowrates in relation to pipe sizes (Henning, 2013)

Drive Pipe Diameter (inches)	Delivery Pipe Diameter (inches)	At Minimum Inflow		At Maximum Inflow	
		Pump Inflow (gallons per minute)	Expected Output (gallons per minute)	Pump Inflow (gallons per minute)	Expected Output (gallons per minute)
3/4	1/2	3/4	1/10	2	1/4
1	1/2	1-1/2	1/5	6	3/4
1-1/4	1/2	2	1/4	10	1-1/5
1-1/2	3/4	2-1/2	3/10	15	1-3/4
2	1	3	3/8	33	4
2-1/2	1-1/4	12	1-1/2	45	5-2/5
3	1-1/2	20	2-1/2	75	9
4	2	30	3-5/8	150	18
6	3	75	9	400	48
8	4	400	48	800	96

4.0 Cost Estimate

4.1 System 1

This system is being fully funded by the Panamanian government, with an allotted budget of $12,500. It will include pipes in one-and-a-half, one, and half-inch diameters at 720 ft, 680 ft, and 3930 ft, respectively. One spring box, a storage tank, a pressure break tank, 2 air-release and 9 clean-out valves, and a flow reducer disk are necessary.

The government plan is to implement the project with five government employees (as many as can fit in one truck), with community involvement being limited to hauling materials from the road to the worksite. However, the community Peace Corps volunteer will recommend that project implementation be completed by the community with training by the government. Having the community implement the system instills a greater sense of ownership, educates the community, and leads to greater chances of project success. Project costs and scheduling have been outlined for both situations. An overview of system costs can be seen in Table 3 below. See Appendix G for detailed cost information.

Table 3: System 1 cost estimate summary

Component	Cost	Percentage of Total
Spring Box	$ 153	3.1%
Pressure Break Tank	$ 10	0.2%
Storage Tank	$ 786	16.0%
Pipes	$ 2,233	45.4%
Spigots	$ 250	5.1%
Air Release	$ 190	3.9%
Labor	$ 1,300	26.4%
Total System Cost:		$ 4,920.00

If implementation is completed by the government, five workers hired by the government will be tasked with implementing the system. Wages for government workers are $4 per hour, resulting in a total labor cost of $4,300. However, if the government permits the community to implement this system, as is recommended, total labor costs will only be $1,300, as community wages are $1 per hour. In this case, one member from each family on the system (7 people total) will be tasked with implementing the system. It is recommended that the government provide a work zone safety training prior to construction. Additionally, the government shall purchase all materials and haul them to the community. Although implementation by the community will use two additional people, implementation is estimated to take the same amount of time as with the five government workers due to the anticipated learning curve.

As can be seen from the cost estimates, community labor reduces implementation costs significantly. A breakdown of the material and labor costs can be found in Appendix G.

4.2 System 2

The cost of this system is broken down into four different components. These four components of this system are the ram pump, the piping, the spring box, and the storage tank. The ram pump is constructed using many different parts. The cost of all the supplies needed for the ram pump comes out to approximately $40. The cost of the piping system comes out to be approximately $35, and the cost of the storage tank comes out to be $50. The cost of the material for the low-profile spring box was calculated to be $115 dollars. Since there will be no cost for labor because the family is building this the total cost of System 2 is $240. A summary of system costs by component can be seen in Table 4 below. A detailed breakdown of the material and labor costs can be found in Appendix G.

Table 4: System 2 cost estimate summary

Componet	Cost	Percentage of Total
Spring Box	$ 115.00	48%
Pipes	$ 42.00	18%
Ram Pump	$ 35.00	15%
Storage Tank	$ 50.00	21%
Labor	$ -	0%
	Total Cost:	240

5.0 Construction Scheduling

5.1 System 1

Project implementation will begin and end during January-March 2018. This is the dry season for the community, providing the least amount of uninterrupted work days. It is expected to take approximately five weeks to implement the project. A summary of construction tasks and durations is provided in Table 5 below.

Table 5: System 1 Construction Tasks Summary

Task Name	Duration
Transporting Materials	1 day
Safety Training	1 day
Level & Compact Ground for Storage Tank	1 day
Place Forms & Pour Base Slab for Storage Tank	1 day
Dig Trench from Tank to Vidal's	1 day
Prepare Spring Location for Spring Box	1 day
Build Spring Box Walls	1 day
Check to Ensure Walls Have No Leaks, Pour Spring Box Cover & Hatch	1 day
Lay First Four Layers of Tank Walls	1 day
Dig Trench From Vidal's to PBT	1 day
Lay Last Four Layers of Tank Walls	1 day
Dig Trench From PBT to Fedal's	1 day
Dig Trench From Nila's to Ernesto's	1 day
Fill Tank Walls With Mortar & Rebar	1 day
Build Pressure Break Tank, Set Forms for Tank Cover	1 day
Pour Storage Tank Cover, Pour Forms for Valve Boxes	2 days
Lay System Pipes	2 days
Check System Pipe Connections, Install Chlorinator, Build First 2 Spigots	1 day
Build Remaining Spigots	1 day
Build and Place Tank Hatch	1 day
Assemble and Install All Valve Boxes	1 day
Test System	1 day
Make Adjustments if Needed and Fill in the Trenches	2 days
Contingency Days	3 days
Clean Construction Site	1 day

Three contingency days have been added to the construction schedule if weather is not cooperative, or task completion takes longer than expected. A more detailed breakdown of the recommended construction schedule can be found in Appendix H.

5.2 System 2

The projected construction period for System 2 is 48 days. This is longer than the estimate for System 1 despite the size of the project because only one family will be working on it. This includes all the time that will be associated with the construction of this project including the time needed to travel into the city to get the materials. This also includes the construction of the ram pump. This is a somewhat complicated procedure so there is construction manual in Appendix F. There is also a complete materials list that can be found in Appendix G. Everything needed for construction should be able to be found in any hardware store. A summary of the tasks and the durations can be found in Table 6 below.

Table 6: System 2 construction tasks summary

Task Name	Duration
Travel into town and gather parts for pump	1 day
Assemble Pump	3 days
Excavate and Level ground for Spring Box	3 days
Gather Material to Build Molds With	2 days
Build Molds for Spring Box	2 days
Put Molds in Place	1 day
Travel into Town and get Material for Concrete	1 day
Mix and Pour Concrete for Spring Box	1 day
Travel into town and get PVC for system	1 day
Have a 55 Gallon Drum Delivered	1 day
Gather Material for Protection the Pump	1 day
Build a Holding and Protection Box for Pump	2 days
Connect System: Spring Box, Ram Pump, and Drum	3 days
Test the System	1 day
Inspect System	5 days
Make adjustments to System	1 day
Clean up from Project	1 day
Total Duration Without any Days off	**48 Days**

6.0 Operation and Maintenance

6.1 System 1

The government's role in this project is to provide the funding and training necessary for implementation. Beyond implementation, it will be the responsibility of the community water committee to operate and maintain the system. The Peace Corps volunteer currently placed within the community should provide technical expertise, if required, beyond the technical data provided in this report.

It is recommended that the system be inspected for leaks or breakage once per season. During this time, the spring shall also be assessed, removing any potential blockage that may have gotten into the box and checking for leaks in the box walls. Upon completion of this system, the water committee shall have a meeting to determine when these checks will be performed and how they will be documented. All valves in the system which are not used on a regular basis, i.e. at the tanks, should be turned on and off three times monthly to ensure that they are still functional.

It is suggested the tanks and the spring be flushed regularly to reduce the risk of bacterial growth and sediment build up. In the case of sickness possibly related to poor water quality, it is recommended that 3M films could be used to test the coliform levels at the source. If these testing films are not available to the community, all valves should be flushed, tanks cleaned thoroughly, and the water currently in the spring boxes should be scooped out through the hatch opening allowing new water to enter the system.

The cost to replace or repair any broken elements within the system should be divided equally between the seven families on the system, with the exception of the spigots. If a family's spigot is inoperable, it will be the family's responsibility to replace the spigot, covering all associated costs. It is recommended that a small monthly fee be collected from the families for use of the water system. This money can be saved in a fund for system maintenance.

6.2 System 2

System 2 will be owned and operated by the family. For the system to run, the spring, ram pump, and the storage drum must be connected by ½-inch PVC pipes. For the ram pump to be operational it needs to be primed with flowing water present. First, the inlet valve needs to be opened while keeping the outlet valve closed. This allows for back pressure to build up. Priming the system is the process of pressing down and releasing the top of the brass swing check valve 20 to 40 times once the system has water running to the pump. The process of priming the pump is shown in Figure 24. This will allow the pump to start working. The family will be responsible for any maintenance needed to keep the system in working order, such as replacing damaged pipes, cleaning the spring, or replacing damaged fittings in the pump. If the pump is used to give water to any nearby households, they will need to have an agreement on payment or maintenance responsibilities between the households.

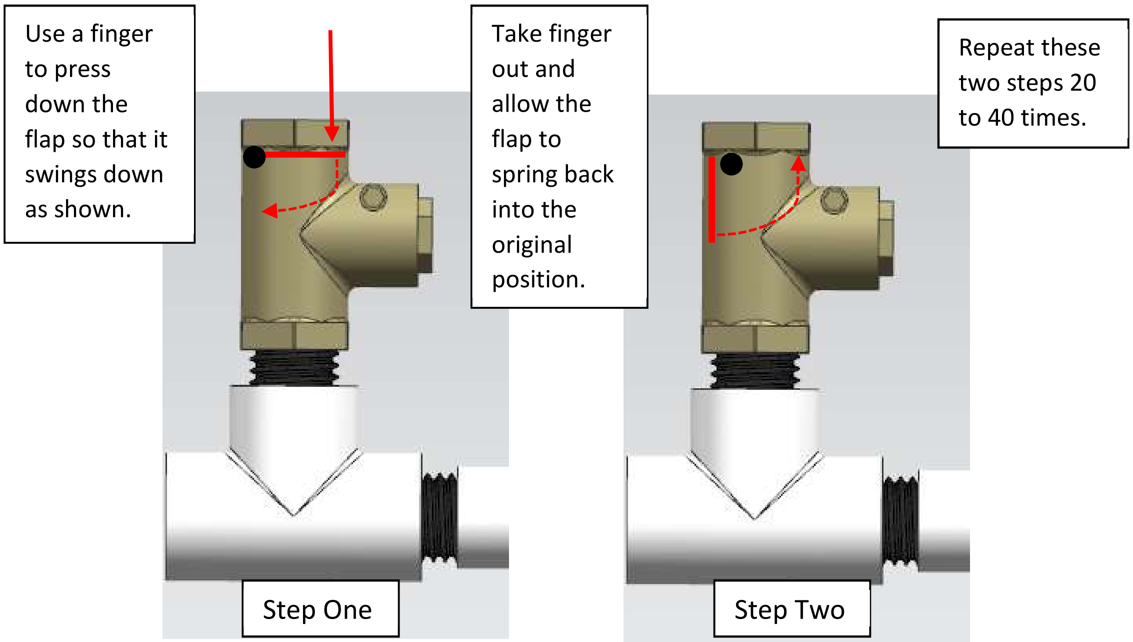

Figure 23: How to prime the ram pump.

7.0 Conclusion

System 1 is a gravity-fed water distribution system that will service 7 homes. Each of the homes has 6 to 10 people living in the household. This system will include a low-profile spring box, pressure break tank, two air release valves, two clean out valves, seven spigots, and a storage tank. These components will be connected with PVC pipes. This system is being funded by the government, which has a maximum budget of $12,500. The design presented here will cost $8,000 which is significantly under budget. For the best chances of project success, it is recommended that the community complete implementation work with training provided by the government, as this would reduce the project cost for System 1 to $5,000.

System 2 is a pump-fed water distribution system that will service one home with the possibility of servicing an additional home in the future. System 2 will include a low-profile spring box, ram pump, and 55-gallon storage drum. These components will be connected by PVC pipes. This system designed to be funded by the family whose house it will serve. There is the possibility that because System 1 is under budget that the cost of System 2 may be able to be funded by the government.

It is recommended that the Peace Corps volunteer share this report with the Panamanian government for consideration in project implementation. It is also recommended to propose System 2 to the government to see if it can be funded by them. Additionally, this report and its design aspects should be shared with the community to provide a better understanding of the project goals.

8.0 References

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9.0 Acknowledgements

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We would like to thank Sierra Schatz (Baí) of Peace Corps-Panama for introducing us to her peaceful community in Cerro Gallina and providing thorough guidance during and after the trip. Thank you for taking care of us when some of our stomachs discovered that we were in Panama and for continuing to send us information throughout the development of the design process.

A special thanks to Cerro Gallina and the families included in both systems; you were vital in support and desire for our involvement. Thank you for allowing us into your lives and sharing your beautiful culture. It was a true pleasure.

APPENDIX A:

STORAGE TANK CALCULATIONS

Storage Tank calculations

Cement Requirements

Assuming a 1:2:3 ratio of dry cement, sand and gravel

	Density, ρ (kg/ m^3)
Dry Cement	1440
Sand	1600
Gravel	1450
Wet concrete	2400

Volume of dry cement in 1 kg:

$$Vol = \frac{1kg}{1440kg/m^3} = 0.000694\, m^3$$

Volume of 1 bag of dry cement (45.36 kg):

$$Vol = \frac{45.36kg}{1440kg/m^3} = 0.0315m^3$$

Volume of sand and gravel given the ratio of 1:2:3 need to mix with one bag of dry cement:

$$Vol_{sand} = 0.0315m^3 * 2 = 0.063m^3$$

$$Vol_{gravel} = 0.0315m^3 * 3 = 0.094m^3$$

Weight of sand and gravel:

$$W_{sand} = 0.063m^3 * \frac{1600kg}{m^3} = 100.8kg$$

$$W_{gravel} = 0.094m^3 * \frac{1450kg}{m^3} = 136.3kg$$

Water needed:

Water to cement ratio = 0.55

$$W_{water} = 45.36kg * 0.55 = 24.95kg$$

Total concrete volume:

$$Vol = \frac{m}{\rho} = \frac{45.36kg + 100.8kg + 136.3kg + 24.95kg}{2400kg/m^3} = 0.128m^3$$

Resources needed to produce one m^3 of concrete:

Dry cement: $1m^3 * \frac{1\,bag}{0.128m^3} = 7.81 \approx 8\ bags$

Sand: $1m^3 * \frac{100.8kg}{0.128m^3} * \frac{1m^3}{1600kg} = 0.492m^3 \ * \frac{35.3ft^3}{1m^3} = 17.41ft^3$

Gravel: $1m^3 * \frac{136.3kg}{0.128m^3} * \frac{1m^3}{1450kg} = 0.734m^3 \ * \frac{35.3ft^3}{1m^3} = 25.93ft^3$

This material reference for 1 m^3 of concrete is used for all of tank calculations

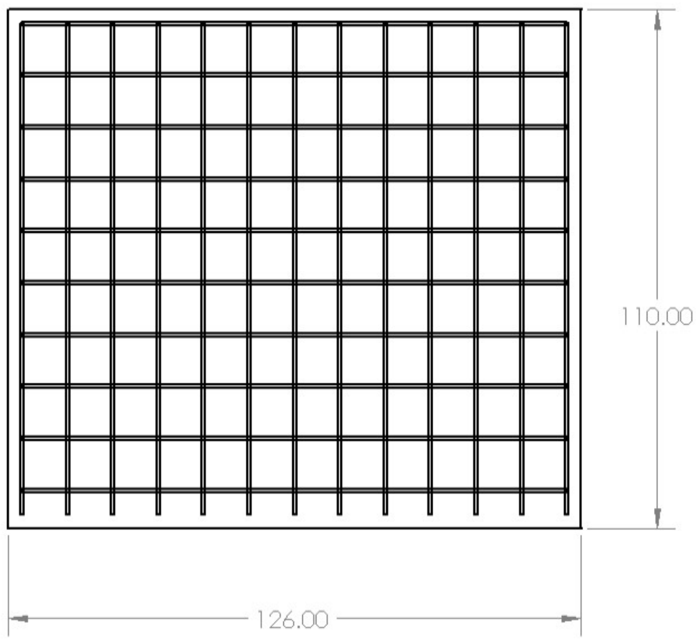
**Peace Corps volunteer recommends 10% extra sand and gravel material for all construction.

STORAGE TANK BASE:

<u>Rebar Requirements</u>

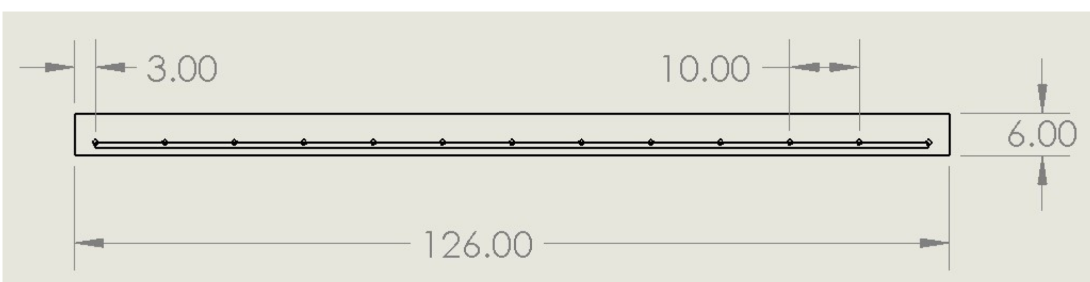
Dimension: 126in * 110in * 6in

Volume: 83160 in^3 = 1.36 m^3



Long side is 126 inches

Rebar located 1.5 inches from the bottom of the base and start 3 inches from either end



$$A_s = \rho bd = 0.002 * 12in * 4.5in = 0.11in^2/ft$$

Where A_s =	Area of steel
fy=	Yield stress
fc'=	Design concrete
ρ=	Reinforcement ratio
b=	Width/spacing
d=	Effective depth from top
	of slab to centroid of
ρg=	rebar
ρs=	Density of gravel
	Density of sand

$$0.20 = 0.003 * b * 4.5in = 14.8in$$

Reference says needs to be between 0.003 and 0.004

This means that the bars must be spaced 14.8 inches or less apart.

$$\frac{126\ in - 3in * 2}{10in} = 12\ spaces,\ 13\ bars$$

Thirteen (13), 104 in rebar bars are needed. They are sold in 30-ft lengths

$$\frac{104\ in}{12\frac{in}{ft} * 30\ ft} = 3.46\ lengths\ per\ bar$$

$$\frac{13\ lengths}{3.46\ lengths\ per\ bar} = \ 4.3\ 30\ ft\ bars$$

In the short direction, 110 inches less rebar is needed

The bars will be spaced 11 inches apart

$$\frac{110\ in - 3in * 2}{11in} = 10\ spaces, 11\ bars$$

Eleven (11), 120 in rebar bars are needed.

$$\frac{120\ in}{12\frac{in}{ft} * 30\ ft} = 3\ lengths\ per\ bar$$

$$\frac{11\ lengths}{3\ lengths\ per\ bar} = 3.67\ 30\ ft\ bars$$

Total rebar needed for base

$$4.3\ bars + 3.67\ bar = 7.97\ bars = 8\ bars$$

Will need 1 small rock every 4 ft^2 (25 rocks total) to hold the rebar approximately 1.5" above the ground when pouring the concrete. Plastic chairs can be used, but this is a more expensive alternative.

Cement Requirements

Dry cement: $7.81 \frac{\text{bags}}{m^3} * 1.36\ m^3 = 10.6\ bags = 11\ bags$

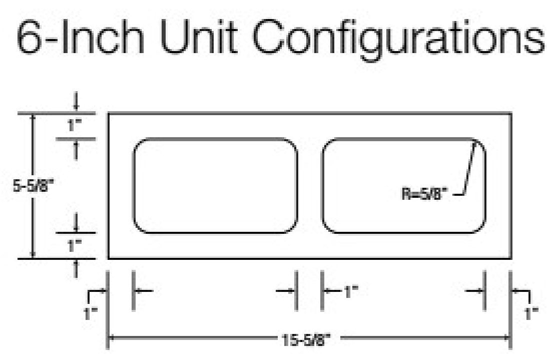
Sand: $17.4 \frac{ft^3}{m^3} * 1.36\ m^3 * 1.1 = 26.03\ ft^3 * \frac{m^3}{35.3\ ft^3} = 0.74\ m^3$

Gravel: $25.93 \frac{ft^3}{m^3} * 1.36\ m^3 * 1.1 = 38.79\ ft^3 * \frac{m^3}{35.3\ ft^3} = 1.09\ m^3$

STORAGE TANK WALLS:

Walls will be laid 4 inches in from each side of the base. They will be 4 feet tall.

The estimate of family water demand, provided by the Peace Corps volunteer is 180 gallons per family per day. Using this demand, a tank was designed to hold enough water for all seven families for one day with an additional 30% as a safety factor.



$$180 \frac{gallons}{family * day} * 7\ families * 1\ day * 1.30 = 1638\ gallons = 219\ ft^3$$

The walls were designed so that CMU blocks would not need to be cut. The resulting dimensions are 7 blocks long by 6 blocks wide (118 inches x 102 inches).

CMU Block Requirement

Per layer

$$(2 * 6\ blocks) + (2 * 7\ blocks) = 26\ blocks\ per\ layer$$

Wall needs to be four feet tall to meet the community demands

$$4\ feet * \frac{12\ inches}{1\ foot} * \frac{1\ block}{6\ inches\ tall} = 8\ blocks = 8\ layers$$

Total Blocks needed

$$26\ blocks\ per\ layer * 8\ layers = 208\ blocks$$

*Peace Corps volunteer recommends 5% extra blocks to account for breakage in transport

$$208\ blocks * 1.05 = 219\ blocks$$

<u>Rebar Requirements</u>

Rebar is added to the tanks, with recommended spacing of 16 inches on center.

Given that the CMU blocks are 16 inches long, 1 bar of rebar should be placed per block.

Since there are 26 blocks in a layer, 26 lengths of rebar are needed

The bar should extend from the top of the tank base to the bottom of the tank cover.

Total length of rebar needed

$$26\ lengths * \frac{48\ inches}{length} = 1248\ inches\ of\ rebar$$

Sold in 30 foot lengths. Total bars required to purchase.

$$1248\ inches * \frac{1\ bar}{30\ feet} * \frac{1\ foot}{12\ inches} = 3.47\ bars = 4\ bars\ of\ rebar$$

<u>Mortar Fill Requirements</u>

Mortar (1:3 ratio) will be used to fill the CMU blocks

Each hollow CMU block has

$$\left(3\frac{5}{8} in * 6.3125\ in * 6\ in\right) * 2 = 274.594\ in^3\ void\ space$$

Total void space in wall

$$274.594\ in^3\ per\ block * 208\ blocks = 57115.5\ in^3 = 0.936\ m^3$$

Mortar is also used to join the blocks with 3/8 inches of fill.

Total mortar needed to joint he blocks

$$\left(6in * 6in * \frac{3}{8} in\right) * 2 + \left(6in * 16in * \frac{3}{8} in\right) * 2 * 208\ blocks = 20592\ in^3 = 0.34\ m^3$$

Total mortar needed for tank walls = 0.936 m^3 + 0.34 m^3 = 1.2776 m^3

Using 1:3 ratio cement to sand

Volume 1 bag cement = 0.0315 m^3

Volume sand = 0.0315 m^3 *3 = 0.094 m^3

Weight sand = 0.094 m^3 * 1600 kg/ m^3 = 150.4 kg

Weight water = 0.094 m^3 * 0.63 = 29.48 kg

$$Vol = \frac{m}{\rho} = \frac{29.48kg + 150.4kg + 45.36kg}{1600kg/m^3} = 0.141m^3$$

For 1 m^3 of mortar:

Dry cement: $1m^3 * \frac{1\ bag}{0.141m^3} = 7.09 \approx 8\ bags$

Sand: $1m^3 * \frac{150.4k}{0.141m^3} * \frac{1m^3}{1600kg} = 0.67m^3 \ * \frac{35.3ft^3}{1m^3} = 23.53ft^3$

Walls need:

7.09 bags *1.2776 = 9.04 bags = 10 bags dry cement

$23.53\ ft^3 \ * \ 1.2776 \ * \ 1.1 \ = \ 33.07\ ft^3\ sand \ * \frac{35.3\ ft^3}{1\ m^3} \ = \ 0.94\ m^3\ sand$

STORAGE TANK COVER:

Dimensions: 126 in * 110 in * 6.5 in

Rebar Requirements

$A_s = \rho bd$

$0.20 = 0.002 * b * 5in = 20in$

Maximum of 18 inch spacing recommended between rebar. For even spacing, bars will be spaced 14 inches apart from each other one the long side and 14.5 inches on the short side.

Nine (9), 30 foot bars needed

Additional rebar should be placed near the hatch as shown in the figure below.

These pieces are each 51. 36 inches long and 4 pieces will be required.

Total bars needed for tank

$$9 + 4 = 13\ bars$$

23 rocks or plastic chairs for rebar placement

Concrete Requirements

Minimum thickness: L/20 = 126 in /20 = 6.3 inch

Slab should be 6.5 inches thick

6.5in * 126in * 110in – 24in *36in * 6.5 in = 84,474 in^3 = 1.38 m^3

Cement fill

Dry cement: $7.81 \frac{\text{bags}}{m^3} * 1.38\ m^3 = 10.78\ bags = 11\ bags$

Sand: $17.4 \frac{ft^3}{m^3} * 1.38\ m^3 * 1.1 = 26.4\ ft^3 * \frac{m^3}{35.3\ ft^3} = 0.75\ m^3$

Gravel: $25.93 \frac{ft^3}{m^3} * 1.38\ m^3 * 1.1 = 39.36\ ft^3 * \frac{m^3}{35.3\ ft^3} = 1.12\ m^3$

Hatch Requirements

2in overhang on each side of the 2ft * 3ft hole.

Dimension: 40in * 28in

Materials:

- 40 in * 28 in piece of timber
- 4 anchor bolts
- 4 5in * 1in * 1in pieces of timber
- 4 3in * 1in * 1in pieces of timber
- 8 1.5in screws

APPENDIX B:
EPAnet FIGURES

EPAnet Figures

Plots based on EPAnet model configurations.

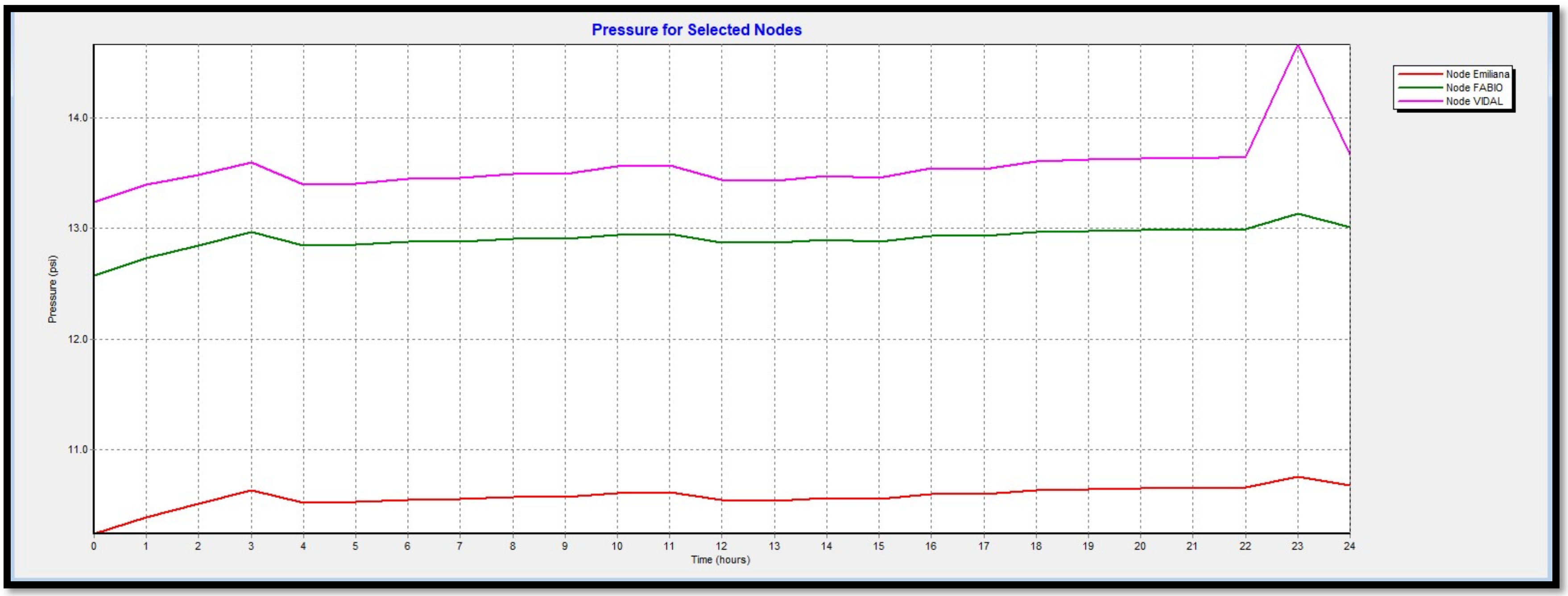


Figure 1: Change of Pressure at Emiliana's, Vidal's, and Fabio's homes over 24 hours

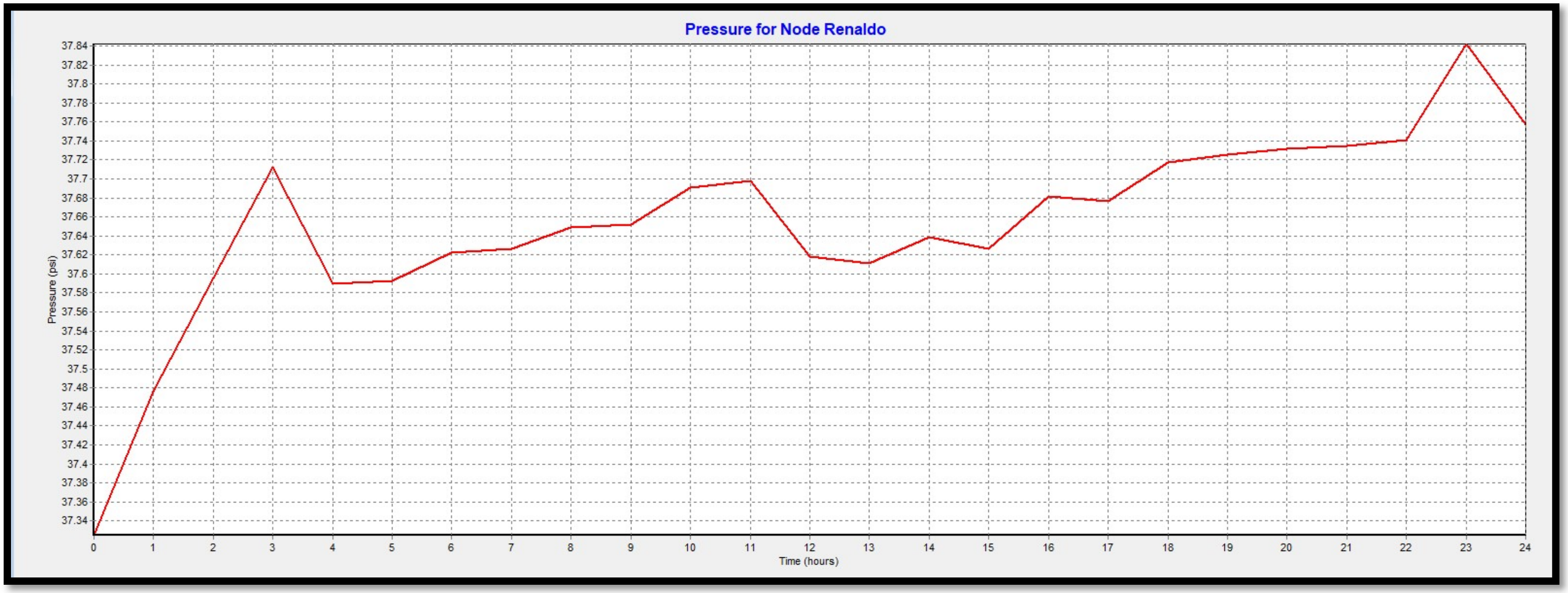


Figure 2: Change of Pressure at Renaldo's Home over 24 hours

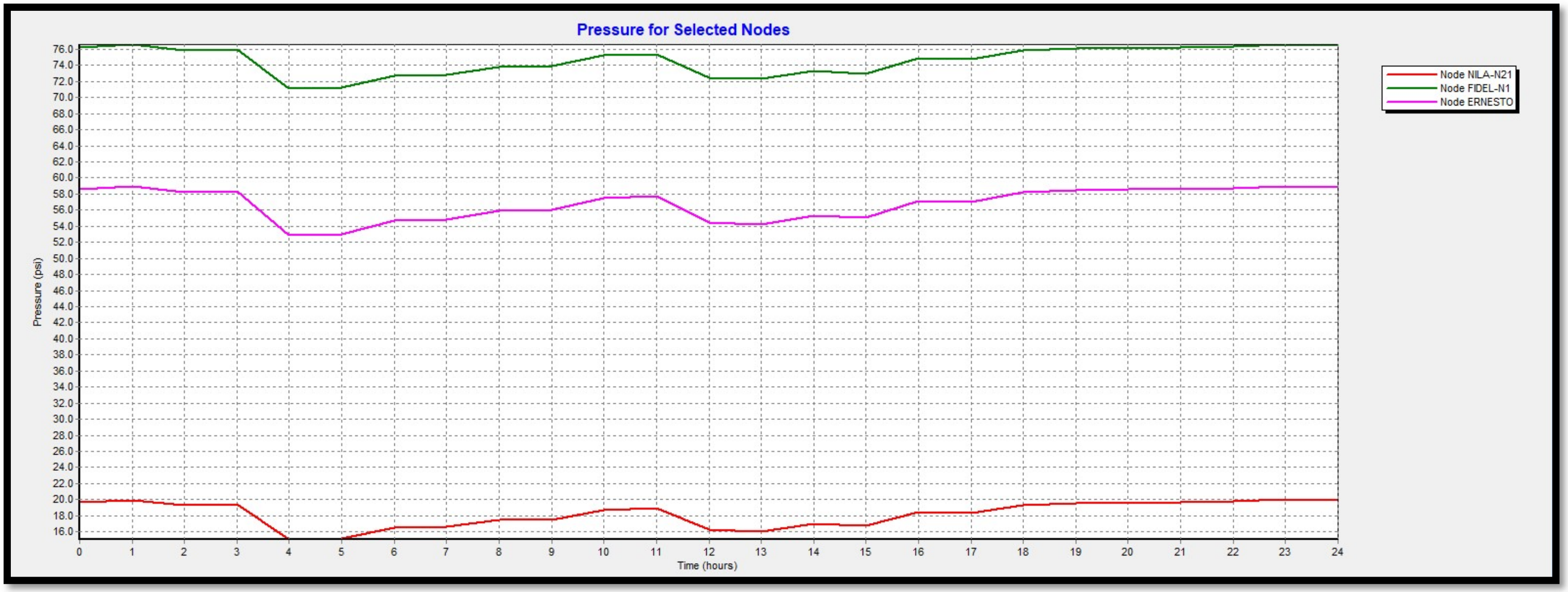


Figure 3: Change of Pressure at Fidel's, Nila's, and Ernesto's over 24 hours

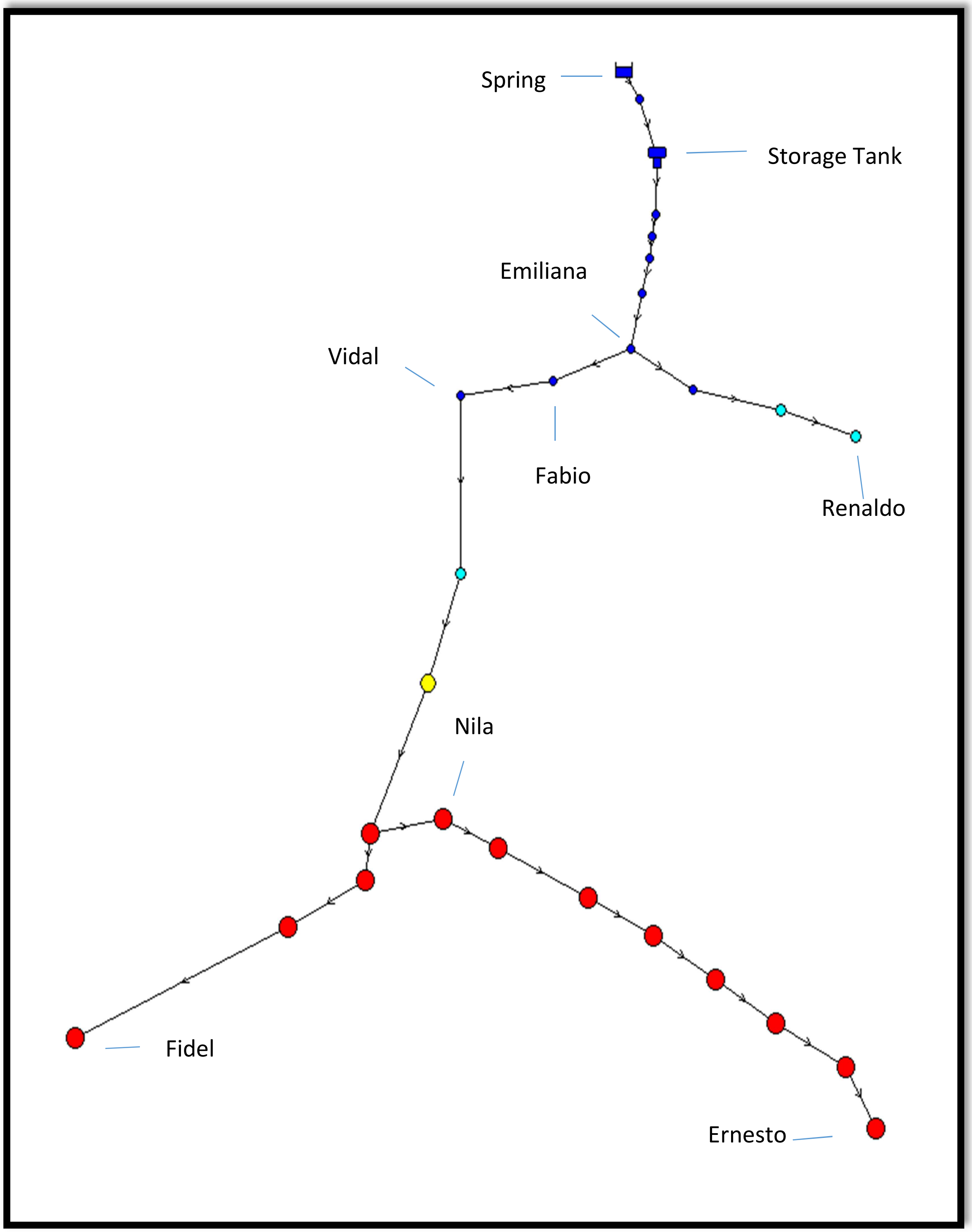


Figure 4: EPAnet model showing pressures without a pressure break tank. Node placement not to scale.

APPENDIX C:
SPIGOT CALCULATIONS

Spigot Calculations

See Figure C1 for a sketch of the spigot layout.

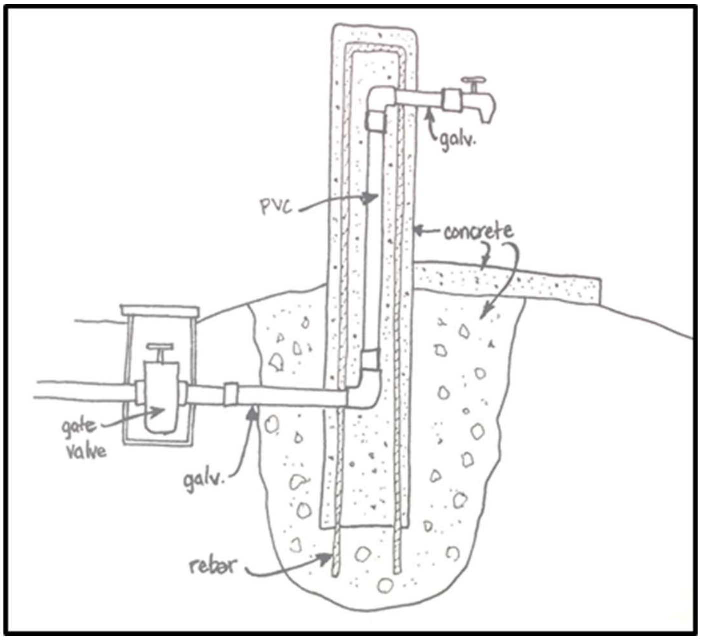


Figure C1: Spigot example from Mihelcic 2009.

Concrete:

Volume wet cement produced from one bag of dry cement = 0.128 m^3

Using a 1:2:3 ratio of cement, sand and gravel.

Total of 1 ft^3 for the foundation and form around the pipe:

Cement:

1 ft^3 * 1 bag/0.128 m^3 *1 m^3 / 35.3 ft^3 = 0.22 bags

Sand:

1 ft^3 * 100.7 kg sand/0.128 m^3 cement *1m^3 sand / 1600 kg sand * 1 m^3 sand/ 35.3 ft^3 sand = 0.0139 m^3 sand (3.67 gallons)

Gravel:

1 ft^3 * 136.7 kg gravel/0.128 m^3 cement *1m^3 gravel / 1450 kg sand * 1 m^3 sand/ 35.3 ft^3 sand = 0.0209 m^3 sand (5.52 gallons)

Pipes will switch to galvanized or brass right before the elbow joint at the top of the spigot. The outlet valve will be brass to minimize deterioration over time. Up until that switch the pipe will be PVC.

Materials necessary for a single spigot.

Material	**Quantity**
PVC	
½" pipe	4.5' (54")
4" pipe	5' (60")
½" valve	1
½" elbow joint	1
½" couplings	2
Galvanized pipe	
½" elbow joint	1
½" threaded couplings	2
½" pipe	1' (12")
½" valve (brass)	1
Reinforced steel (3/8th)	9.25'

APPENDIX D:

GUIDELINES FOR THE CONSTRUCTION OF LOW-PROFILE TOMAS & DESIGNS

Guidelines for the construction of low-profile tomas

Introduction

It's hard. It's frustrating. It will make you think you're not qualified to do your job. It won't be pretty, and it definitely won't be perfect. You won't capture all the water. You will be left second-guessing what you did.

But, if you can get past all of that, you will hopefully end up with some sort of structure that captures the majority of the water and sends it to the community. And that is a beautiful thing. This is probably the only time in your life that you will have the opportunity to help someone get running water at their house.

The purpose of a toma

The purpose of a toma is to capture the water in such a way that it is easier for the water to leave the toma through the conduction line than to seep out elsewhere. You have to do this without changing the groundwater hydrology so that the spring doesn't move and surface elsewhere, leaving you with an empty concrete monument. The bottom line is that you want to make it as easy as possible for the spring to flow into the toma and get the water out of there as fast as possible. You don't want water to build up or be stored in the toma as this will create water pressure which will encourage the water to look for alternate exits which could ruin the toma. This is the most important thing to remember when building a toma. The rest is just guidelines.

Overview of low-profile tomas

Low-profile tomas are small and follow the ground contours (Figure 1). There are concrete walls on the sides and downstream end of the toma (Figure 2). The toma itself is filled with rocks, leaving lots of voids for the water to flow through. The whole thing is covered with a concrete slab to prevent runoff from entering and contaminating the spring water. Tomas have 3 exit pipes—the overflow, conduction line, and cleanout (Figure 3). The overflow is to allow water that doesn't fit in the condutction line to escape without looking for alternate routes and potentially ruining the toma. It is usually a piece of 2" PVC pipe covered with mesh at the end to prevent critters from getting in. For overflow pipe sizing see Thomas Jordan's book *Handbook of gravity-flow water systems*, page 103. Make sure the overflow is far enough from the toma wall that water leaving the overflow won't cause erosion of the toma wall or ground the toma wall sits on. The conduction line is to pipe water to the storage tank. I recommend that the conduction line has a shutoff valve followed by an air-release valve leaving the toma. The cleanout is 2" PVC pipe with a male adapter and threaded cap. This allows you to drain the toma for cleaning and get all the dirt out. The cleanout should be as low as possible. The conduction line goes just above the cleanout, and the overflow has to be completely above the conduction line. The toma also has an access hatch with a lid above the pipes so that the toma can be opened up for cleaning.

Figure 1: Low-profile toma.

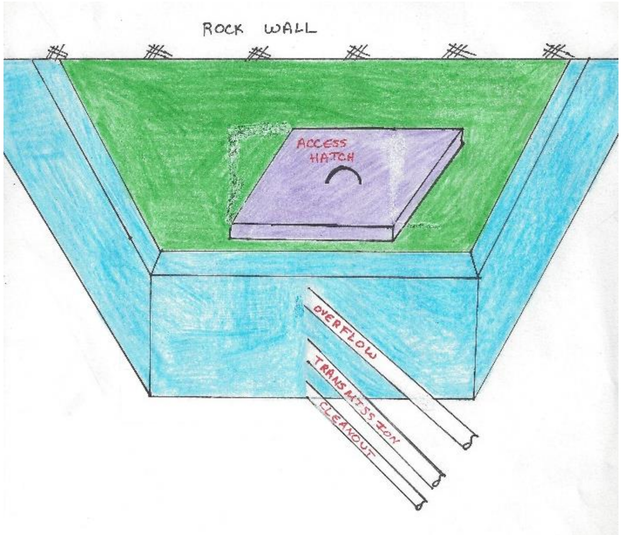


Figure 2: Diagram of a low-profile toma. The blue is the wing walls and the green is the concrete slab that is poured on top. The purple is the access hatch lid. Most likely your toma won't have such straight edges like this drawing. Rather it will look more like Figure 1. Remember, low-profile tomas follow the ground profile to avoid using more materials than necessary or having water buildup in the toma.

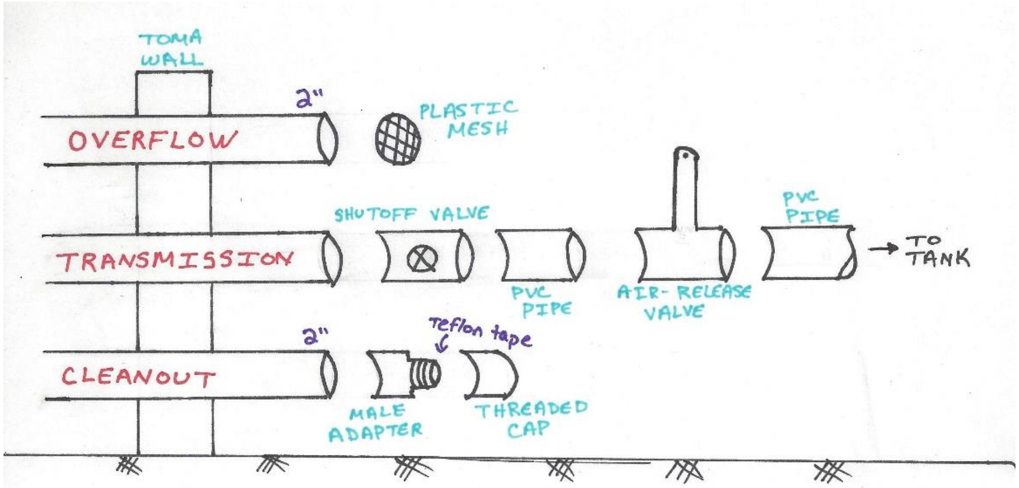


Figure 2: Pipes leaving the toma: overflow, conduction (transmission) line, and cleanout.

Flow rate measurements and initial investigations

Before building a toma and designing an aqueduct, you'll need to do almost a year's worth of flow rate measurements and initial investigations. When you measure the flow rate, you're probably going to capture all the water just downstream of the spring and measure the flow rate. I would recommend doing this monthly during the dry season (definitely make sure to get a measurement at the end of the dry season so that you know the minimum flow rate) as well as one measurement during the wettest part of the wet season (to know the maximum flow for conduction line sizing). When you do these flow rate measurements, it's also worthwhile to do a little bit of investigation. Clear a little bit of the monte (no need to excavate all the way down to the impermeable layer) to get an idea of where the spring(s) is actually coming out. Note how it changes during the seasons. You'll want to build the toma during the summer so that you capture the water that's live year-round, but it's also useful to know where the water comes out during the winter. Also, having a good idea of where the springs are will allow you to more accurately estimate material quantities. You'll want to investigate several springs during the dry season so that at the end of the dry season you can pick the one with the highest flow rate. The water should be coming out of one spot (ideally), or a small area (less ideal but more likely). Waterlines does not fund projects that are stream intakes.

Also, you should make sure that there's an impermeable layer somewhere (you may have to dig down a bit) that you will be able to tie the walls into. Without an impermeable layer to pour the concrete on, the water will just find a way to escape under whatever you build. If there's a lot of water, you and your community are going to want to use the spring, but you really can't build a good springbox without some type of impermeable layer. True story. Trust me.

Materials

In order to determine how much materials to buy, you'll have to estimate the finished size of the toma. Measure a square around the area where the water surfaces. It's better to overestimate; however, I would recommend starting by buying only a couple bags of cement and a corresponding amount of sand so that you don't have a bunch of leftovers at the end. On the other hand, if you're also going to build a tank you can buy more cement and sand initially for the toma knowing that whatever you don't end up using for the toma will be used for the tank.

To calculate the materials needed for the concrete slab covering the toma (including the lid):
Assume the slab is 8 cm (3 in.) thick.
V_{mix} = Area of toma * 0.08 m

The slab will be 1 cement : 4.5 cascajo, if the cascajo is dirty (comes from a river). You can use 1 cement : 5 cascajo if the cascajo is clean (bought) (Bingley, 2004).

$V_{cascajo} = V_{mix}$ (Jordan, 2007)
$V_{cement} = 1/4.5 * V_{mix}$ (for dirty cascajo) or $V_{cement} = 1/5 * V_{mix}$ (for clean cascajo)

To calculate the materials needed for the wing walls:
Calculate the total length of the walls along the sides and bottom part of the toma. Assume they have a height of 0.3 m and a width of 0.15 m.

V_{wall} = Total length of walls * 0.3 m * 0.15 m

For a stone masonry wall assume 35% mortar and 65% stone (Jordan, 2007).

$V_{mix} = 0.35 * V_{wall}$

The mix will be 1 cement : 4 sand (Jordan, 2007).

$V_{sand} = V_{mix}$
$V_{cement} = ¼ * V_{mix}$

You will need Sika-1 for the walls.
If you're going to plaster the toma walls, you'll need some more cement, Sika-1, and bought sand, but it won't be much.

Materials list:
- ☐ Cement: Calculate as described above. There are approximately 2 cubos (10 gal.) in a bag of cement.
- ☐ Black plastic trash bags: One trash bag per bag of cement to protect the cement during transport.
- ☐ Cascajo: Calculate as described above.
- ☐ Sand: Calculate as described above.
- ☐ Rebar, 3/8": 1 rama (30') for access hatch lid.
- ☐ Wire: 1 lb. for tying rebar for access hatch lid.
- ☐ Teflon tape: 1 roll for the threaded connections.
- ☐ Sika-1: 2-3 jugs depending on the size of your toma. Make sure to buy Sika-1 (which makes the concrete impermeable) not Sika-2 (which makes the concrete set faster).
- ☐ PCV glue: 1 bottle for gluing connections.

- ☐ Nails: 1 lb. to make a frame for the access hatch and lid.
- ☐ 1x4s: You can use can use scraps, but it helps to have something to use as a form for the access hatch and lid.
- ☐ Sacos: Enough to cover the rocks before you pour the concrete slab. You don't have to use them, but I find this makes it easier.
- ☐ Rocks: You'll need a bunch of rocks of various sizes, but you'll probably be able to collect them from the area.

Breather tubes:
- ☐ ¾" PVC pipe, SDR 21: 1 tramo
- ☐ ¾" caps: One per breather tube. I do about 1 breather tube per m^2.

Overflow:
- ☐ 2" PVC pipe, SDR 26: 3'
- ☐ Plastic mesh: 1' to put over the opening

Condcution line:
- ☐ PVC pipe, size of conduction line: 1 tramo
- ☐ Shutoff valve, size of conduction line: 1
- ☐ Air-release valve, size of conduction line: 1

Cleanout:
- ☐ 2" PVC pipe, SDR 26: 3'
- ☐ 2" male adapter: 1
- ☐ 2" threaded cap: 1

Tools

Below is a list of recommended tools for toma construction. If you're on a tight budget you can make do without some of them, but having them will make the job easier.

- ☐ **2-3+ Cubos**: These are useful for everything--diluting Sika-1, moving concrete around, excavating dirt, collecting rocks, rinsing, etc.
- ☐ **3+ Totumas/KLIM cans**: These are useful for measuring water, Sika-1, cement, sand, and gravel, as well as cleaning the toma.
- ☐ **2-3 Shovels**: For clearing the toma area and mixing concrete.
- ☐ **Machetes**: Make sure at least one person brings theirs. The day you clear the toma area you'll need more.
- ☐ **1 Pickax:** Personally I don't allow pickaxes at the toma worksite because I'm so afraid of puncturing the impermeable layer. The workers don't appreciate this, but it greatly reduces my stress. There's rarely a time when you really need a pickax, but you might want to have one handy.
- ☐ **1 Saco**: If you're going to use a saco to mix the concrete, be sure to bring one. Also be sure to rinse the concrete off and leave it to dry once you're done mixing so that you can use it again.

- ☐ **3-4’ Metal mesh**: You’ll need this to sieve the sand. If you buy sand, you can probably get away without this. Bought sand has some small rocks in it, but they are fine in the walls, and you can pick them out by hand for the plaster if you don’t have mesh. If you are getting sand from the river you definitely need this.
- ☐ **1 Wooden float**: For concrete finishing.
- ☐ **1-2 Trowels:** For placing the concrete and plastering the walls.
- ☐ **1 Hacksaw:** For cutting rebar and PVC pipe.
- ☐ **1 Tape measure**: Not absolutely necessary, but it helps.
- ☐ **1 Leatherman or pliers and wire cutters**: For cutting the wire and tying the rebar in the access hatch lid (if you do a reinforced concrete lid).
- ☐ **Wood saw:** For cutting wood for the access hatch and frame for the lid. There’s not a lot of wood to cut so if you don’t have a wood saw you could get away with using the hacksaw.
- ☐ **Hammer**: For nailing together the frames for the access hatch and lid.

Construction logistics

Tomas should be built during the summer to ensure that you capture the water that’s live year round. Also, it’s easier to work during the dry season because there’s less water that you’ll have to work around and divert while building. I like working with about 6 people. Toma construction is slow, precise, detailed work requiring patience. If you have too large of a group it’s hard to make sure everyone is doing what they’re supposed to be doing, and you’ll probably have people sitting around because there isn’t anything for them to do. You’ll have to be very involved and hands on during toma construction. In terms of time, it can take anywhere from 3 days to a week or more, depending on the size of the toma, how much you have to dig to get down to the impermeable layer, and how things go. Ideally you’ll be able to work consecutive days until you finish.

The “spring”

The “spring” is where ever the water is surfacing. You need to make sure that you’re capturing spring water not surface runoff or a stream. Ideally the water will be surfacing at a single spot. More likely you’ll have a several springs in a small area. You might also have water seeping up from all over an area with no clear spring. Whatever it is, just make sure that you are getting spring water not soil moisture, surface runoff, or a stream.

When you build the toma, you want the springs to be free flowing. That means that the overflow pipe needs to be lower than where the spring surfaces so that the water flows out of the spring above the standing water level in the toma. This is to ensure that there is no hydraulic resistance caused by the toma that will prevent the water from surfacing there. Water is lazy and will always follow the easiest path. Therefore, if by building the toma you create hydraulic resistance to the water surfacing at the current spring, it will find somewhere else to surface (slowly over time) so the spring will move and eventually your toma won’t be capturing any water because it will be surfacing somewhere else that’s easier. On this same note, when you’re clearing the area for the toma, you want to clear away the dirt and rocks where the spring is as much as possible to make it as easy as possible for the water to surface there.

The impermeable layer

The impermeable layer is what prevents the water from infiltrating back down into the earth, and it's what you have to tie the walls into so that water doesn't escape from the springbox. Just because the water is flowing over the surface doesn't mean that you have a good impermeable layer. That just means that it's easier for the water to flow across the surface than down; however, as soon as you have even a couple of inches of head (which will happen even in a low-profile toma) the water will start flowing down/under the wall if you don't have an impermeable lay to tie the wall into.

Also note that if you puncture the impermeable layer during construction, water will infiltrate, and you will lose the spring. If you lose your water source, there won't be any aqueduct, so be very careful.

What the impermeable layer looks like varies greatly. It could be a clay layer or a bedrock layer. Make sure that is substantial enough it won't get damaged during the first wet season which will cause all of the water will start escaping out under the walls. (True story. Trust me.) The impermeable layer is so important because you need something to tie the walls into that water won't seep out under. Also, clearing the toma down to the impermeable layer should reduce the amount of sediment in the water.

Clearing the area

The first step is to clear cut the area with a machete. Only clear cut where the spring is, a little bit of work space, and a clear path to the toma (that you'll layer be able to carry materials on). Remember that vegetation is important, so you don't want to clear cut any more than you absolutely have to. However, you also don't want roots growing into the toma because they can clog it and cause other problems.

Then you want to start digging (usually with your hands) around where the water is coming out to find the springs and clean that out. You need to clear everything down to an impermeable layer, especially where the walls are going to be. Remember that the spring needs to be free flowing, so you don't want to dig a big hole down because all the pipes should be even lower than that. An easy way to clear the toma is by throwing water on the rocks. This washes away everything that easily comes loose without risk of damaging the impermeable layer. You usually don't have to remove large rocks (since you're going to be filling it back in with rocks anyway) unless you need to remove them in order to clear down to the impermeable layer. If they aren't in the way, just leave them.

If you don't immediately have an obvious impermeable layer, it works well to start digging a little ways downstream of where the toma will be. This way you can look for the impermeable layer without worrying about puncturing it and losing the spring. Keep digging until you find something good. Once you have found the impermeable layer, follow it back upstream to the toma. Be careful because sometimes the layers can change, even in a small area.

Deciding toma limits

The toma doesn't have to be very big at all. In fact, the smaller it is, the less work it will be to build and the less materials you'll have to buy. In some cases it might make more sense to build 2 smaller tomas and connect them with a junction box instead of building a toma over a large area without springs.

You might not be able to capture all of the water, but these are the main things to keep in mind. You want to capture the majority of the water that flows during the summer. You want to capture all of the water that you think is hydrologically connected. That is to say, you don't want to leave a spring uncaptured if you think it's directly connected to one of the springs in the toma because water might decide to come out there instead of in the toma and then you will lose that water.

When deciding where the walls will go, make use of what's already there—rocks, rock/dirt walls, etc. You usually don't build a wall on the upstream side because that's where the water is coming from. Ideally you will back/tie into a dirt or rock wall (Figure 4). If spring water is coming in from the sides, then you won't build side walls either. Even if you don't build side wing walls, you still need something the downstream wall can tie into on each side to make sure that the water doesn't escape around the sides of the downstream wall (Figure 5).

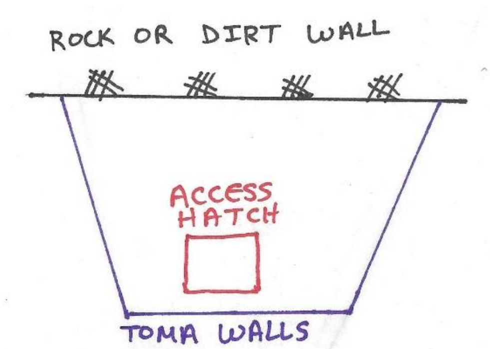


Figure 4: Toma with wing walls tied back into rock or dirt wall on the upstream side.

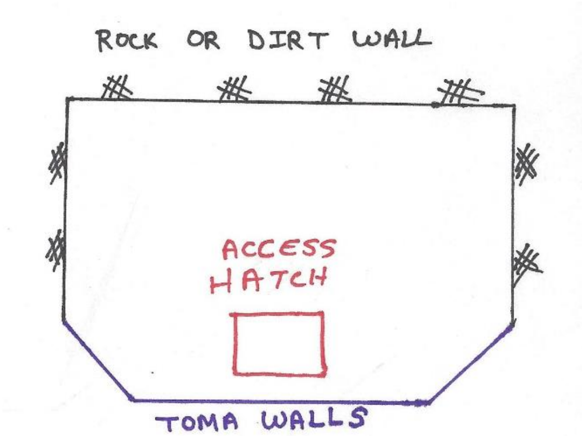


Figure 5: Toma without side walls. Downstream wall is tied into rock or dirt walls on the sides.

Whatever you end up deciding, it's important to document what you did and why. It's also helpful to have pictures and/or diagrams of where the springs are because once you build the toma you/anyone who comes to work on it in the future will never be able to see that again. Include this in your completion report and leave a copy with the water committee in case someone else comes to work on the toma in the future when you're gone. The more information and details you provide, the more useful this will be.

You never pour a concrete floor in the toma. Water comes up from the ground, and pouring a concrete floor will block this water. Also, pouring a concrete floor if you can't find the impermeable layer doesn't work because water can just go under the floor if you don't have an impermeable layer to tie into.

Construction

Once you have cleared the area and decided the extents of the toma, it's time to start building.

1. Clay wall and exit pipes

The first thing you're going to do is build clay walls just upstream of where the actual wing walls will go (Figures 6 and 7). Ideally you'll want at least 6 inches between the clay wall and the actual wall so that you have room to work. Put the 3 exit pipes in the clay, and make sure the pipes are aligned how you want them. Remember that the overflow should be lower than the springs so that they are free flowing. This clay wall doesn't have to be as tall or long as the actual wall will be; it just has to capture and divert the water through the pipes so that you have a dry place to build the walls, and it only has to last a couple of hours while you build the wall and the concrete sets (ideally it will last 24 hours, but that's not always possible). It also helps to put clay under and between the pipes downstream of where the toma wall will be to stabilize them during the construction process. You don't want them to move if bumped because that could lead to holes in the wall.

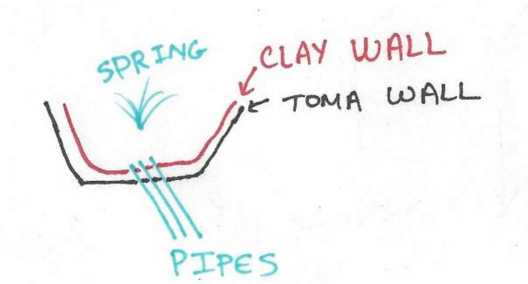


Figure 6: Diagram of clay wall and toma wall.

Figure 7: Picture of clay wall with pipes. This clay wall still needs some work because the area just downstream of the clay wall where the actual wall will go still has water.

2. The walls

Remember that it's really important for the bottom of the wing walls to tie into the impermeable layer. If you have a thick clay layer, you can dig in a little bit to get the wing wall in the clay layer so that water doesn't escape under the wall. Also remember that water will take the easiest path, so make sure it's easy for the water to get out of the toma so that it doesn't look for other escape paths.

The wing walls are stone masonry. Find a bunch of fist-sized rocks. You want these to be strong rocks (ones that won't break easily break when you bang them against another rock). Wash them to get the dirt off. (Your gente will probably think you're crazy, but the mortar won't bind well if there's mud on the rocks.) When you're ready to start, make a small batch of mortar, 1 cement : 4 sand. Use 1 Sika-1: 9 water. Put some mortar on the ground and then place a layer of rocks. Make sure there is enough space between the rocks for the mortar (Figure 8). Fill the spaces between the rocks with mortar. Keep going up until the wall is the height you want, about 1 ft. Make sure there aren't any holes in the wall. I know this sounds obvious, but it's hard to see between the clay wall and the actual wall, so make sure everything is filled in and covered, especially right around the pipes.

Figure 8: Stone masonry construction for wing walls. (This toma has more exit pipes than normal; just ignore that.)

Sometimes building the wing walls need to be a multistep process. Make the wall the best you can. Come back the next day, and get rid of the clay wall. Close the cleanout pipe to see make sure there aren't any leaks above the cleanout pipe. If the wall doesn't leak, great job! If it does, don't worry. Use clay to divert water if needed and fix the wall where needed. If it's just a minor leak, that can be fixed with plaster.

Plastering the outside of the walls is a good idea, but isn't absolutely necessary and can be done before or after pouring the top concrete slab, but if you have holes on the inside of the wall that need to be filled in, you need to do that before pouring the concrete slab. The mix is 1 cement : 3 bought sand with 1 Sika-1 : 9 water. You can do 1 or 2 coats, depending on whether or not water is leaking/seeping through the walls. Each coat should be 1 cm thick, and you need to wait at least 1 day between coats.

3. Filling with rocks

Once the walls are set, fill the toma with rocks. The goal is to have as many gaps and holes as possible for the water to flow through. Let me repeat that. You're purposefully trying NOT to fill in the holes. Start with big rocks (6"-8" diameter) then move up to smaller rocks (~2" diameter). You need to be especially careful where the springs are to make sure that there's plenty of space for the water to flow freely and that it isn't going to get clogged.

Leave a space without rocks about 1' x 1' for the access hatch to use for cleaning. You should be able to access the tubes from there (Figure 9). Find 4 rocks with a flat side that fit together to create a box of empty space for the access hatch, but make sure they don't fit together too well because you want to make sure there's plenty of space for the water to flow. Build a square out of 1x4s to act as formwork to keep the mix out when you pour the concrete slab.

Figure 9: Access hatch space. It's easiest if the access hatch is square or rectangular, but sometimes it ends up being a different shape, which is fine.

The rocks should be stable enough that you can walk on it. The rocks should slope downward towards the exit. You have some flexibility with the final height: either you can have the rocks stop a couple of inches below the top of the walls so that the concrete slab is level with the top of the walls or you can have the rocks be level with the top of the walls and pour the concrete slab over the rocks and walls. Or you can do a mixture of the two in order to make things work. Just be sure you're thinking about how the concrete slab will tie into the walls. Once you have filled the toma with rocks, I recommend covering it with sacos that you will then pour the mix on top of (Figure 10). If you aren't going to cover the rocks with sacos, you have to go down to smaller rocks and make sure there aren't any holes that the mix can fall through.

Figure 10: Toma filled with rocks and beginning to be covered with sacos before pouring the concrete slab.

4. Breather tubes

You need about 1 breather tube per m^2 in the toma so that air can escape. These are different from the air-release valves. To make one, cut a 3’ piece (it’s easier to make it too long and then cut it shorter when you install it) of ¾” PVC pipe, SDR 21. Use a hot nail to melt holes in the bottom 2’ of the pipe, about 4 holes per inch. Melt a hole in a smooth ¾” cap. Glue the cap onto the end of the pipe without the holes (Figure 11). As you’re placing the rocks, place the breather tubes as needed. The holes should be completely below the concrete (if there are holes above the concrete slab contamination can get in), so cut the pipe as needed. The part of the pipe without holes sticks up above the concrete slab.

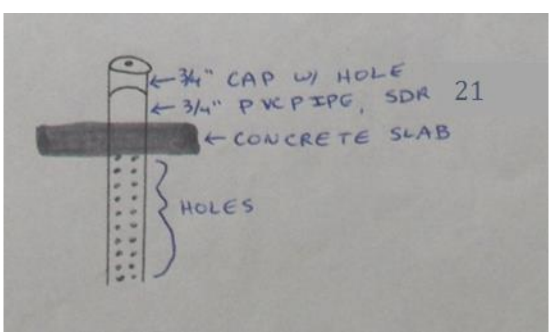


Figure 11: Diagram of breather tube

5. The concrete slab

Finally pouring the concrete slab is probably the easiest part. The mix is 1 cement : 4.5 dirty cascajo or 1 cement : 5 clean cascajo. You don't need Sika-1 for the slab. Wet the walls where they are going to join with the slab before pouring the concrete to get a good bind. Start placing in the highest/farthest part of the toma and work your way down towards the pipes. The slab should be 3" thick. Try to make it uniform. As you're placing the concrete, make sure you're thinking about how/where runoff is going to flow over the toma and drain without flowing into the toma through the access hatch.

6. Runoff protection

You want to keep runoff from entering the toma when it rains. There are a couple of things you can do. First, build a raised lip for the lid to sit on unless you're going to seal it with concrete every time you open it (Figure 12). (I recommend against sealing with concrete because then it's an ordeal every time you want to get in the toma to clean it or check things out if there's a problem.) Another thing you can do is build little concrete walls that are about 2" tall and 2" wide that run at diagonals across the concrete slab to divert runoff off of the toma and away from the access hatch.

Figure 12: Access hatch lid on raised lip.

Finally, the access hatch needs a lid. I make it from reinforced concrete (usually 2 rebar going each way) and a rebar handle. I only needs to be 3" thick. The mix should be the same as for the slab, 1 cement : 4.5 dirty cascajo or 1 cement : 5 clean cascajo.

Junction boxes

You don't want to connect 2 tomas directly because pressure differences can cause water to flow backwards and water entering one toma from another toma could potentially cause erosion problems. Therefore, you need a junction box to join 2 tomas. The purpose of a junction box is for water from 2 (or more) pipes to come in and then flow out through a single pipe. Junction boxes don't have to be big; 1 ft. x 1 ft. x 1 ft. is sufficient. Junction boxes can be stone masonry like the toma walls, concrete block, or ferrocement. They should have 3 exit pipes—overflow, conduction line, and cleanout, like the toma. When you're doing your design, don't forget that the water will return to atmospheric pressure at the junction box.

Toma Repair

Whether it's the toma you built a few months or a year ago or a toma built years ago by another group, knowing how to fix tomas is almost as important as knowing how to build them. Tomas are tricky and fragile, and depending on the site conditions, sometimes they break. Some of them might even need yearly repairs. Think of it as "maintenance."

In order to determine whether or how you should repair a toma, you need to really understand what the problem is. Don't just listen to what your gente say, investigate it. There are no hard rules for what you should do; it will depend on the situation. However, below are some possible situations and my suggestions.

Before you get started on a toma repair project, make sure that there is a good impermeable layer. This might require some digging around downstream of where the current toma is. If you don't have a good impermeable layer, it might not be possible to fix the toma.

Situation 1: Spring has moved and water is surfacing elsewhere. Toma isn't capturing anything.
In this case you need to rebuild the toma. First, find the impermeable layer. It could be that the spring moved because there was too much water pressure in the toma so it didn't want to surface there anymore. To prevent this from happening again, make sure that all the exit pipes, including the overflow pipe, are below the level of the spring so that the spring is free flowing. Clear the area, and build a new toma. If the old toma isn't in the way and isn't making it harder for the spring to surface, you can leave it in place and either build your new toma completely separately from it or tie into/engulf the old toma with the new toma.

Situation 2: Water is escaping through the walls.
If the problem is just that water is escaping through the walls but not under the walls (i.e. there is a good impermeable layer that the walls are tied into but the walls themselves have sprung leaks further up), the toma should be relatively easy to fix. Try opening the cleanout to see if lowering the water level will stop the leaks. If so, leave the cleanout open while patching the leaks and repellando the toma walls with cement, bought sand, and Sika-1. I would use a 1 cement : 1 bought sand mix with 1 Sika-1 : 8 water around the pipes or where there are other major cracks and then repellar the entire wall with a 1 cement : 2 bought sand mix with 1 Sika-1 : 8 water. If opening the cleanout doesn't stop the flow but you can build a mud wall inside the access hatch (like when you build a toma), to stop the flow, you can do that. You won't be able to patch a leak without stopping the flow first, unless you use Sika-2.

If you can't stop the flow, you can try using Sika-2 to patch the leak. Follow the instructions on the jug. I would describe it more as "instantaneously" setting than "fast" setting. I found that mixing it in place works better because it sets so fast that I didn't have time to mix it and then put it on the leak.

If there is a big hole, another trick to fixing leaks is to put a piece of pipe in the hole where the leak is. Glue an adapter on the end of the pipe before putting it in the hole. Fill in around the pipe with mud so that all the water flows out the piece of pipe. Fix the leak and repellar the wall with this extra pipe of cemented in place. Once the concrete has cured (wait at least 1 week), put a threaded cap on the end of the pipe. Often it's really hard to stop the water flow, so this technique allows you to divert the water so that you can make the repair without having to stop the water flow. When fighting against water, we usually lose.

If none of the above work, you can build new walls just downstream of the existing toma that tie into the old toma. You probably don't need to destroy the old toma. Clear down to the impermeable layer. Build a mud wall just downstream of the toma with the 3 pipes (cleanout, conduction line, and overflow). Then build a new concrete wall like you're building a toma that ties back into the old toma. Leave all 3 pipes leaving the old toma completely open. Fill the space between the old wall and the new wall with rocks like you're building a toma, and then cover it with a concrete slab. If the new wall is a ways away from the old toma wall, you might want to build a second access hatch near the new pipes.

Situation 3: Water is escaping from under the walls.
This is most likely because there isn't a good impermeable layer that the walls are tied into. You need to clear down to the impermeable layer and then build new walls, as described in Situation 2. If you can't find an impermeable layer, see Situation 4.

Situation 4: No impermeable layer.
No impermeable layer is no good. First, try digging deeper. Look around the area to see if there is exposed bedrock or an impermeable layer anyway, maybe along a stream bed. Then follow that impermeable layer towards your toma. You have to be pretty strict to get your gente to dig deeper.

If that really doesn't work, the only thing I can suggest is lowering the standing water level (head) in the toma as much as possible so that there is less pressure causing the water to look for places to escape. Unfortunately, I don't think there's much you can do if there isn't an impermeable layer to tie the walls into because the water will just undercut and escape under whatever you build.

One question in toma repair is what to do with the old toma. If it's not blocking/making it harder for the spring to surface and it isn't in the way, you can leave it where it is. It's a lot of work to destroy and remove an old toma. Also, sometimes the old tomas help collect and divert at least some of the water, which makes the toma repair easier. That said, sometimes it is necessary to remove the old toma. This could be because it's blocking the spring. Also, if you can't see what's going on inside the old toma, you might have to destroy/remove it so that you can see where the springs are and adjust your repair accordingly. I would highly recommend only destroying the old toma if you have a plan to rebuild a better toma. If you don't have a good impermeable layer to build on, I would recommend against destroying the existing toma. Something is better than nothing, and without a good impermeable layer, there really isn't much that you can do.

Conclusion

Every toma is going to be different. The most important thing is to capture as much water as possible without changing the hydrology and ensure that the easiest way for the water to leave the toma is through the conduction line. Just remember that, and do what you have to do to make your toma work.

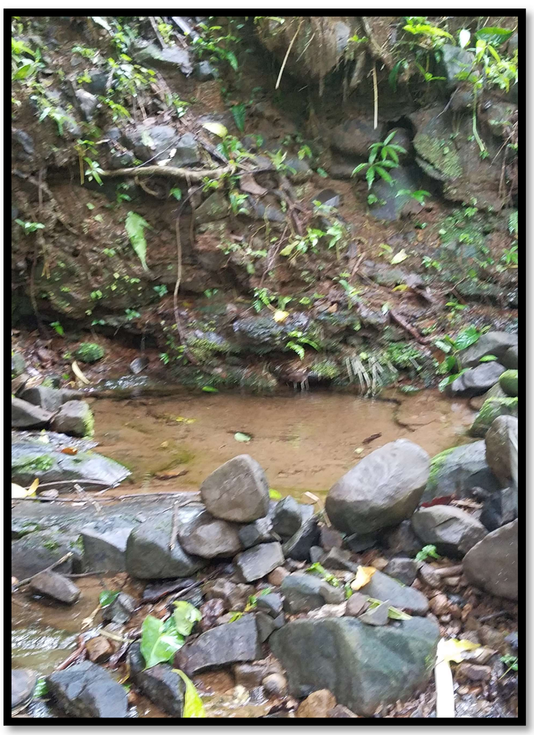
APPENDIX E:

SPRING BOX CALCUATIONS

Appendix E

The designs presented below follow design criteria presented in Snyder's report on Construction of Low-Profile Tomas. The report in its entirety can be found in Appendix D.

Lower Spring



Spring Dimensions: 5.9 x 5.5 feet

Walls should be just slightly taller than the ground surface, assuming a maximum of one foot (0.3m) height for digging to an impermeable layer

Wing Walls (x2)

Thickness = 0.5 ft

Width = 6.5 ft

Height = 1 ft

Per wall:

$V_{wall} = (6.5\ ft)(1\ ft)(0.5\ ft) = 3.25\ ft^3$

Assume 35% mortar, 65% rocks/stones

$V_{mix} = 0.35 * V_{wall} = 0.35\ (3.25\ ft^3) = 1.14\ ft^3$

1:4 cement to sand

$V_{sand} = V_{mix} = 1.14\ ft^3$

$V_{cement} = \frac{1}{4} V_{mix} = \frac{1}{4}\ (1.14\ ft^3) = 0.28\ ft^3$

$m = \rho v = (1440\ kg/m^3)\ (0.28\ ft^3)\ (1m^3 / 35.3\ ft^3) = 11.6$ kg dry cement

2 Jars Sika -1 to make it impermeable

Front Wall

Thickness = 0.5 ft

Width = 3 ft

Height = 1 ft

$V_{wall} = (3\ ft)(1\ ft)(0.5\ ft) = 1.5\ ft^3$

Assume 35% mortar, 65% rocks/stones

$V_{mix} = 0.35 * V_{wall} = 0.35\ (1.5\ ft^3) = 0.525\ ft^3$

1:4 cement to sand

$V_{sand} = V_{mix} = 0.525\ ft^3$

$V_{cement} = \frac{1}{4} V_{mix} = \frac{1}{4}\ (0.525\ ft^3) = 0.13\ ft^3$

$m = \rho v = (1440\ kg/m^3)\ (0.13\ ft^3)\ (1m^3 / 35.3\ ft^3) = 5.35$ kg dry cement

1 Jar Sika -1 to make it impermeable

Cover

Area = $(6\ ft)(3\ ft) + 2\ (\frac{1}{2}\ (2.5 * 6)) = 33\ ft^2 = 3.1\ m^2$ (Need breather tube every $1 m^2$ so 3 tubes)

Thickness = 3 in = 0.08 m

$V_{wall} = (6.5\ ft)(1\ ft)(0.5\ ft) = 3.25\ ft^3$

Assume 35% mortar, 65% rocks/stones

$V_{mix} = (33\ ft^2)\ (3\ in)\ (1\ ft/12\ in) = 8.25\ ft^3$

V_{gravel} (cascajo) = $V_{mix} = 8.25\ ft^3$

$$V\_cement = ⅕ V\_mix = ⅕ (8.25 ft^3) = 1.65 ft^3$$

$$m = \rho v = (1440 kg/m^3) (1.65 ft^3) (1m^3 / 35.3 ft^3) = 67.31 kg dry cement$$

Rosa

Spring Dimensions: 6.5 x 2.5 feet

Wing Walls
Thickness = 0.5 ft
Width = 7.11 ft
Height = 1 ft

Per wall:

V_wall = (7.11 ft)(1 ft) (0.5 ft) = 3.56 ft^3

Assume 35% mortar, 65% rocks/stones

V_mix = 0.35 * V_wall = 0.35 (3.56 ft^3) = 1.24 ft^3

1:4 cement to sand

V_sand = V_mix = 1.24 ft^3

V_cement = ¼ V_mix = ¼ (1.24 ft^3) = 0.31 ft^3

m = ρ v = (1440 kg/m^3) (0.31 ft^3) (1 m^3 / 35.3 ft^3) = 12.69 kg dry cement

2 Jars Sika -1 to make it impermeable

Front Wall
Thickness = 0.5 ft
Width = 2 ft
Height = 1 ft

V_wall = (2 ft)(1 ft) (0.5 ft) = 1 ft^3

Assume 35% mortar, 65% rocks/stones

V_mix = 0.35 * V_wall = 0.35 (1 ft^3) = 0.35 ft^3

1:4 cement to sand

V_sand = V_mix = 0.35 ft^3

V_cement = ¼ V_mix = ¼ (0.35 ft^3) = 0.0875 ft^3

m = ρ v = (1440 kg/m^3) (0.0875 ft^3) (1m^3 / 35.3 ft^3) = 3.6 kg dry cement

1 Jags Sika -1 to make it impermeable

Cover
Area = (2*7) + 2(½ (1.25*7)) = 22.75 ft^2 = 2.1 m^2   (Need 2 breather tubes)

V_wall = (6.5 ft)(1 ft) (0.5 ft) = 3.25 ft^3

Assume 35% mortar, 65% rocks/stones

V_mix = (22.75 ft^2) (3 in) (1 ft / 12 in) = 5.67 ft^3

V_gravel = V_mix = 5.67 ft^3

V_cement = ⅕ V_mix = ⅕ (5.67 ft^3) = 1.14 ft^3

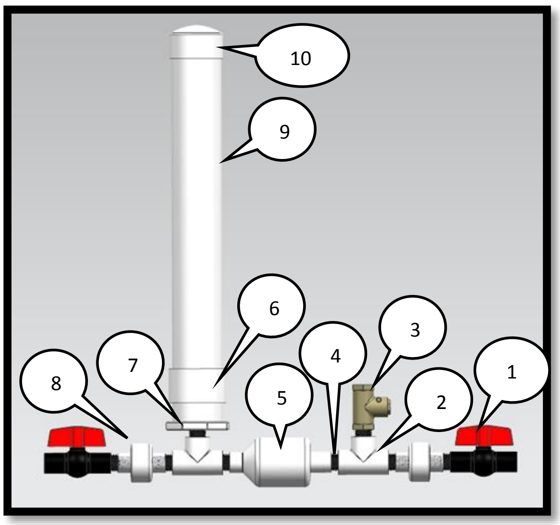
m = ρ v = (1440 kg/m^3) (1.14 ft^3) (1m^3 / 35.3 ft^3) = 46.4 kg dry cement

APPENDIX F:

RAM PUMP CONSTRUCTION INSTRUCTION GUIDE

Ram Pump Construction Manual

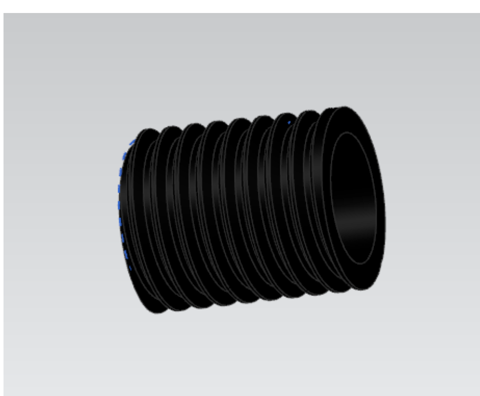
This document will explain the different steps needed to assemble a homemade ram pump. All the pieces should be able to be found at any hardware store. If parts cannot be found that are the same, the design can be changed as necessary. The size of the fittings should stay the same though. An example is if there are no threaded fittings at the store, they can be replaced with non-threaded parts. You will just need change the design slightly. But as mentioned all parts in the design should be able to be found at any hardware store.

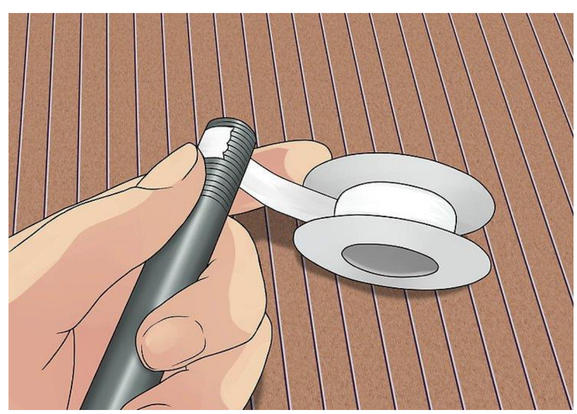


#	Part Name	Quantity
1	½" Threaded PVC Control Valve	2
2	½" Threaded PVC T Joint	2
3	½" Threaded Brass Swing Check Valve	1
4	½" Short Threaded PVC Nipple	8
5	½" PVC Check Valve	1
6	2" Coupling	1
7	½" x 2" PVC Pressure Reducer	1
8	½" Threaded PVC Union	2
9	2" PVC Pipe	1
10	2" PVC Cap	1

Step 1

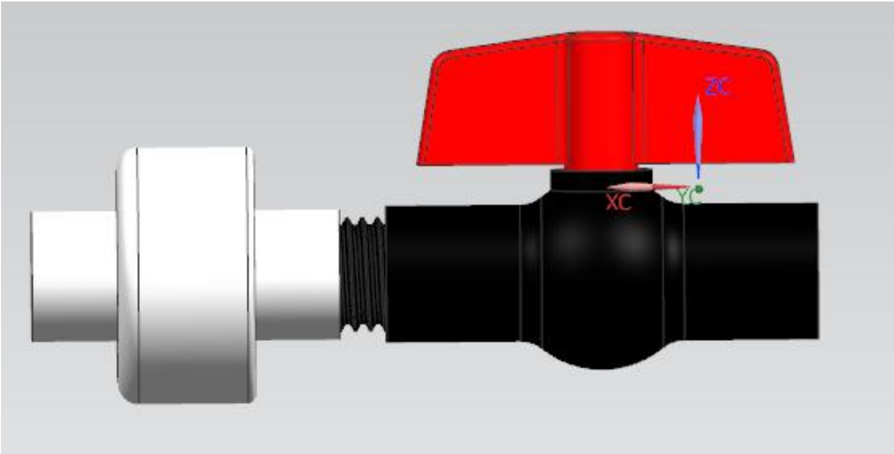
Gather the white Teflon tape and all the threaded PVC nipples. There should be eight (8) ½ inch threaded nipples. Place at least four (4) layers of the Teflon tape on the threads of each of the nipples. This will make sure that the connections are secure and water tight.





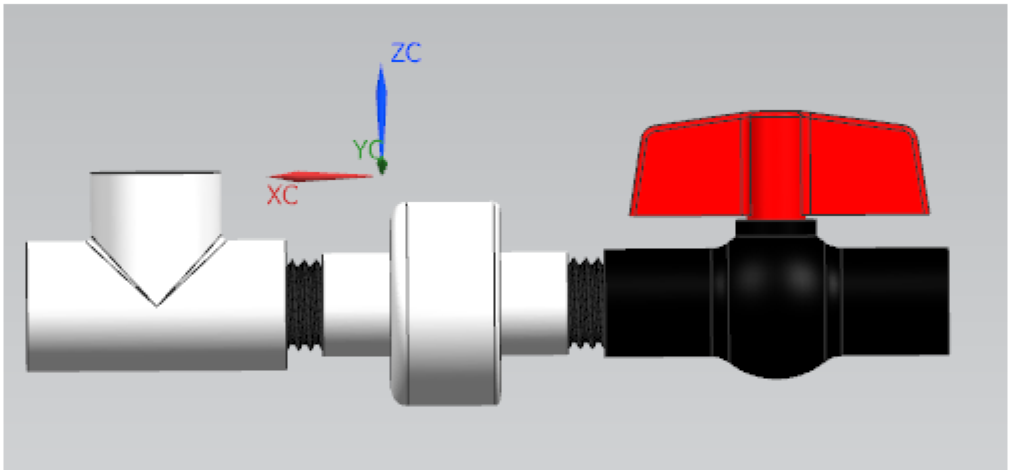
Step 2

Take one PVC ball valve, one threaded nipple with Teflon Tape, and one union. First screw the threaded nipple into the PVC ball bearing. Then screw in the other end of the threaded nipple into the union. Make sure to screw it in tightly to prevent leakage.



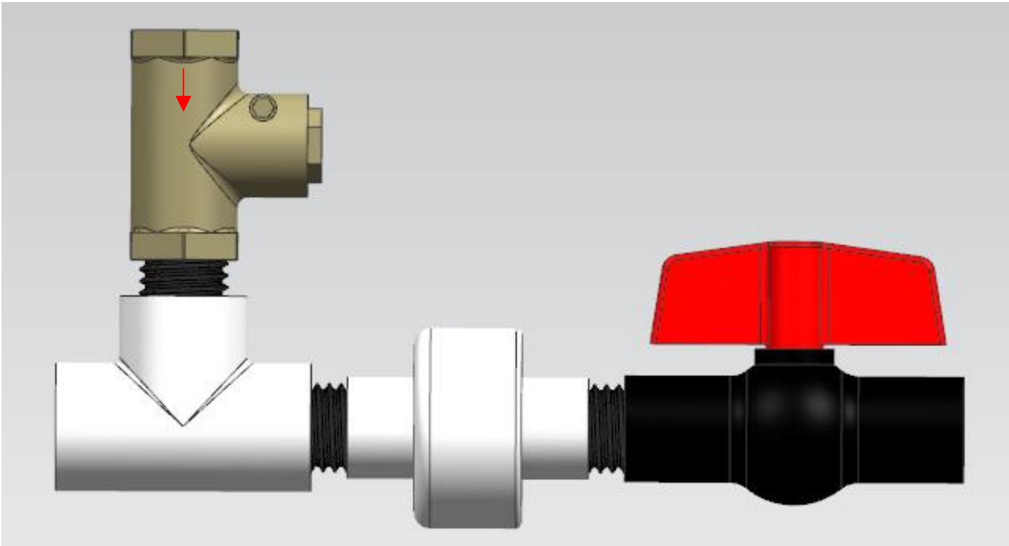
Step 3

Take one threaded nipple, the assembled part thus far as shown above, and the T joint. First screw the threaded nipple into the union. Then screw the T joint onto the other end of the threaded nipple so that the top of the T joint is pointing upward, the same direction as the valve on the ball valve is pointing.



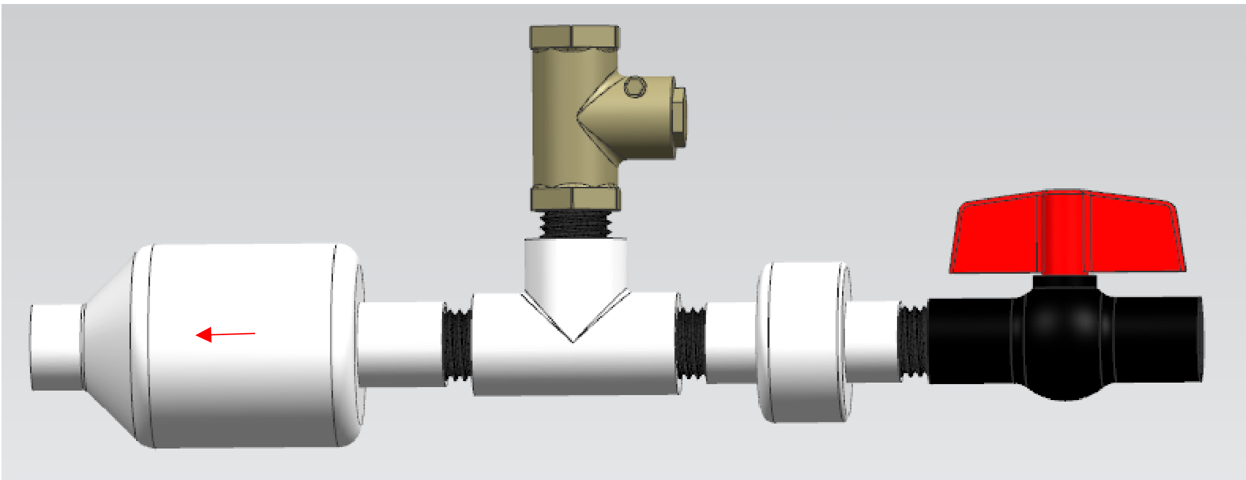
Step 4

Take one threaded nipple, the brass swing check valve, and the part that has been assembled thus far. Screw the threaded nipple into the T joint. Then screw in the brass swing check valve into the other side of the threaded nipple. **Make sure that the arrow that indicated flow direction on the brass swing check valve is facing downward.**



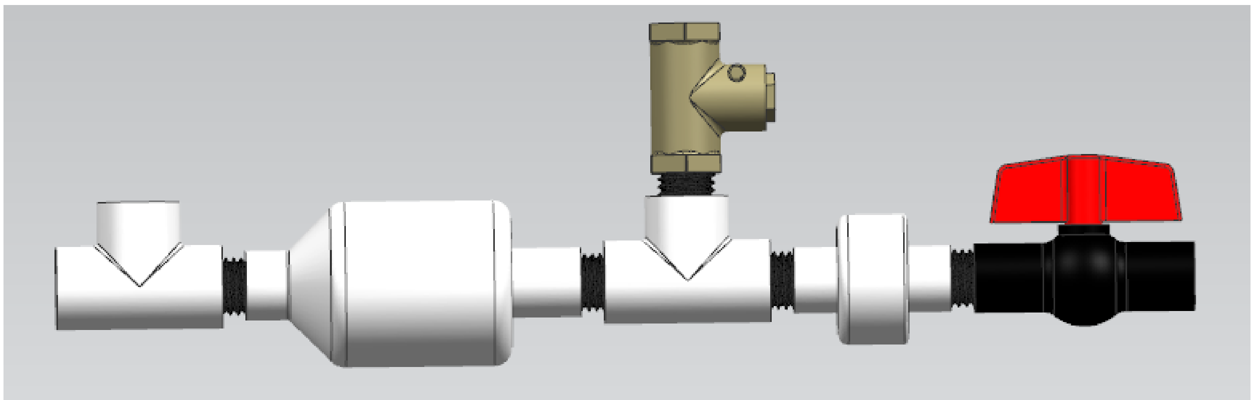
Step 5

Take one threaded nipple, the PVC in line check valve, and the part that has been assembled thus far. Screw the threaded nipple into the left side of the T joint. Then screw the PVC check valve into the other side of the threaded nipple. **Make sure that the flow in the valve is pointed away from the inlet.**



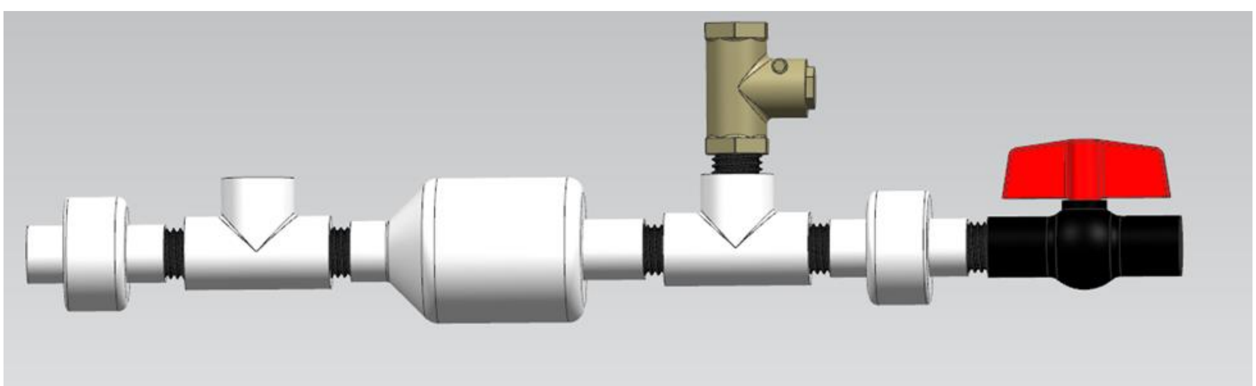
Step 6

Take one threaded nipple, the other T joint, and the part that has been assebled thus far. Screw the threaded nipple into the check valve. Then screw the T joint into the other end of the threaded nipple. The top of the T joint should be facing upward.



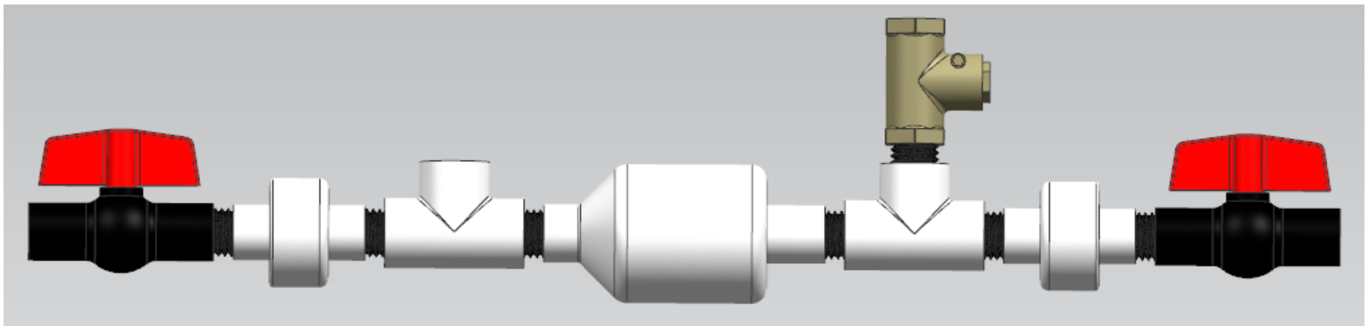
Step 7

Take one threaded nipple, the other PVC union, and the part that has been constructed thus far. Screw the threaded nipple into the left side of the T joint. Then screw the union into the other side of the threaded nipple.



Step 8

Take one threaded nipple, the other PVC ball valve, and the part that has been constructed thus far. Screw the threaded nipple into the union. Then screw the PVC ball valve into the other end of the nipple with the control valve facing up.

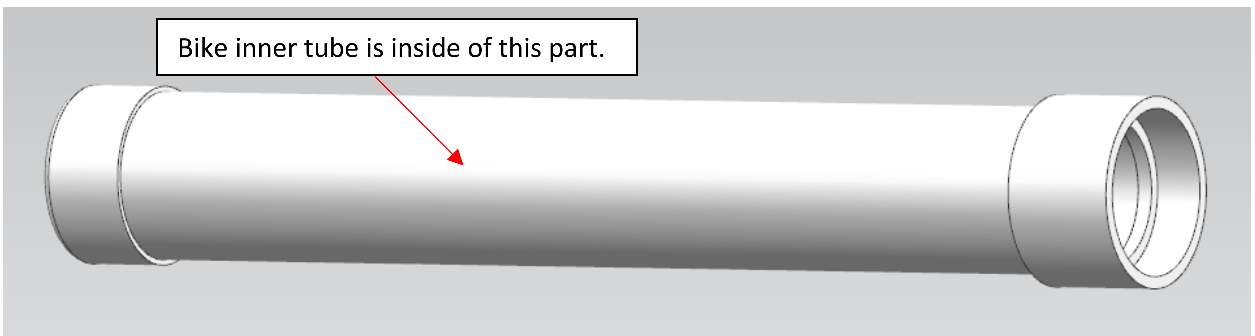


Step 9

This step is where the pressure tank is constructed. Take the 16” section of 2” PVC and the 2” PVC cap. Then take the PVC cement and apply it to the inside of the cap and the outside of the 2” PVC pipe that will be in contact with the cap. Then slide the cap over the end of the 2” PVC pipe that you applied the liquid cement to. The general technique is shown on in the figure below. Note that this is just an example of how to apply the cement. The pipe in this pump is much smaller than the one depicted in the picture.

Step 10

This step is a contination of the construction of the pressure tank. Take the part of the pressure tank that was just constructed, the bike innertube that is partially inflated, and the 2” coupler. First, place the partially inflated bike innertube inside the part of the pressure tank that was constructed in step 9. Then take the part of the pressure tank that was constructed in step 9 with the bike innertube inside and coat the outside of the end of 2” pipe with PVC cement on the opposite end of the cap where the coupler will slide over. Then take the coupler and coat inside of the coupler with PVC cement where it will be in contact with the outside of the 2” PVC pipe. Then slide the 2” pipe into the coupler.

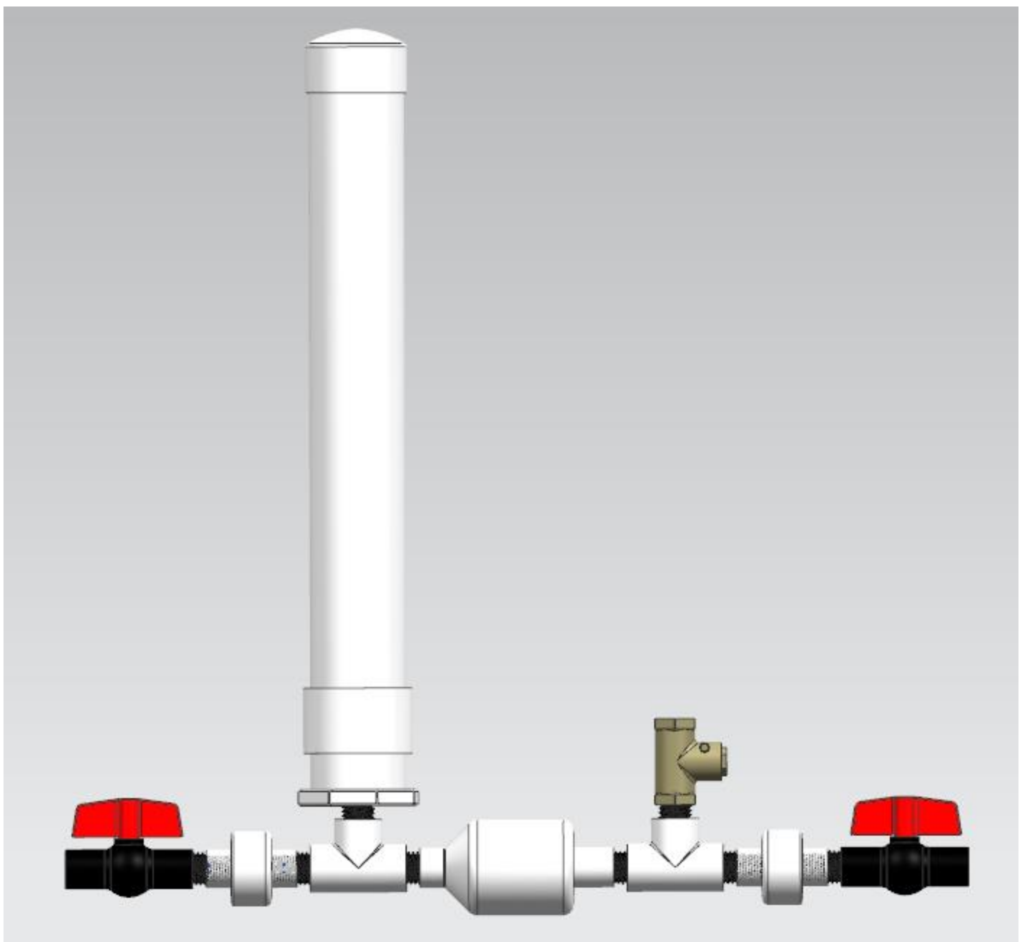


Step 11

Take the part of the pressure tank that was constucted in step 10 and the pressure reducer. Take PVC cement and coat the inside of the coupler that will be in contact with the pressure reducer. Then take the PVC cement and coat the outside of the pressure reducer that will be in contact with the coupler.The pressure reducer will slide into the coupler and will form the part below.

Step 12

This is the last step in the construction of the ram pump. This step is where the pressure tank and the rest of the part that was previously constructed are combined. Take the pressure tank that has been constructed, a threaded nipple, and the part that was constructed in the first 8 steps. Take the threaded nipple and screw it into the top of the T junction. Then screw the pressure tank onto the other end of the threaded nipple. Make sure that this connection is secure.



APPENDIX G:

MATERIALS & LABOR COST BREAKDOWNS

SYSTEMS 1 & 2

Source & Additional Data Pertaining to System Costs

Cost estimates are provided by the Peace Corps volunteer based on material costs at the Hardware store in Cerro Mesa.

Highlighted costs were not available at the time of printing and were estimated based on average costs available at US hardware stores.

It is assumed that it will take two-three trips to deliver all of the materials to the community. This delivery will be fulfilled by government employees.

Additional materials which should be available in the community at no cost include the following.

4 shovels for trenching

1-2 hacksaws

1-2 machetes

1 wood saw

1-2 hammers

2 trowels

1-2 wire cutters

Buckets/barrels for mixing concrete and mortar

String for leveling

Measuring device (tape measure)

System 1 Estimate

Table 1: Materials Cost Breakdown for System 1

	Material	Unit	Unit Cost	Quantity Needed	Total Cost
Lower Spring Box	Concrete				
	Dry cement (45.3592 kg sacks)	$ 9.75	1.86	$ 18.14	$ 33.73
	Sand (m3)	$ 23.00	0.05	$ 1.08	$ 0.05
	Gravel (m3)	$ 24.00	0.23	$ 5.61	$ 1.31
	Sika-1 (jug)	$ 20.00	2.00	$ 40.00	$ 80.00
	1" PVC (30 ft length)	$ 7.25	1.00	$ 7.25	$ 7.25
	PVC glue (1 bottle)	$ 25.00	1.00	$ 25.00	$ 25.00
	1" PVC caps	$ 0.30	2.00	$ 0.60	$ 1.20
	Nails (1lb)	$ 4.12	1.00	$ 4.12	$ 4.12
	Timber	$ -	0.00	$ -	$ -
	Sacos (bags which grain & sand come in)	$ -	0.00	$ -	$ -
	Large rocks	$ -	0.00	$ -	$ -
Pressure Break Tank	Concrete				
	Dry cement	45.3592 kg sack	$ 9.75	0.37	$ 8.48
	Sand	m3	$ 23.00	0.03	$ 0.68
	Gravel	m3	$ 24.00	0.06	$ 0.24
	Rebar (3/8")	30 ft bar	$ 4.25	0.06	$ 0.39
	1/2" PVC	30 ft length	$ 6.75	0.03	$ 0.23
Storage Tank (Base)	Cement				
	Dry cement	45.3592 kg sack	$ 9.75	11.00	$107.25
	Sand	m3	$ 23.00	0.74	$17.02
	Gravel	m3	$ 24.00	1.09	$26.16
	Rebar (3/8" diam)	30 ft bar	$ 4.25	8.00	$34.00
	Control valve (1.5")	1 valve	$ 8.00	1.00	$8.00
	Tie wire	1 roll	$ 1.00	22.00	$22.00
	Timber provided by community			0.00	$0.00
Storage Tank (Walls)	CMU	1 6x8x16" block	$ 0.65	219.00	$ 142.35
	Mortar				
	Cement	45.3592 kg sack	$ 9.75	10.00	$ 97.50
	Sand	m3	$ 23.00	0.94	$ 21.62
	1.5" PVC	30 ft length	$ 9.00	1.00	$ 9.00
	Rebar (3/8" diam)	30 ft bar	$ 4.25	4.00	$ 17.00
Storage Tank (Cover)	Cement				
	Dry cement	45.3592 kg sack	$ 9.75	11.00	$ 107.25
	Sand	m3	$ 23.00	0.75	$ 17.25
	Gravel	m3	$ 24.00	1.12	$ 26.88
	Rebar	30 ft bar	$ 4.25	13.00	$ 55.25
	Anchor bolt	4 bolts	$ 1.00	2.00	$ 2.00
	8 1.5" screws	1 screw	$ 0.08	8.00	$ 0.64
	1.5" galvinized pipe	21ft length	$ 60.00	1.00	$ 60.00
	1.5" brass elbow	1 elbow	$ 5.00	3.00	$ 15.00
	Rocks				$ -
	Timber for hatch & pouring slab				$ -

	1/2" PVC	30 ft length	$ 6.75	130.90	$ 949.05	
	1" PVC	30 ft length	$ 7.25	22.61	$ 163.89	
	1.5" PVC	20 ft length	$ 8.95	35.84	$ 320.73	
	Control (cleanout) valve (1/2")		$ 1.50	1.00	$ 1.50	
	Concrete for cleanout protection					
	Dry cement	45.3592 kg sack	$ 9.75	12	$ 117.00	
	Sand	m3	$ 23.00	0.83	$ 19.09	
	Gravel	m3	$ 24.00	1.24	$ 29.76	
	Rebar (3/8")	30 ft length	$ 4.25	2.00	$ 8.50	
Pipes	Control (cleanout) valve (1.5")		$ 10.50	1.00	$ 10.50	$ 2,233.41
	Y-union (1.5")		$ 1.84	1.00	$ 1.84	
	Y-union (1/2")		$ 0.40	1.00	$ 0.40	
	T-union (1/2")		$ 0.30	7.00	$ 2.10	
	T-union (1")		$ 1.05	1.00	$ 1.05	
	Flow reducer (1")	1 unit	$ 69.00	1.00	$ 69.00	
	Flow reducer (1/2")	1unit	$ 59.00	7.00	$ 413.00	
	PVC glue & primer	1 package	$ 25.00	1.00	$ 25.00	
	Couplings		$ 0.50	202.00	$ 101.00	
	1/2" PVC	30 ft length	$ 6.75	1.05	$ 7.09	
	1/2" galvinized pipe	10' length	$ 12.25	0.70	$ 8.58	
	Control valve (1/2"PVC)		$ 1.50	7	$ 10.50	
	Control valve (1/2"Brass)		$ 7.42	7	$ 51.94	
	Elbow (1/2" PVC)		$ 0.25	7	$ 1.75	
	Elbow (1/2" GALV)		$ 0.89	7.00	$ 6.23	
	Couplings (PVC)		$ 0.50	14.00	$ 7.00	
Spigots (7 in total)	Couplings (threaded)		$ 1.40	14.00	$ 19.60	$ 326.27
	Clamps		$ 2.30	8.00	$ 18.40	
	Rebar (3/8")	30 ft length	$ 4.25	2.16	$ 9.17	
	Concrete for pipe					
	Dry cement	45.3592 kg sack	$ 9.75	1.54	$ 15.02	
	Sand	m3	$ 23.00	0.10703	$ 2.46	
	Gravel	m3	$ 24.00	0.16093	$ 3.86	
	4" PVC	2 ft length	$ 9.41	17.5	$ 164.68	
	Reducer to 1/2"	1unit	$ 59.00	2	$ 118.00	
	1/2" PVC	Use scrap piping. No additional cost				
	1 1/4" reduction to 1/2"		$ 8.00	2	$ 16.00	
	1 1/4" PVC	10 ft length	$ 4.56	1	$ 4.56	
	1 1/4" end cap with small hole		$ 0.98	2	$ 1.96	
	Rubber ball		$ 0.25	2	$ 0.50	
	T-union (1/2" PVC)		$ 0.30	1	$ 0.30	$ 188.19
	Concrete					
	Dry cement	45.3592 kg sack	$ 9.75	3	$ 29.25	
	Sand	m3	$ 23.00	0.184	$ 4.23	
	Gravel	m3	$ 24.00	0.27	$ 6.48	
	Rebar (3/8")	30 ft lentgh	$ 4.25	1	$ 4.25	
Air Release	T-union (1.5" PVC)		$ 2.66	1	$ 2.66	
Material Transport	Trip from Cerro Mesa to community	*1-way trip*	$4.00	*6*	*$24.00*	*$ 24*
					Total Material Cost	***$ 3,721***

	Component	Quantity	Cost
Contingency	Air release	1	$ 94.10
	Clean out (1.5)	1	$ 186.69
	Pipe (2")(30' length)	5	$ 50.00
	Addtional delivery trip	2	$ 16.00
	5% additional mortar for masonry walls	-	-
	Cement (45.3592 kg sack)	0.5	$ 4.88
	Sand (m3)	0.047	$ 1.08
	Total contingency		**$ 353**

System 1 Labor Estimate

Task	Labor time (hrs)	Gov. Labor cost	Comm. Labor cost	
Transporting Materials	8	$160	$56	
Safety Training	8	$160	$0	
Level & Compact Ground for Storage Tank	8	$160	$0	
Place Forms & Pour Base Slab for Storage Tank	8	$160	$0	
Dig Trench from Tank to Vidals	8	$160	$0	
Prepare spring location for spring box	8	$160	$0	
Build spring box walls	8	$160	$0	
Check to ensure walls have no leaks, pour spring box cover & hatch	8	$160	$0	
Lay first four layers of tank walls	8	$160	$0	
Dig trench from Vidal's to PBT	8	$160	$0	
Lay last four layers of tank walls	8	$160	$0	
Dig trench from PBT to Fedal's	8	$160	$0	
Dig Trench from Nila to Ernesto's	8	$160	$0	
Fill tank walls with mortar & rebar	8	$160	$0	
Build Pressure Break Tank, set forms for tank cover	8	$160	$0	
Pour Storage Tank Cover, Pour Forms For Valve Boxes	16	$320	$0	
Lay System Pipes	16	$320	$0	
Check System Pipe Connections, install chlorinator, Build first 2 spigots	8	$160	$0	
Build Remaining Spigots	8	$160	$0	
Build and Place Tank Hatch	8	$160	$0	
Assemble and install all valve boxes	8	$160	$0	
Test System	8	$160	$0	
Make adjustments if needed and fill in the trenches	16	$320	$0	
Contingency Days	3	$60	$0	
Clean Construction Site	8	$160	$0	
Total	**219**	**$4,220**	**$56**	$4,300

Notes:
Community to assist in hauling materials from the road to the project site.
5 government workers to complete all project work.
$4 per hour

5 pieces (30 ft) per hour with 5 workers
4 days to lay all of the pipes

Total implementation time frame
22 work days
almost 4 weeks

System 1 Labor Estimate Alternative

Task	Labor time (hrs)	Gov. Labor cost	Comm. Labor cost	
Transporting Materials	8	$160	$7	
Safety Training	8	$80	$28	
Level & Compact Ground for Storage Tank	8	$0	$56	
Place Forms & Pour Base Slab for Storage Tank	8	$0	$56	
Dig Trench from Tank to Vidals	8	$0	$56	
Prepare spring location for spring box	8	$0	$56	
Build spring box walls	8	$0	$56	
Check to ensure walls have no leaks, pour spring box cover & hat	8	$0	$56	
Lay first four layers of tank walls	8	$0	$56	
Dig trench from Vidal's to PBT	8	$0	$56	
Lay last four layers of tank walls	8	$0	$56	
Dig trench from PBT to Fedal's	8	$0	$56	
Dig Trench from Nila to Ernesto's	8	$0	$56	
Fill tank walls with mortar & rebar	8	$0	$56	
Build Pressure Break Tank, set forms for tank cover	8	$0	$56	
Pour Storage Tank Cover, Pour Forms For Valve Boxes	16	$0	$112	
Lay System Pipes	16	$0	$112	
Check System Pipe Connections, install chlorinator, Build first 2 sp	8	$160	$56	
Build Remaining Spigots	8	$0	$56	
Build and Place Tank Hatch	8	$0	$56	
Assemble and install all valve boxes	8	$0	$56	
Test System	8	$0	$56	
Make adjustments if needed and fill in the trenches	16	$0	$112	
Contingency Days	3	$0	$21	
Clean Construction Site	8	$0	$56	
Total	**219**	**$240**	**$987**	$1,300

Notes:
Government to assist in hauling materials to the community.
Government to provide training & testing of the system.
1 community worker per family in the system (7 workers)
Assume that 7 community workers will take the same amount of time as 5 government workers due to the learning curve.
$4 per hour government, $1 per hour community

Total implementation time frame
22 work days
almost 4 weeks

System 2 Estimate

Materials Cost Breakdown for System 2

	Material	Unit Cost	Quantity Needed	Total Cost	Cost Summation
Spring Box	Concrete				115.3274968
	Dry cement (45.3592 kg sacks)	$ 9.75	1.38	$ 13.46	
	Sand (m3)	$ 23.00	0.05	$ 1.04	
	Gravel (m3)	$ 24.00	0.16	$ 3.87	
	Sika-1 (jug)	$ 20.00	3.00	$ 60.00	
	1" PVC (30 ft length)	$ 7.25	1.00	$ 7.25	
	PVC Glue (1 bottle)	$ 25.00	1.00	$ 25.00	
	1" PVC Caps	$ 0.30	2.00	$ 0.60	
	Nails (1lb)	$ 4.12	1.00	$ 4.12	
	Timber	$ -	0.00	$ -	
	Sacos (bags which grain & sand come in)	$ -	0.00	$ -	
	Large rocks	$ -	0.00	$ -	
Pipes	1/2" PVC (30 ft)	$6.75	4	$27.00	$41.37
	Control valve (1")	$3.95	2	$7.90	
	Elbow (1")	$1.00	1	$1.00	
	8 Oz PVC cement	$4.33	1	$4.33	
	Roll of teflon tape	$0.57	2	$1.14	
Ram Pump	Control valve (1/2")	$1.50	2	$3.00	$35.22
	PCV check valve (1/2")	$5.99	1	$5.99	
	Brass swing check valve (1/2")	$8.98	1	$8.98	
	PVC union (1/2")	$0.35	2	$0.70	
	Short threaded nipple (1/2")	$0.40	8	$3.20	
	PVC T (1/2")	$0.30	1	$0.30	
	PVC reducer bushing (2" x 1/2") schedule 40 PVC reducer bushing spigot x FPT	$1.06	1	$1.06	
	2" PVC cap	$0.95	1	$0.95	
	Coupling (2")	$0.54	1	$0.54	
	2" PVC (20 ft)	$9.50	1	$9.50	
	Old bike inner tube *recycled one can be used	$1.00	1	$1.00	
	Lumber for box protection (ft2)	$0.00	13	$0.00	
Storage Tank	55 gallon drum	$50.00	1	$50.00	$50.00
		Total Material Cost		***$240***	

	Component	Quantity	
Contingency	Bike inner tube	1	$ 1.00
	Total contingency		**$ 1.00**

Labor Cost for System 2

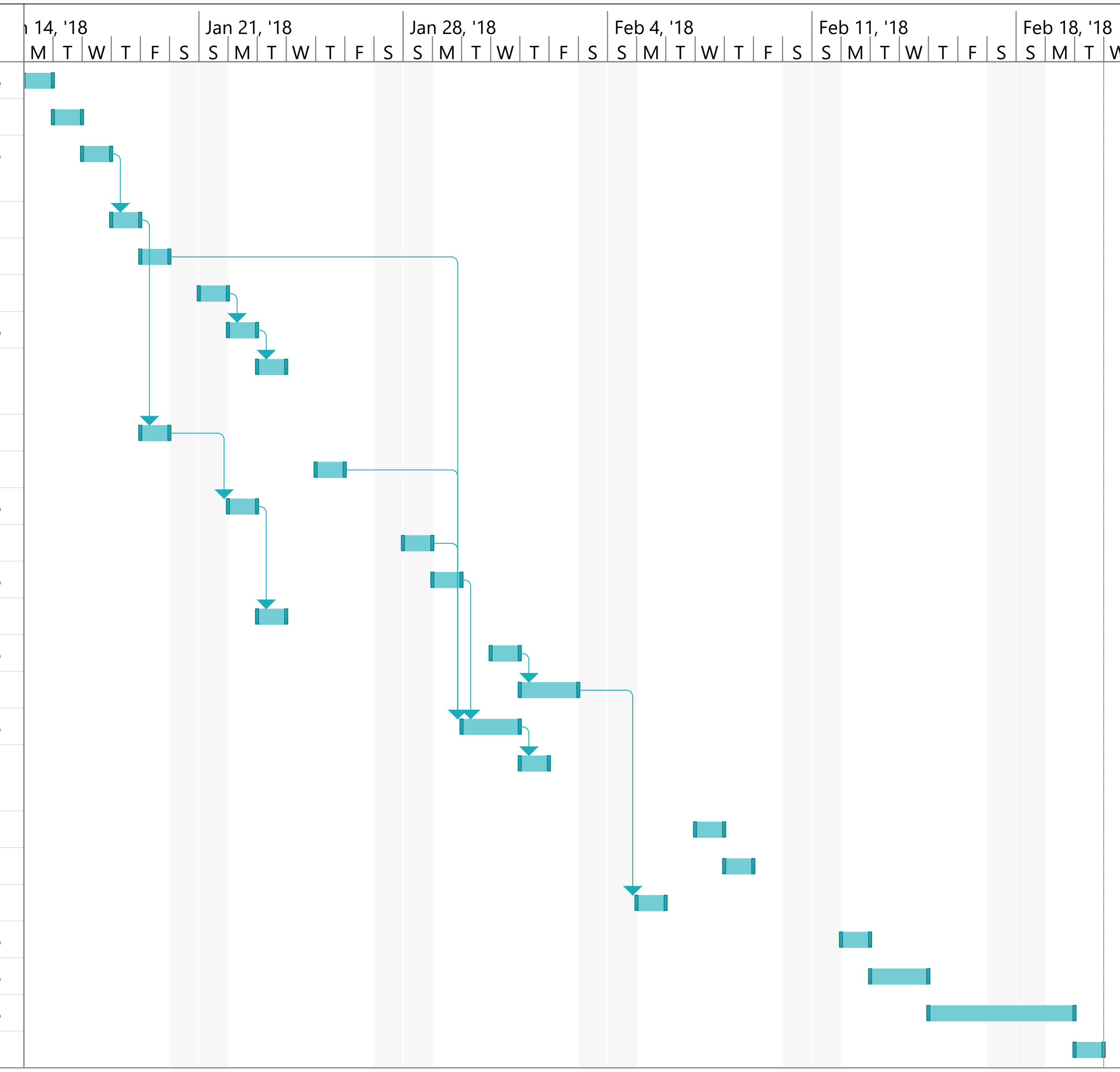
Labor Cost
$0.00

APPENDIX H:

CONSTRUCTION SCHEDULES

SYSTEMS 1 & 2

ID		Task Mode	Task Name	Duration	Start	Finish
1			Transporting Materials	1 day	Mon 1/15/18	Mon 1/15/18
2			Safety Training	1 day	Tue 1/16/18	Tue 1/16/18
3			Level & Compact Ground for Storage Tank	1 day	Wed 1/17/18	Wed 1/17/18
4			Place Forms & Pour Base Slab for Storage Tank	1 day	Thu 1/18/18	Thu 1/18/18
5			Dig Trench from Tank to Vidal's	1 day	Fri 1/19/18	Fri 1/19/18
6			Prepare spring location for spring box	1 day	Sun 1/21/18	Sun 1/21/18
7			Build spring box walls	1 day	Mon 1/22/18	Mon 1/22/18
8			Check to ensure walls have no leaks, pour spring box cover & hatch	1 day	Tue 1/23/18	Tue 1/23/18
9			Lay first four layers of tank walls	1 day	Fri 1/19/18	Fri 1/19/18
10			Dig trench from Vidal's to PBT	1 day	Thu 1/25/18	Thu 1/25/18
11			Lay last four layers of tank walls	1 day	Mon 1/22/18	Mon 1/22/18
12			Dig trench from PBT to Fedal's	1 day	Sun 1/28/18	Sun 1/28/18
13			Dig Trench from Nila's to Ernesto's	1 day	Mon 1/29/18	Mon 1/29/18
14			Fill tank walls with mortar & rebar	1 day	Tue 1/23/18	Tue 1/23/18
15			Build Pressure Break Tank, set forms for tank cover	1 day	Wed 1/31/18	Wed 1/31/18
16			Pour Storage Tank Cover, Pour Forms For Valve Boxes	2 days	Thu 2/1/18	Fri 2/2/18
17			Lay System Pipes	2 days	Tue 1/30/18	Wed 1/31/18
18			Check System Pipe Connections, install chlorinator, Build first 2 spigots	1 day	Thu 2/1/18	Thu 2/1/18
19			Build Remaining Spigots	1 day	Wed 2/7/18	Wed 2/7/18
20			Build and Place Tank Hatch	1 day	Thu 2/8/18	Thu 2/8/18
21			Assemble and install all valve boxes	1 day	Mon 2/5/18	Mon 2/5/18
22			Test System	1 day	Mon 2/12/18	Mon 2/12/18
23			Make adjustments if needed and fill in the trenches	2 days	Tue 2/13/18	Wed 2/14/18
24			Contingency Days	3 days	Thu 2/15/18	Mon 2/19/18
25			Clean Construction Site	1 day	Tue 2/20/18	Tue 2/20/18



Project: Implementation Schedu
Date: Mon 12/11/17

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

System 2 Schedule

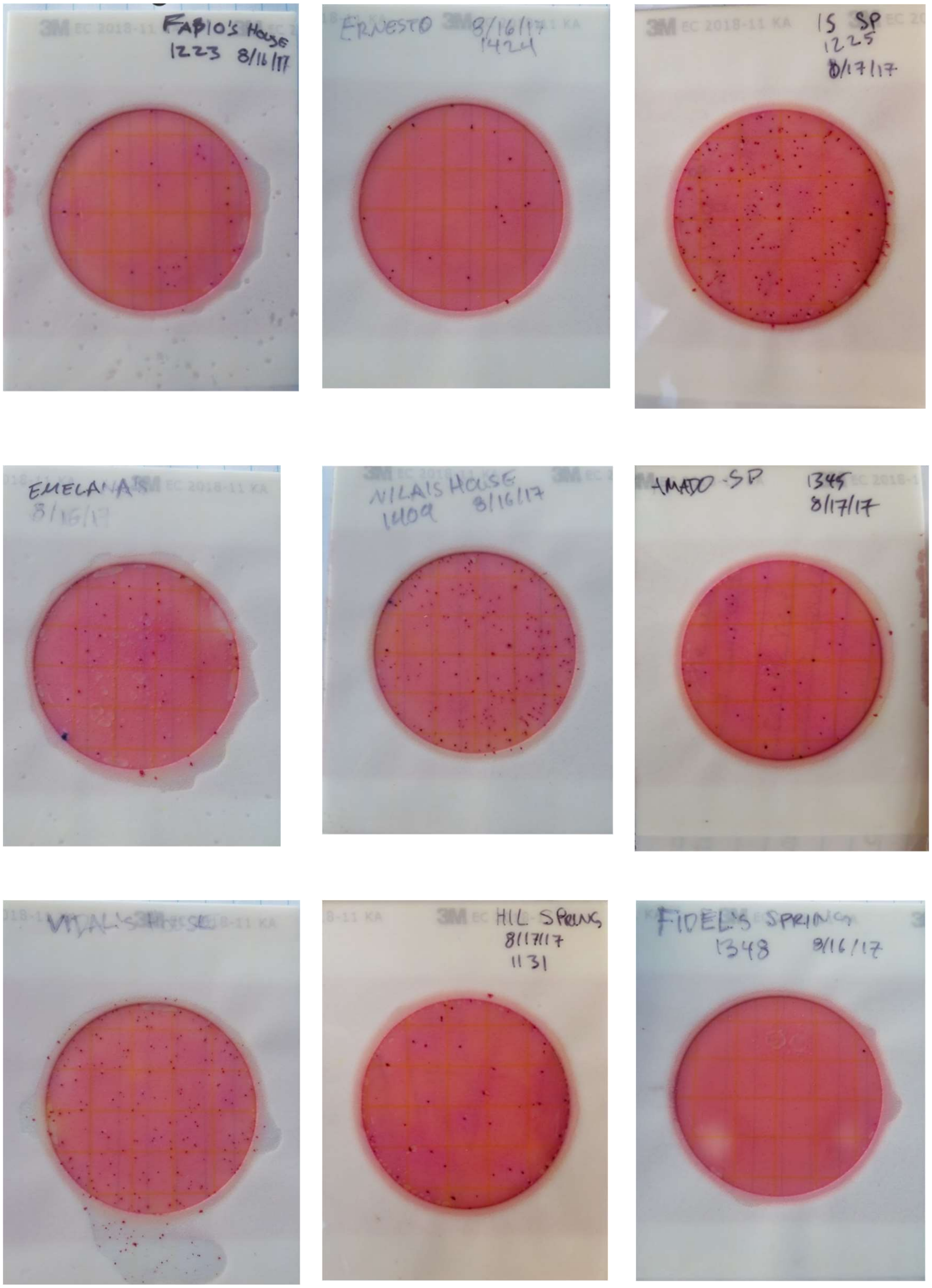
Task #	Task Description	Task Duration
Task 1	Travel into town and gather parts for pump	1 day
Task 2	Assemble Pump	3 days
Task 3	Excavate and Level ground for Spring Box	3 days
Task 4	Gather Material to Build Molds With	2 days
Task 5	Build Molds for Spring Box	2 days
Task 6	Put Molds in Place	1 day
Task 7	Travel into Town and get Material for Concrete	1 day
Task 8	Mix and Pour Concrete for Spring Box	1 day
Task 9	Travel into town and get PVC for system	1 day
Task 10	Have a 55 Gallon Drum Delivered	1 day
Task 11	Gather Material for Protection the Pump	1 day
Task 12	Build a Holding and Protection Box for Pump	2 days
Task 13	Connect System: Spring Box, Ram Pump, and Drum	3 days
Task 14	Test the System	1 day
Task 15	Inspect System	5 days
Task 16	Make ajustments to System	1 day
Task 17	Clean up from Project	1 day

Total Duration Without any Days off	**48 Days**

APPENDIX I:

WATER QUALITY RESULTS

Appendix I



Coliform and E. Coli results from 3M field tests.

Complete Water Test Results

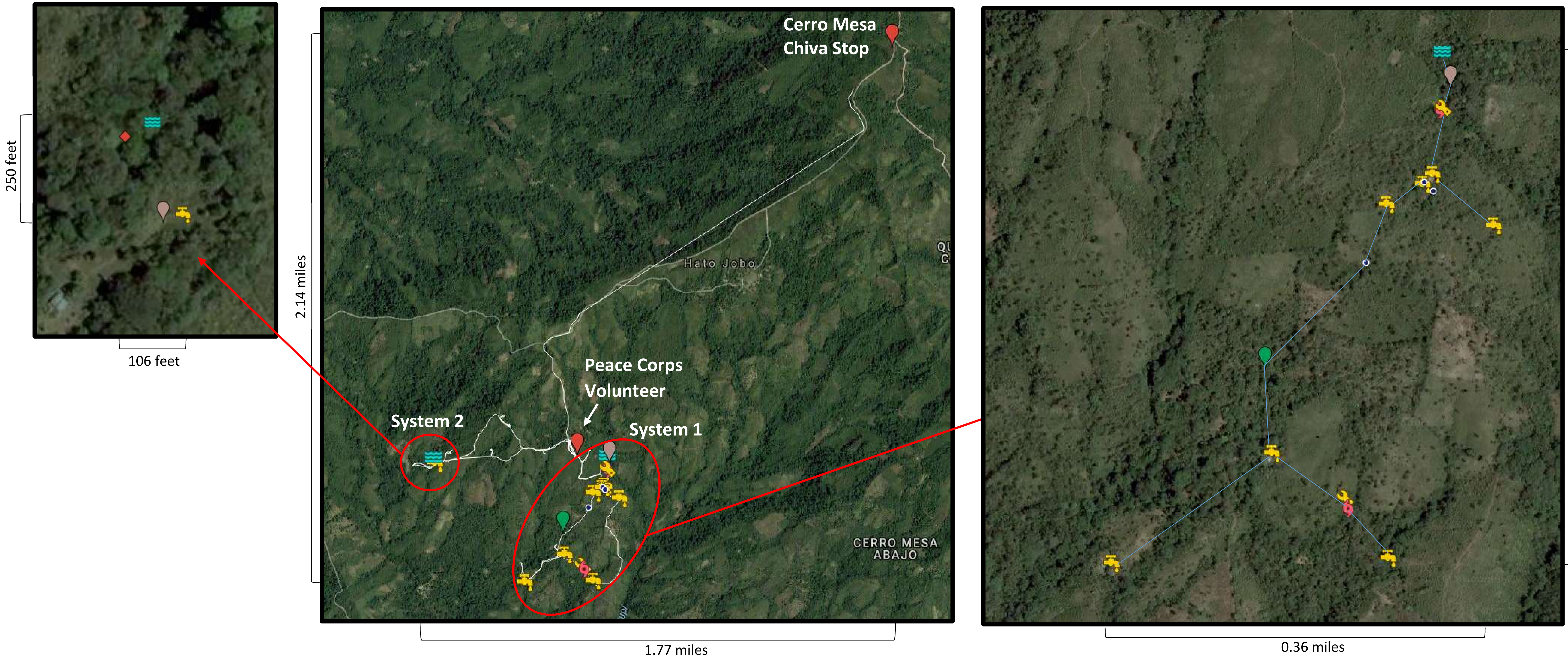
Read 8/18 7:39 am

Name	Date	Time	Coliform Count	E.Coli Count
Fabio	8/16	12:23	29	0
LS 2	8/16	11:36	155	0
Emiliana	8/16		38	1
Vidal	8/16		219	0
Nila	8/16	2:09	174	1
Ernesto	8/16	2:24	18	0
Victor US	8/16	11:09	10	0

Read 8/19 9:30 am

Name	Date	Time	Coliform Count	E.Coli Count
Small Source	8/17	10:55	9	0
SYS 2 SP	8/17	10:11	11	0
IS Spring	8/17	12:25	180	0
Filtered Water	8/18	12:00	0	0
Hill Spring	8/17	11:31	47	0
Amado-SP	8/17	13:45	38	0
Rosa Source	8/17	11:46	7	0

APPENDIX J:
DRAWINGS
SYSTEM 1 & 2



LEGEND:

Spigot

Spring Source

Air Release Valve

Flow Reducer

Pressure Break Tank

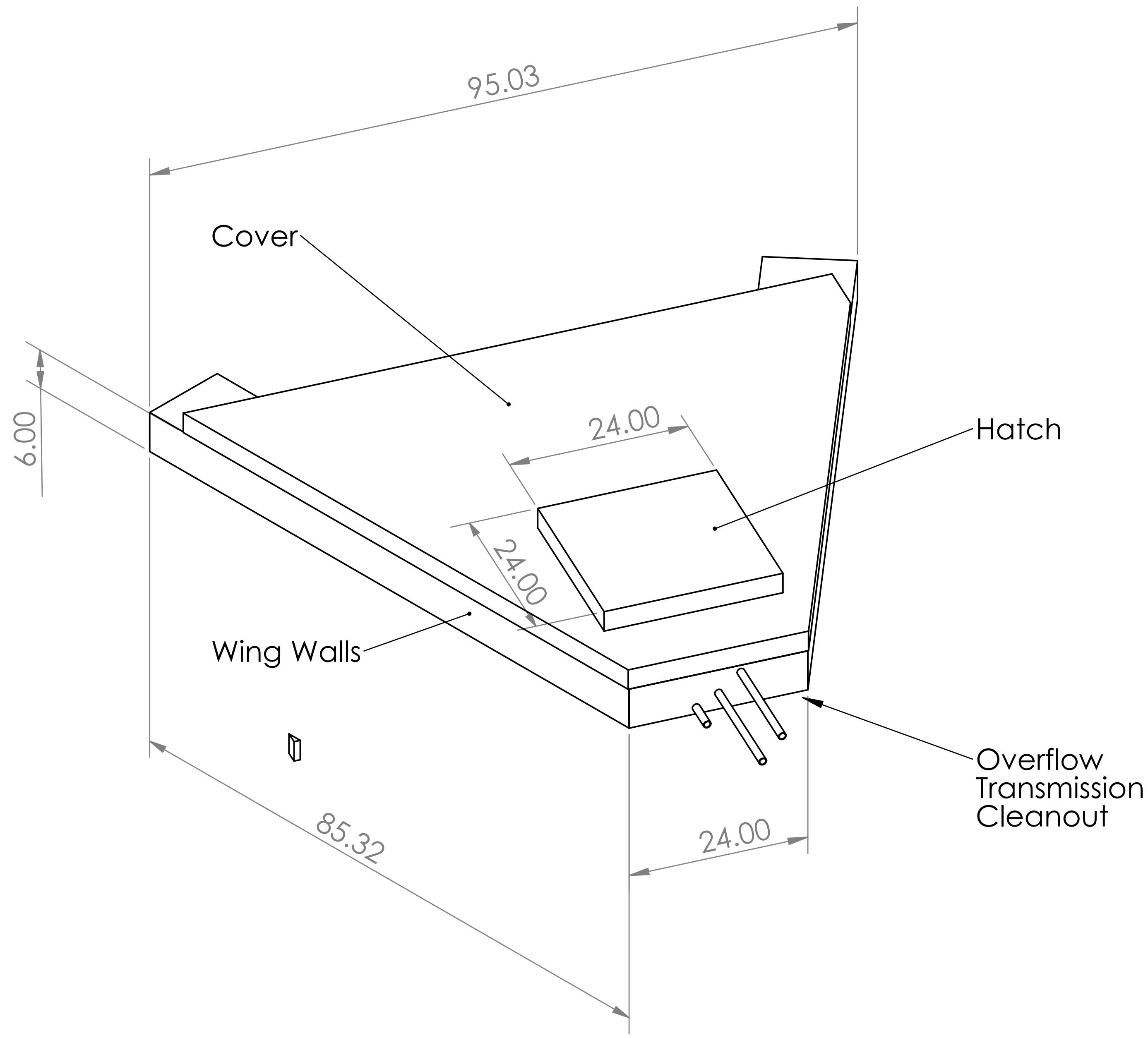
Storage Tank

Ram Pump

Cleanout Valve

TITLE:

Complete System Map



NOTES:
Spring box dimensions are all estimates and will change to match the profile of the spring surroundings.
This drawing is provided as a visual for the general shape and required components of the box.

Materials:
1:2:3 mixing ratio cement
0.5 inch PVC pipe
Rocks
PVC glue
Sika-1
Timber
Nails
Sacos

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

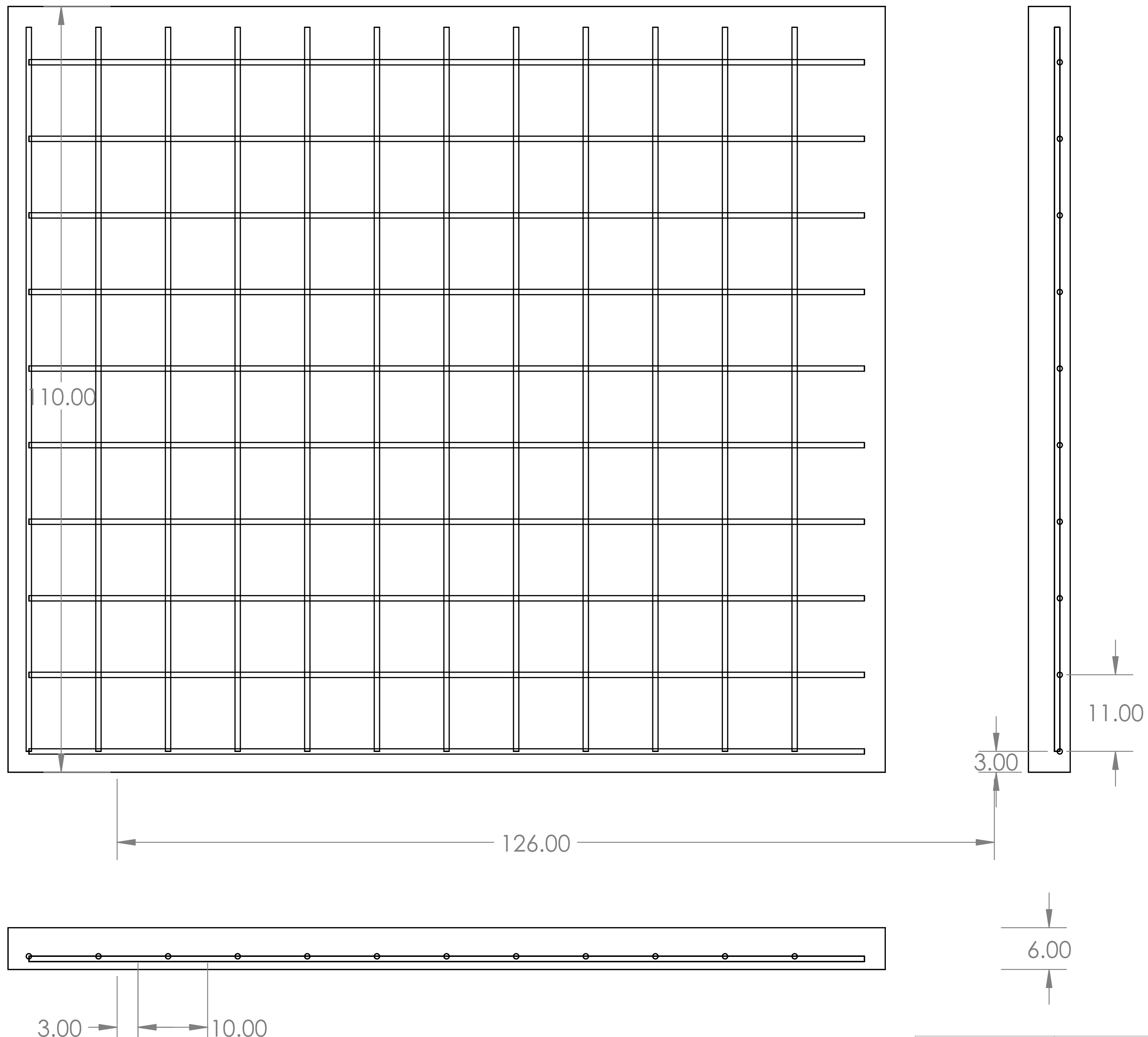
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Lower Spring

SIZE	DWG. NO.	REV
B		

SCALE: 1:25 WEIGHT: SHEET 1 OF 1



NOTES:
Materials:
3/8 inch rebar
1:2:3 mixing ratio cement
Tie wire

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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

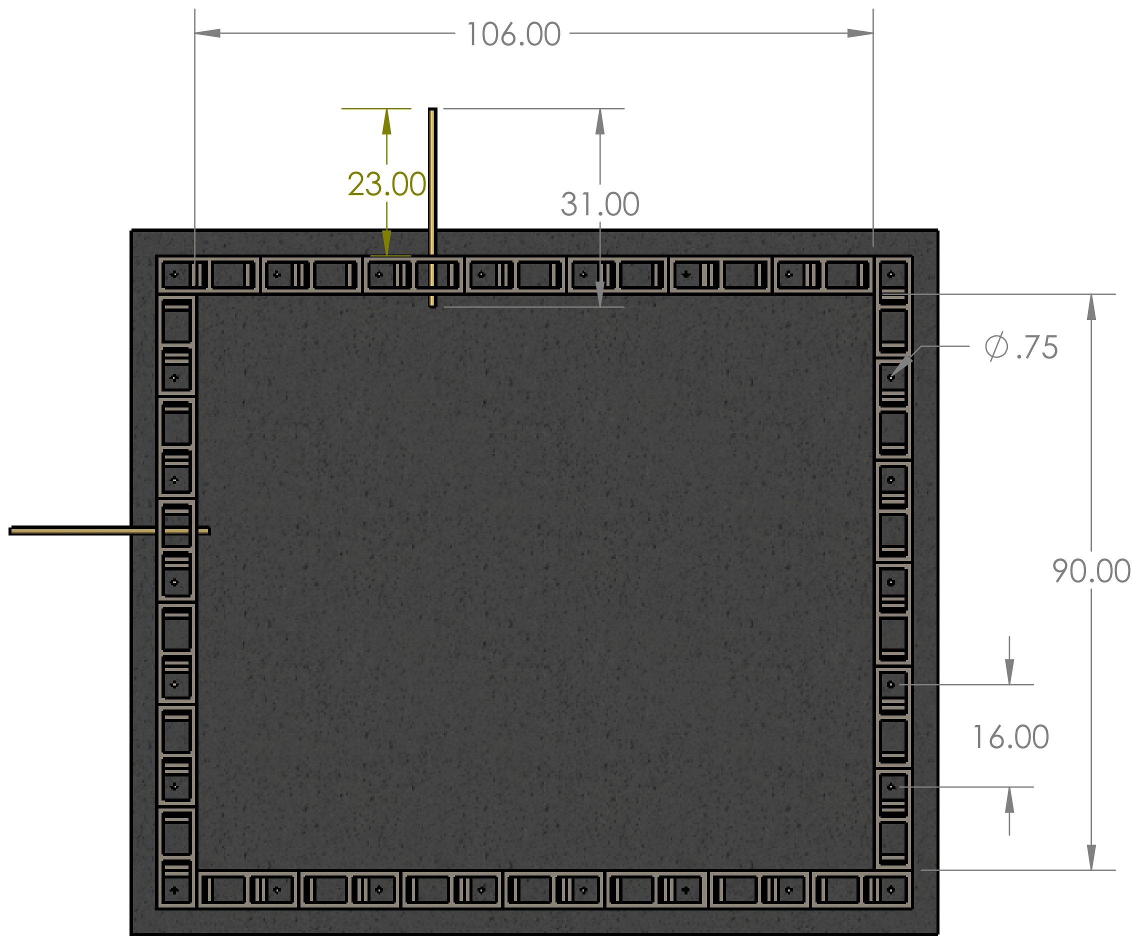
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

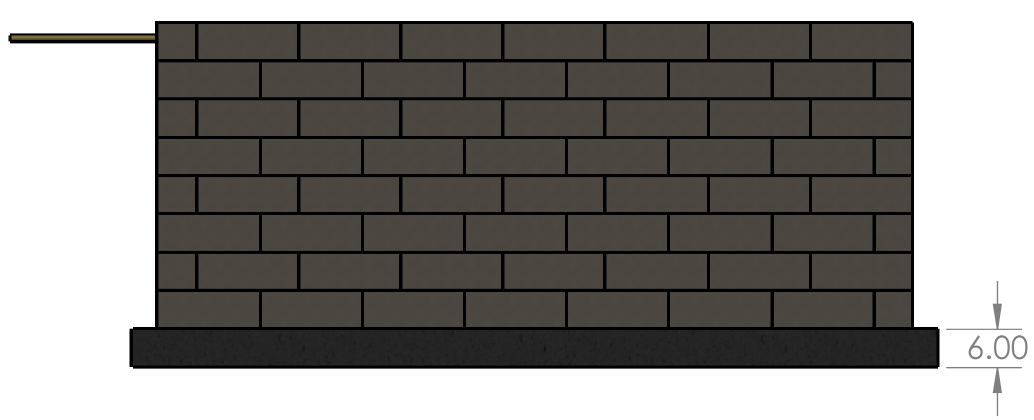
COMMENTS:

TITLE:
Storage Tank Base

SIZE	DWG. NO.	REV
B		

SCALE: 1:50 WEIGHT: SHEET 1 OF 1





NOTES:
Masonry walls should be constructed 3 layers at a time (no more than 1 meter high) with a 24 hour curing time before laying subsequent sections

Materials:
3/8 inche rebar
6 inch CMU blocks
1:3 mixing ratio mortar
1.5 inch PVC

NEXT ASSY	USED ON
APPLICATION	

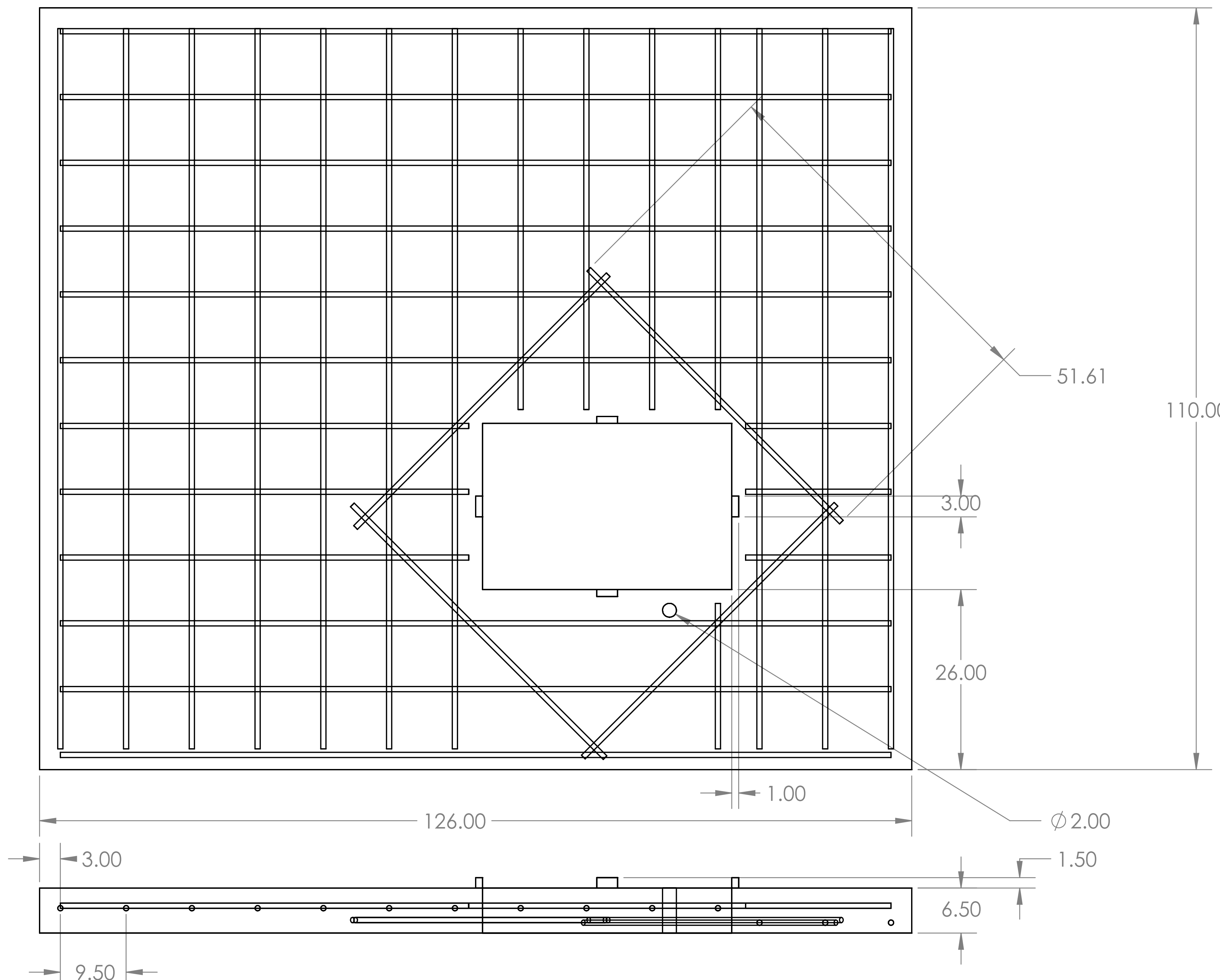
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:
Wall View

SIZE	DWG. NO.	REV
B		

SCALE: 1:50 WEIGHT: SHEET 1 OF 1



NOTES:

Materials:
3/8 inch rebar
1:2:3 mixing ratio cement
Timber blocks
Anchor blots
Tie wire

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APPLICATION	

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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		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

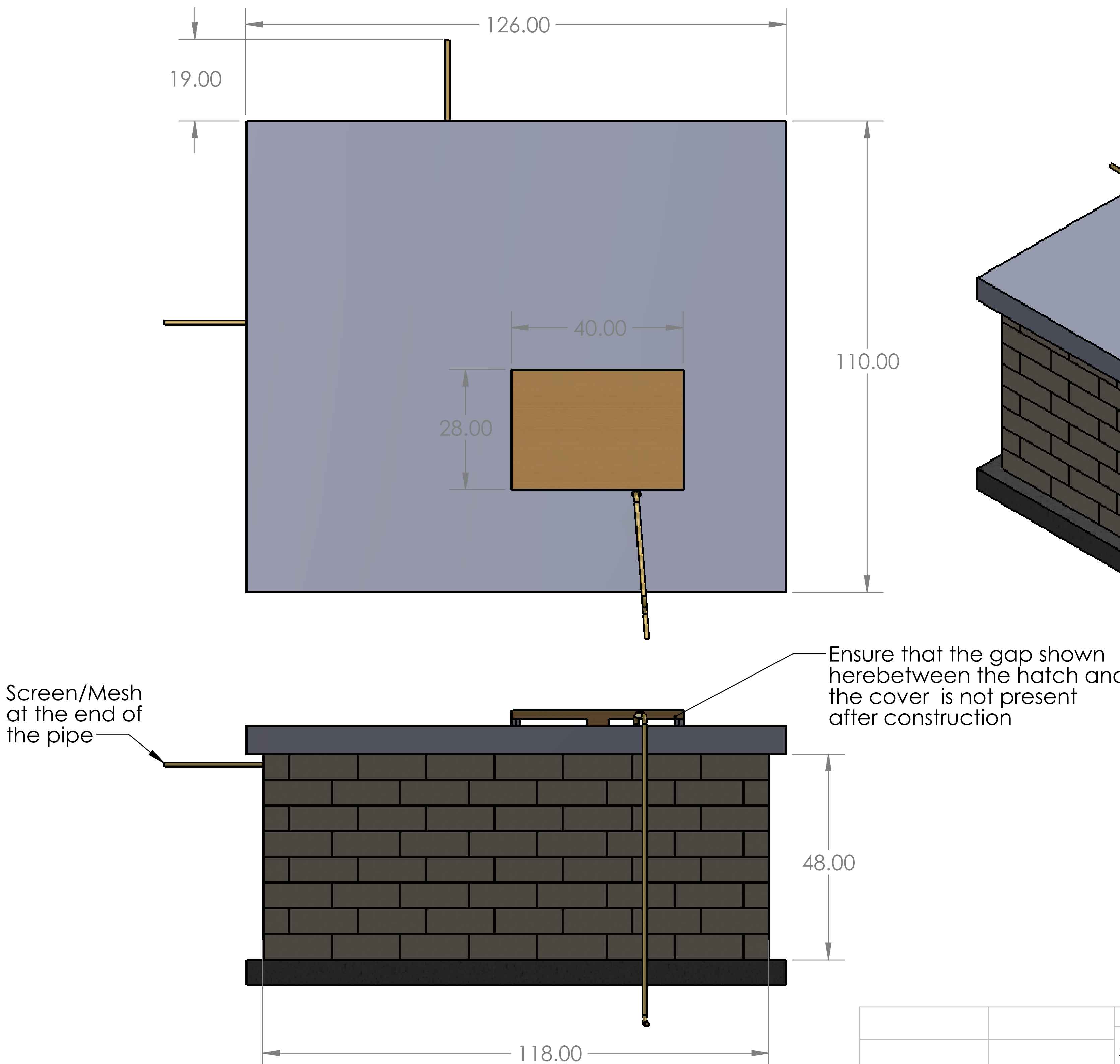
COMMENTS:

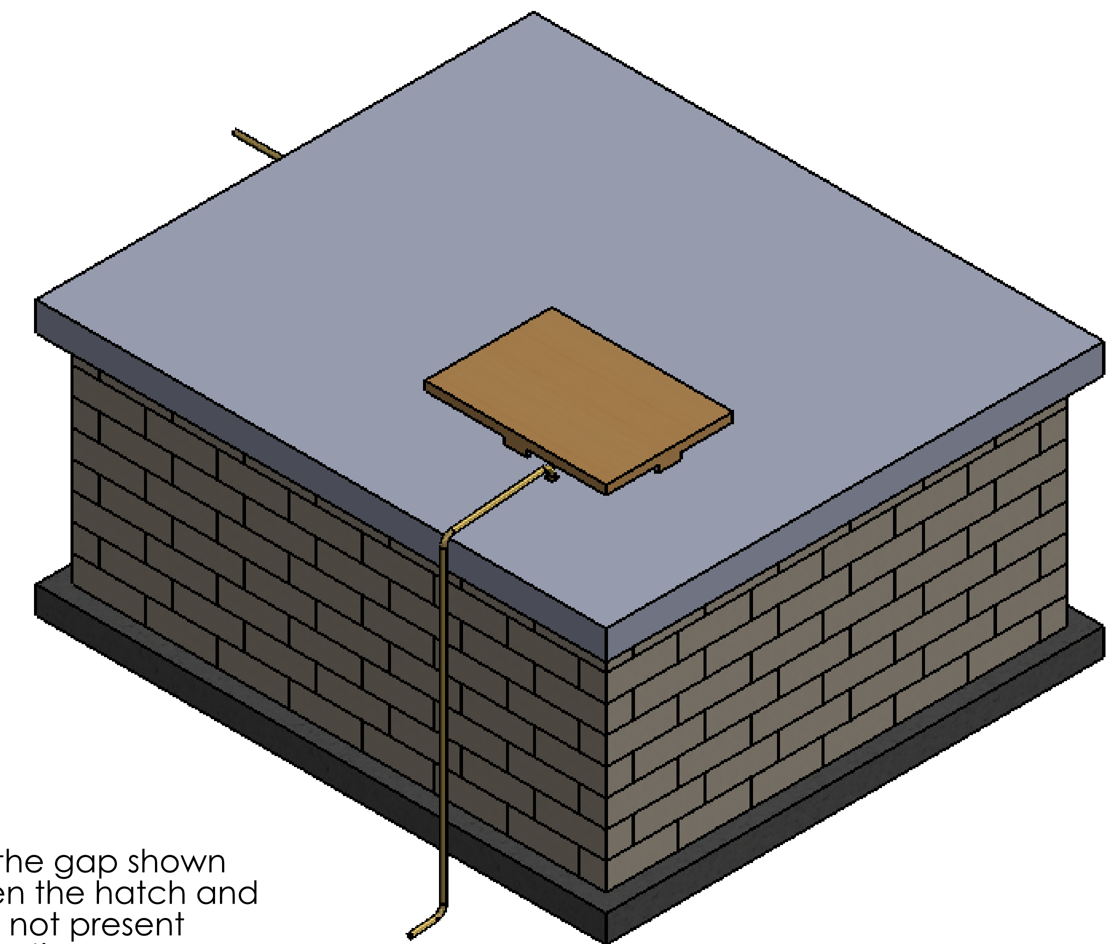
TITLE:

Cover

SIZE	DWG. NO.	REV
B		

SCALE: 1:48 WEIGHT: SHEET 1 OF 1





Components:

Timber Hatch
Galvinzed inlet pipe
Galvinized outlet pipe
Galvinized overflow pipe
CMU masonry walls reinforced with rebar
Cement slabe reinforced with rebar
Cement cover reinforced with rebar

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		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

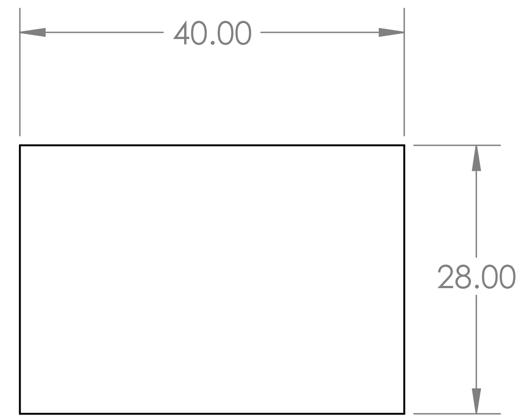
COMMENTS:

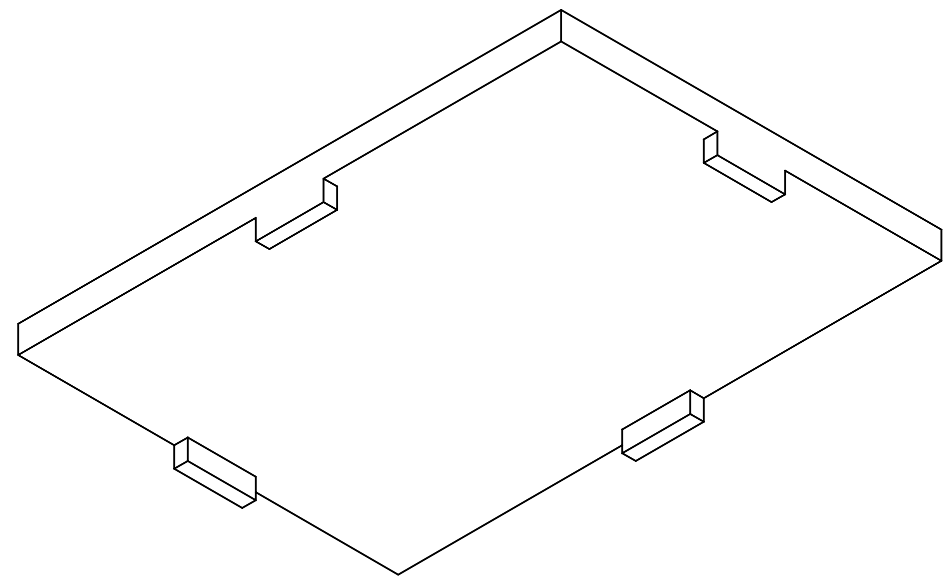
TITLE:

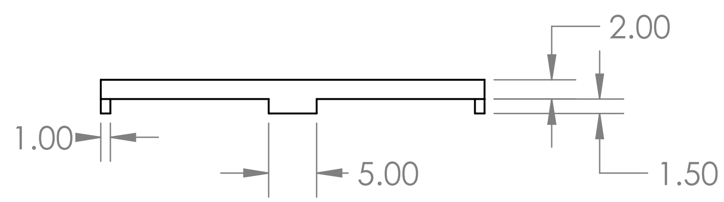
Tank Model View

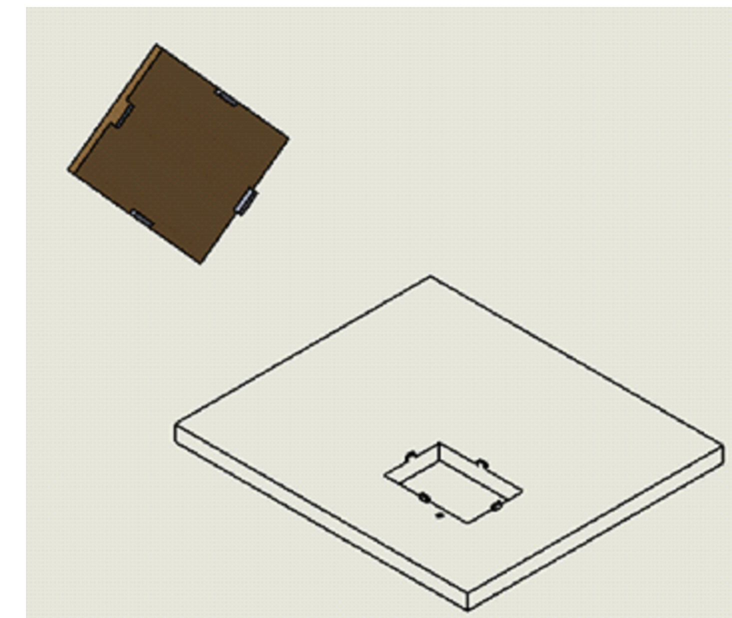
SIZE	DWG. NO.	REV
B		

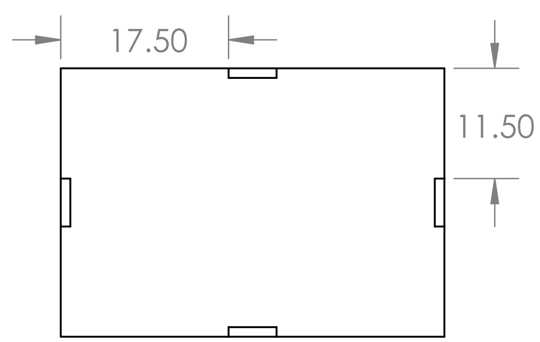
SCALE: 1:50 WEIGHT: SHEET 1 OF 1











NOTES:
Hatch placed ontop of the hold within the storage tank cover.

Materials:
Timber
Nails

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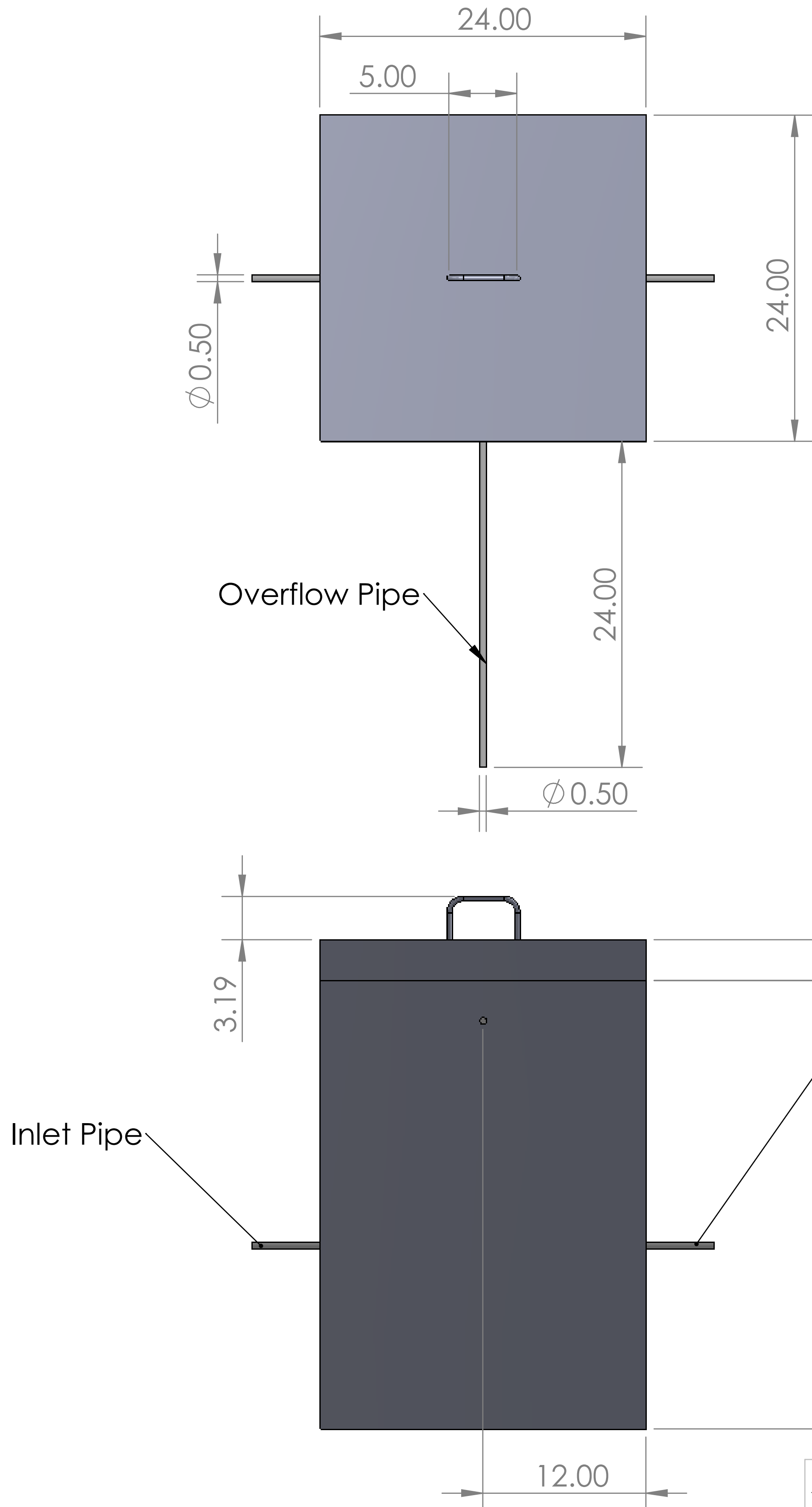
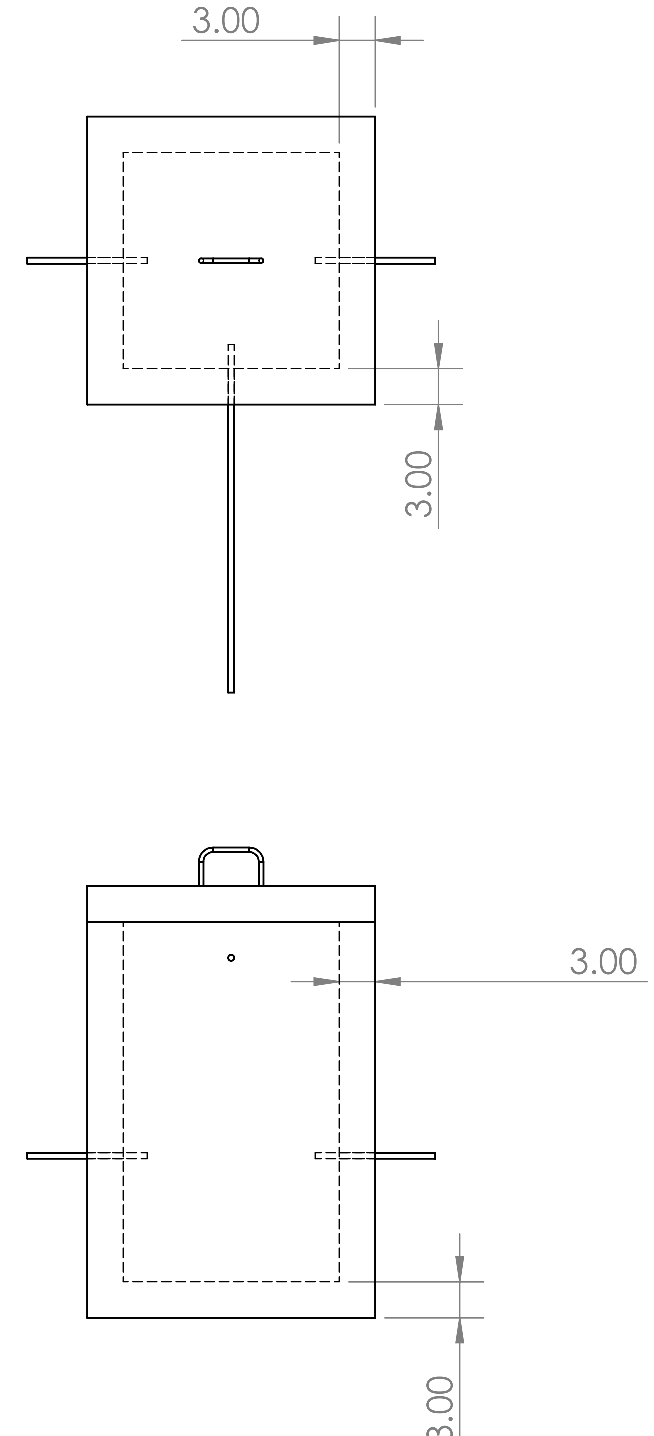
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

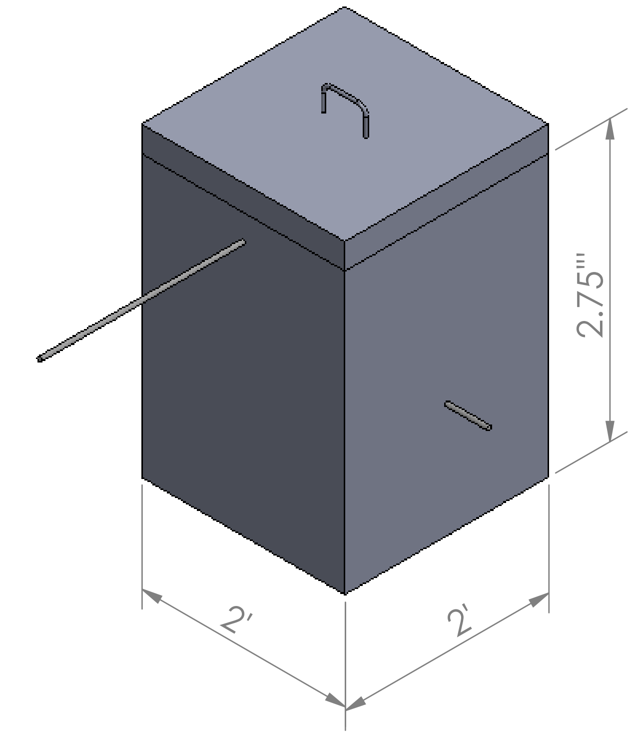
TITLE:

Hatch

SIZE	DWG. NO.	REV
B		
SCALE: 1:48	WEIGHT:	SHEET 1 OF 1







NOTES:
The inlet and outlet pipes on this box should lie level with the piping for the total system at 2 feet below the ground surface.

Tank Materials:
1:2:3 mixing ratio cement
3/8" rebar
1/2" PVC pipe sdr 13.5

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APPLICATION	

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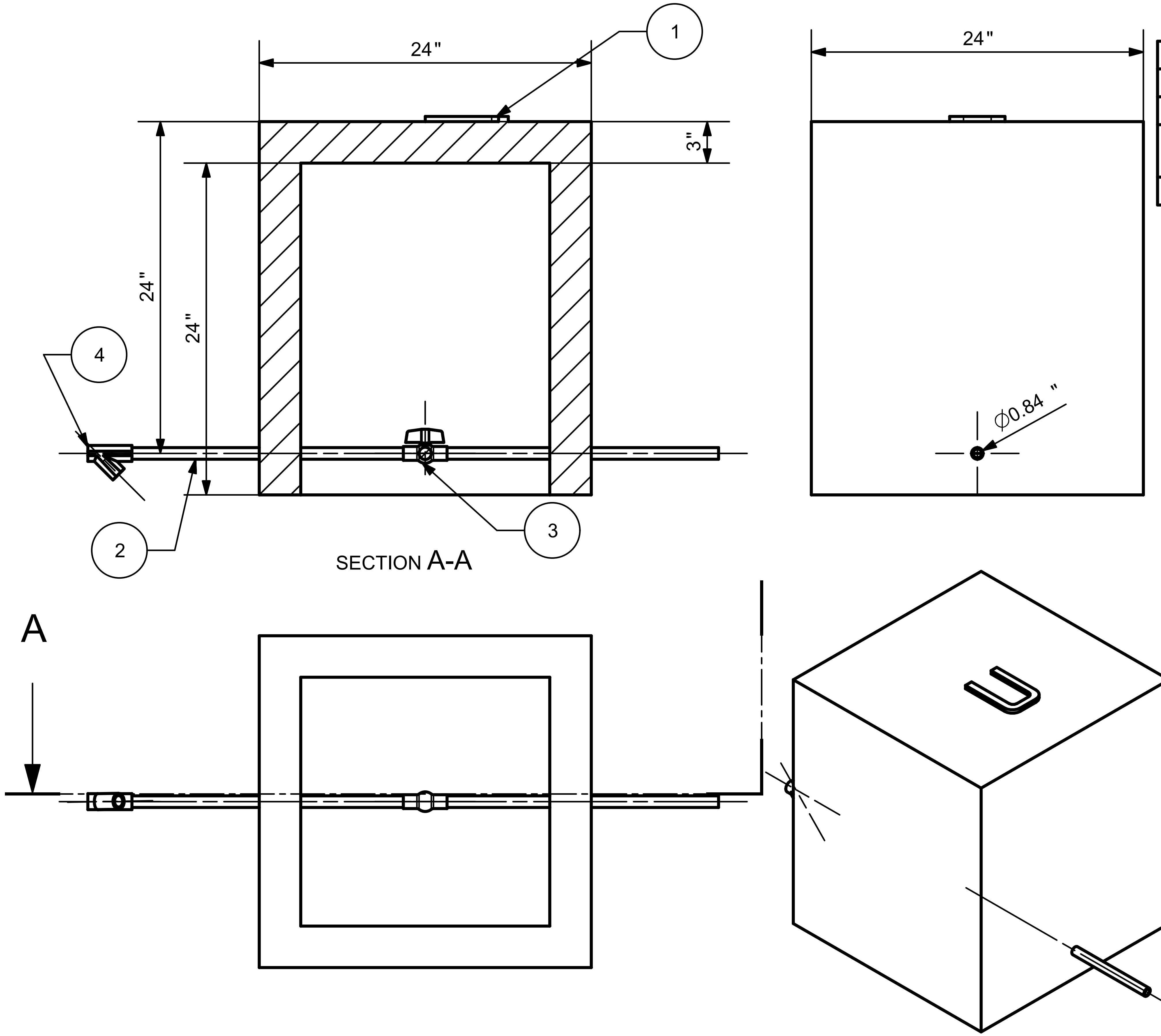
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:
Pressure Break Tank

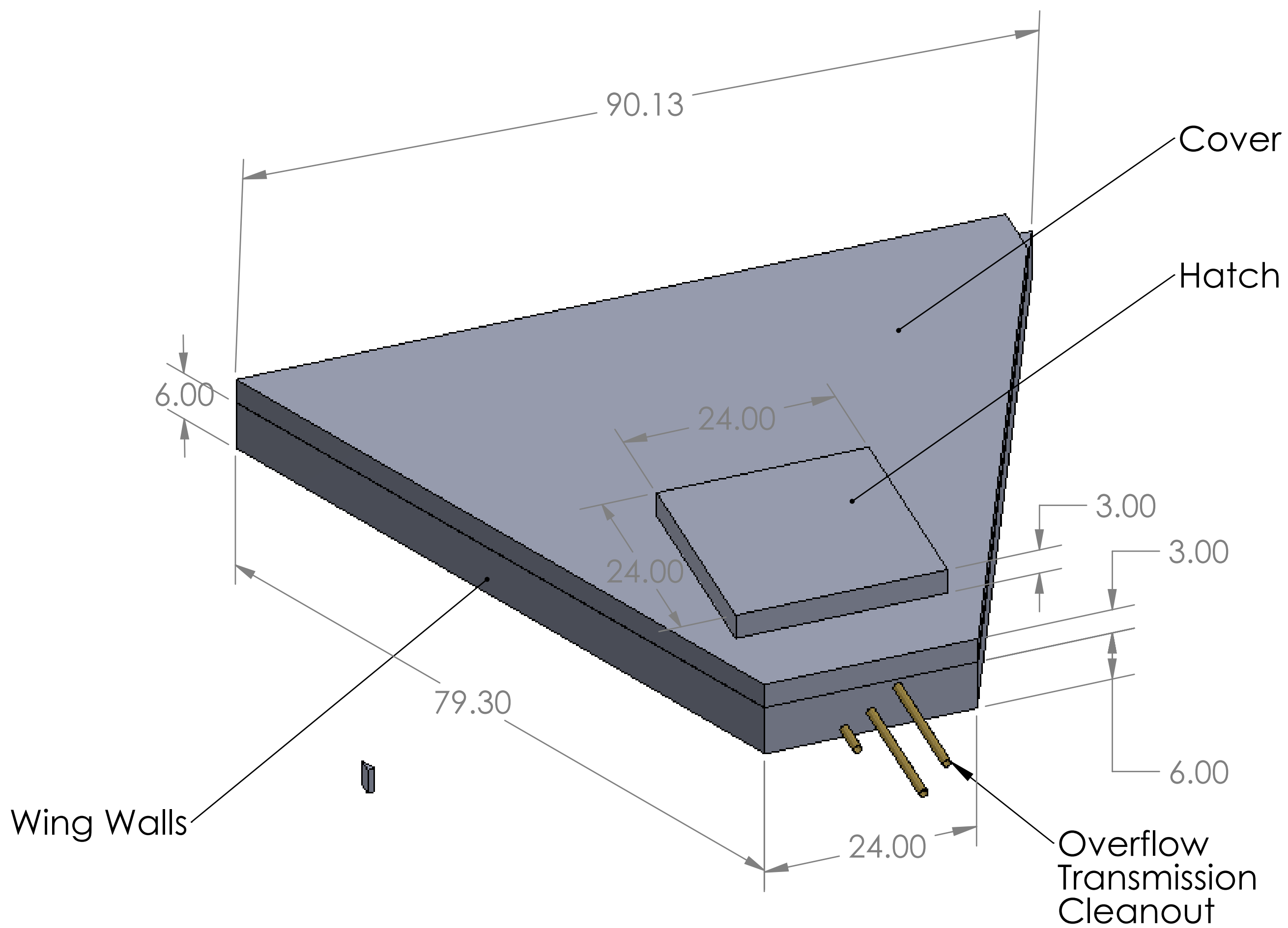
SIZE	DWG. NO.	REV
B		

SCALE: 1:16 WEIGHT: SHEET 1 OF 1



PC NO	PART NAME	QTY
4	1/2 inch wye joint	1
3	1/2 inch Check Valve	1
2	1/2 inch PVC pipe	2
1	Concrete Box with Rebar Handle on Cover	1

Clean Out Valve and Concrete Cover Box



NOTES:
Spring box dimensions are all estimates and will change to match the profile of the spring surroundings.
This drawing is provided as a visual for the general shape and required components of the box.

Materials:
1:2:3 mixing ratio cement
0.5 inch PVC pipe
Rocks
PVC glue
Sika-1
Timber
Nails
Sacos

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

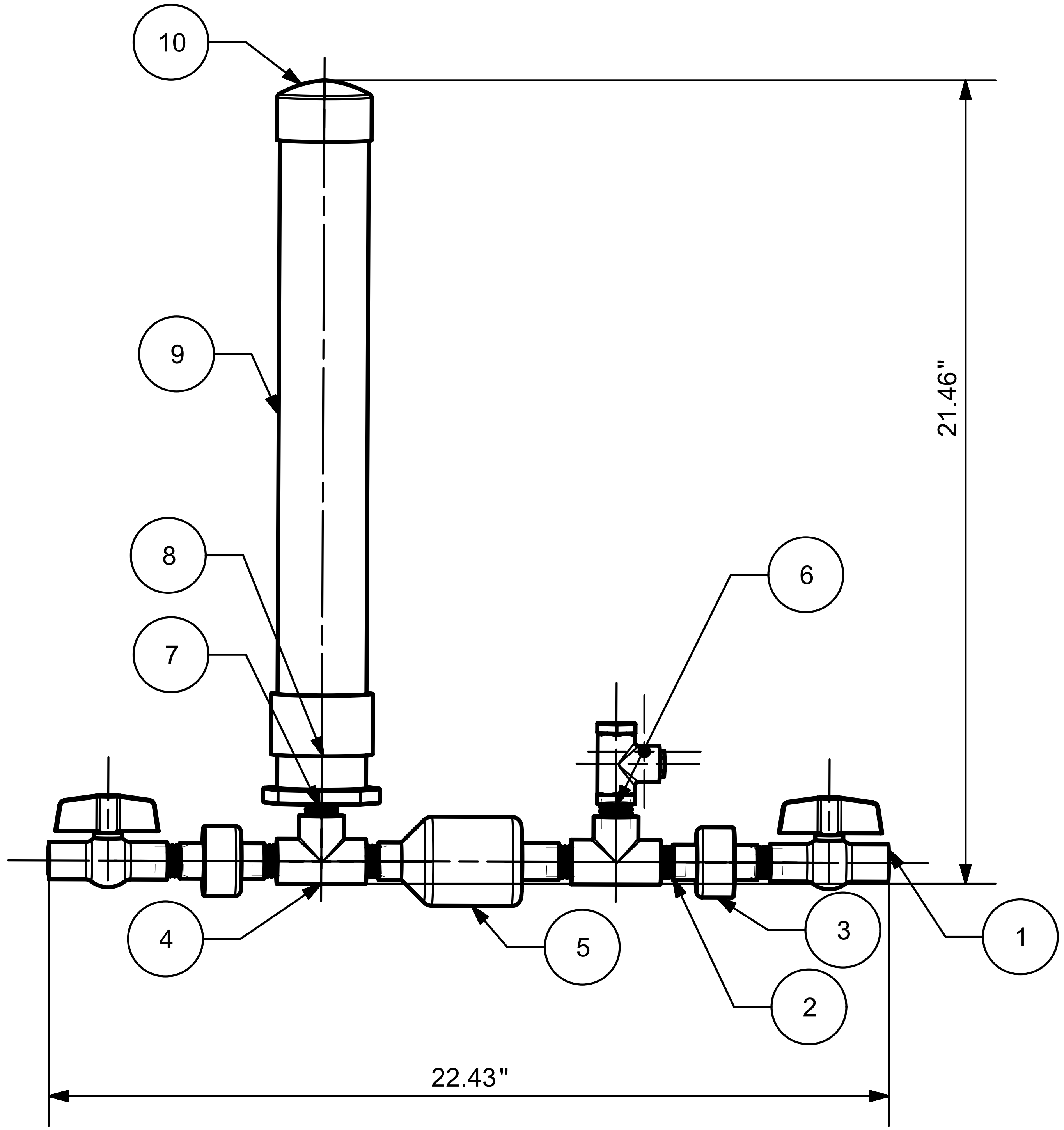
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

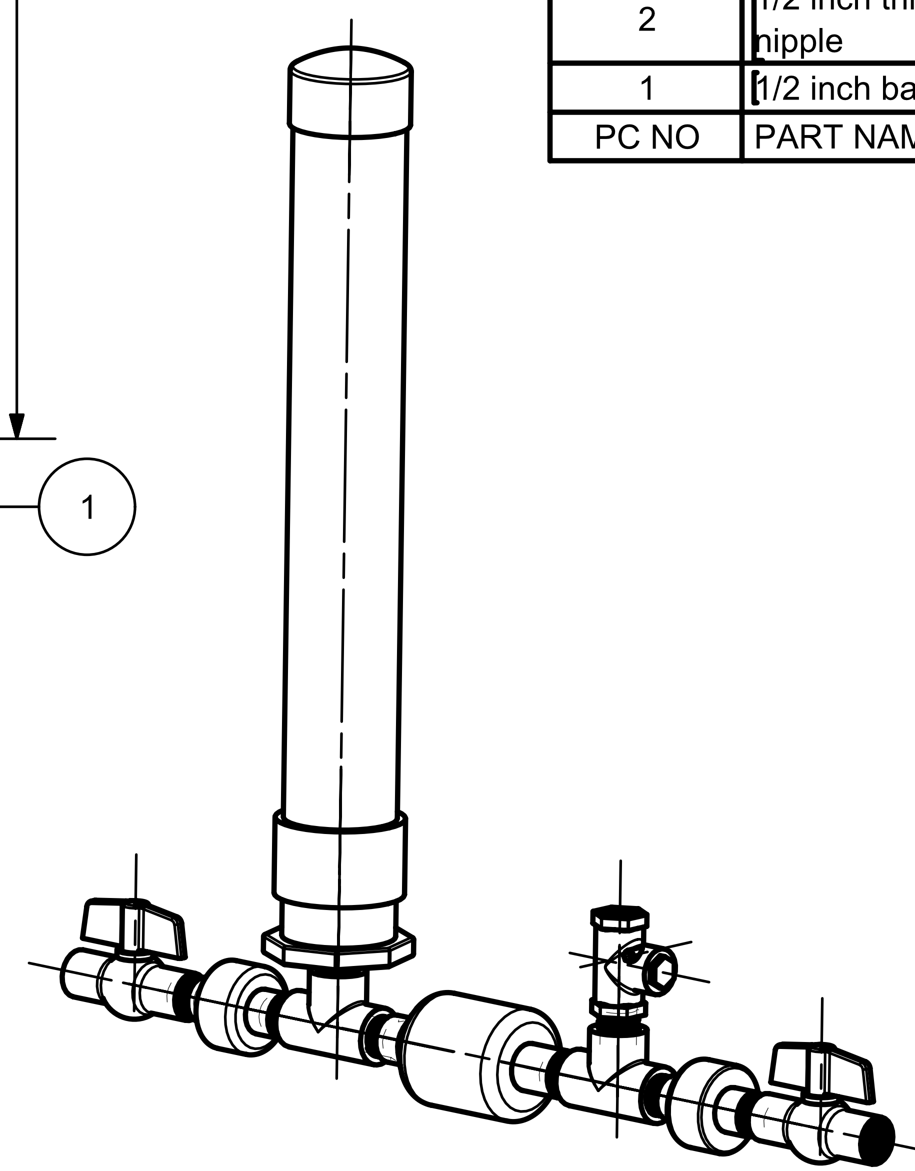
TITLE:
System 2 Spring Box

SIZE **B** DWG. NO. Rosa Spring REV

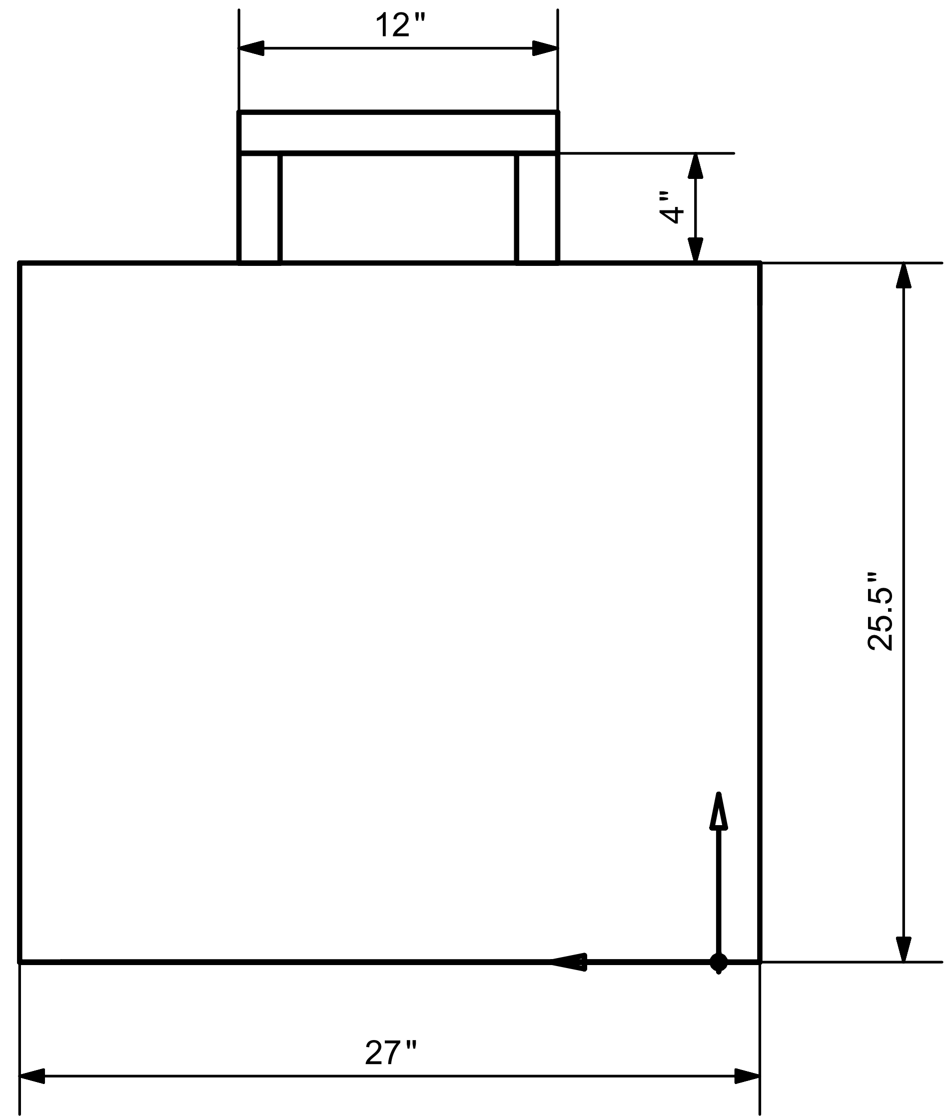
SCALE: 1:25 WEIGHT: SHEET 1 OF 1

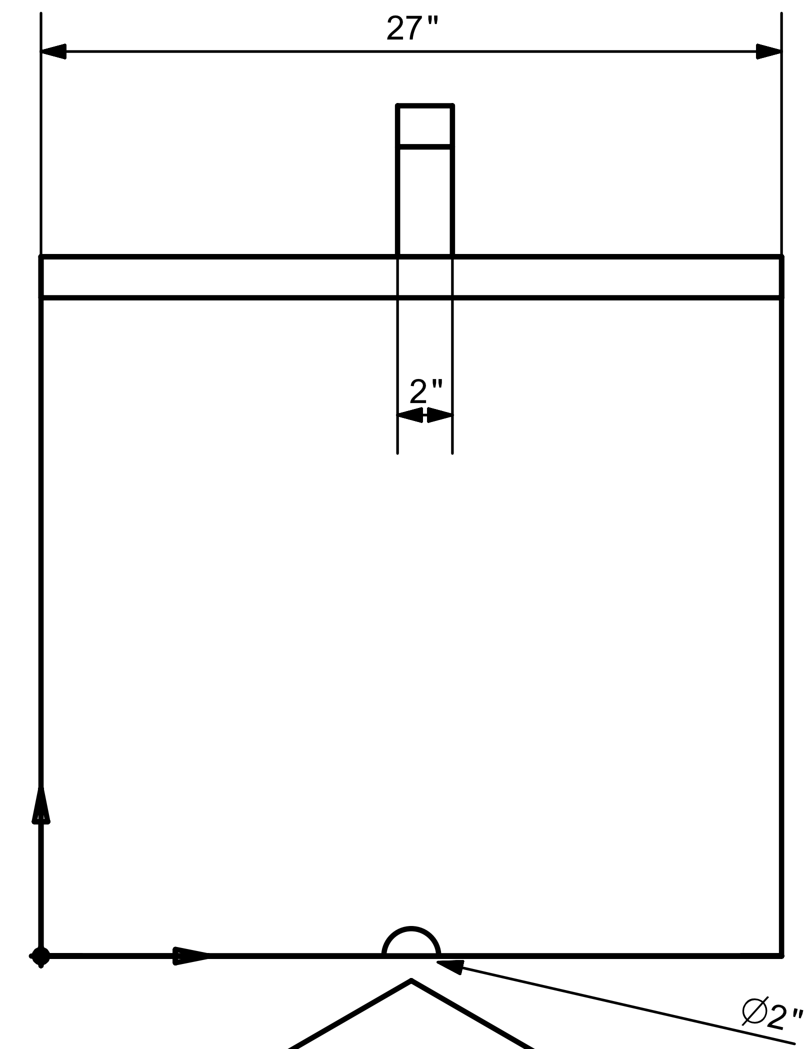


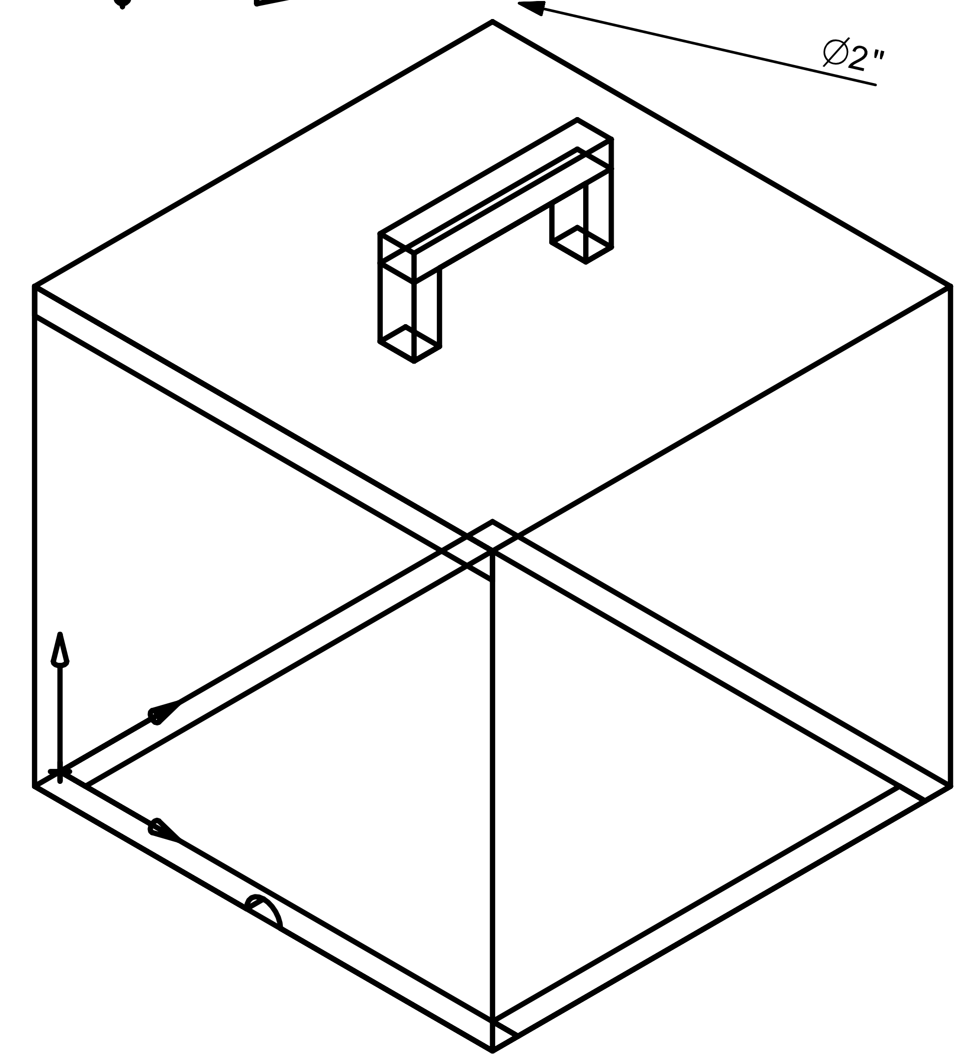
PC NO	PART NAME	QTY
10	2 inch cap	1
9	16" section of 2" PVC pipe	1
8	2 inch coupler	1
7	1/2 inch to 2 inch reducer bushing	1
6	1/2 inch threaded brass swing check valve	1
5	1/2 inch threaded check valve	1
4	1/2 inch threaded T joint	2
3	1/2 inch threaded union	2
2	1/2 inch threaded nipple	8
1	1/2 inch ball valve	2



Ram Pump Assembly







1	Wood	All

Ram Pump
Protective
Cover