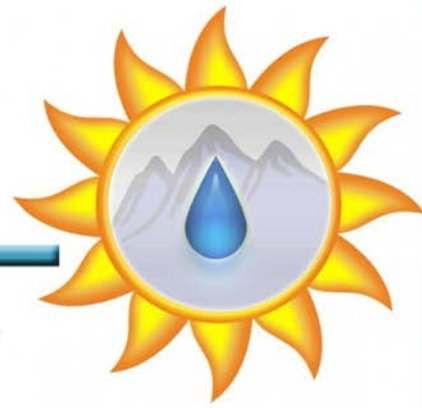


**HARD BODY**  
ENGINEERING



# Engineering a Sustainable Water Distribution System in Western Panama

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**iDesign 2012**

**Michigan Technological University**

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**Disclaimer:**

It should be noted that this report was created by undergraduate students participating in an International Senior Design project sponsored by Michigan Technological University. This is not a professional engineering report, and has been created for the purpose of providing ideas to improve the lives of the citizens in Cerro Mesa, Cerro Peña and Hato Pión, Panama.

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## Executive Summary

Team Hard Body has developed a design recommendation for a water distribution system to serve three of the four communities of the Ngöbe Bugle people in the Provincia de Chiriquí, Panama. The central community, Hato Pilón Abajo, already has in place a water distribution system. This proposed design will supply potable water to the remaining three communities, where approximately 250 people reside in about fifty homes. Currently, residents walk up to twenty minutes to obtain water for domestic use.

At the start of this project, Team Hard Body travelled to the country of Panama and spent a week in the communities collecting information. While in the communities, an assessment was done on the needs of the people as well as the capacity for development of a water distribution system. There was considerable observation of local customs and social structure in order to gain understanding of community operation and the implications of this proposed development. Quantitative data collected included: a topographical study, water quality tests, water supply estimation, and community demographics and use data. From analysis of the collected data and through further research, Team Hard Body has prepared a design and recommendations for the communities to implement the most sustainable solution to their potable water needs.

The final design is composed of a spring box at a water source that can provide an adequate supply of water for the communities, a supply pipeline, and a 6400 gallon concrete storage tank. Found in this report are the designs for two pressure relief components which will prevent a buildup of high pressures in the system that might otherwise rupture the piping. An in-line chlorinator design is included to ensure proper disinfection within the system. Also included, are detailed hydrological calculations, a design and construction schedule, detailed design components and recommendations, as well as maintenance manuals, cost estimations, and an abridged design manual in Spanish. Research was conducted on all aspects of this design to ensure the utmost quality of the final proposed system with respect to the economical limitations of the communities. The cost of the completed project is estimated to be \$9,200. This estimate is based on local material costs and the assumption that all unskilled manual labor be donated as an in-kind service.

Sustainability is one of the principal considerations for this project. Each element is designed to achieve the maximum performance at the lowest possible cost. Likewise, the system components are designed for easy maintenance by community members. Maintenance tasks include: inspection of air release valves and pressure relief basins, bi-yearly cleaning of spring box and storage tank, refilling chlorination tablets and repair of any pipeline or spigot breaks. This infrastructure development will only succeed with the commitment and participation of community members.

## Introduction

In August 2012, students from Michigan Technological University's International Senior Design Course travelled to the country of Panama collecting data in rural communities to develop engineering solutions to their most pressing issues. Projects varied from micro-hydropower electricity generation to potable water distribution systems. Once in country, the students dispersed into teams of four and travelled to their three designated regions.

Team Hard Body travelled to Hato Pilón Abajo, in Chiriquí Panama (Figure 1). The team was tasked with designing a water distribution system to supply potable water to three communities surrounding Hato Pilón Abajo. The design conditions are that the system be feasible and sustainable given their income and remote location. Currently Hato Pilón Abajo has an operational water supply system. This system was the basis for many of the assumptions found in this report as well as initial design concepts. The communities intended to receive water from this system are Hato Pilón Arriba, Cerro Mesa, and Cerro Peña (Figure 2). Their residents currently obtain their water from nearby streams and creeks, and a few families employ the use of rainwater catchment techniques.

The months of September to November were spent developing a plan that is economical and can be easily built with little or no knowledge of hydrology. Environmental and social considerations were included in many aspects of the design. There are several workers from the Peace Corps Volunteer Service that reside in the region and are likely to aid in the construction of this project.

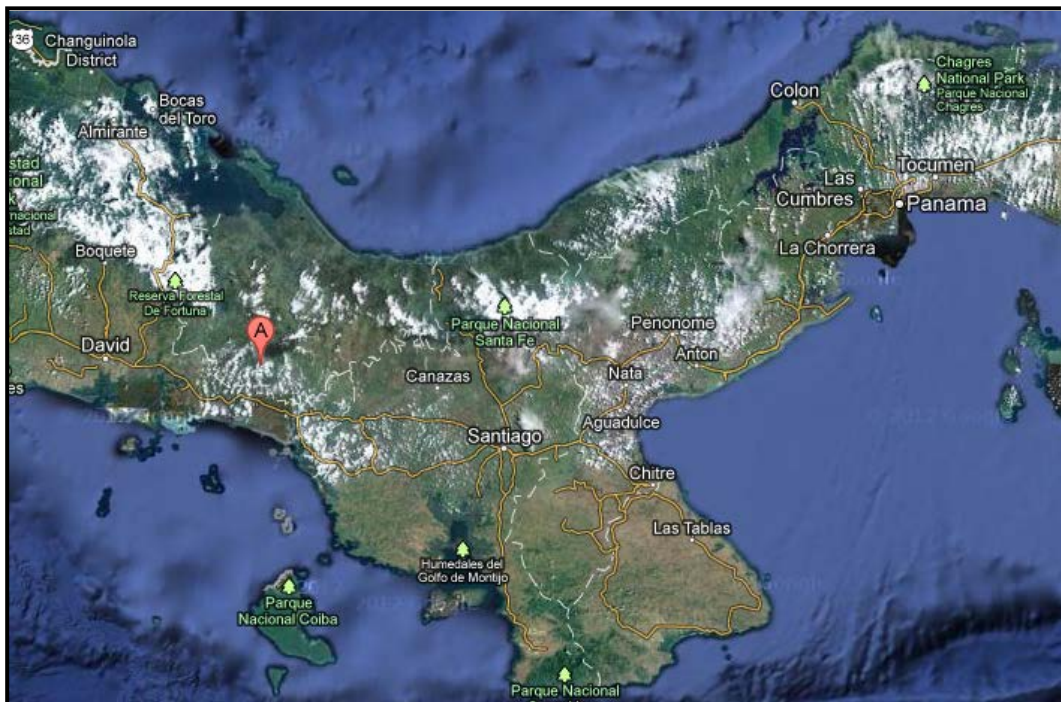


Figure 1 Location of Hato Pilón (A) in Poviaicia de Chiriqui Panama. Courtesy of Google Maps

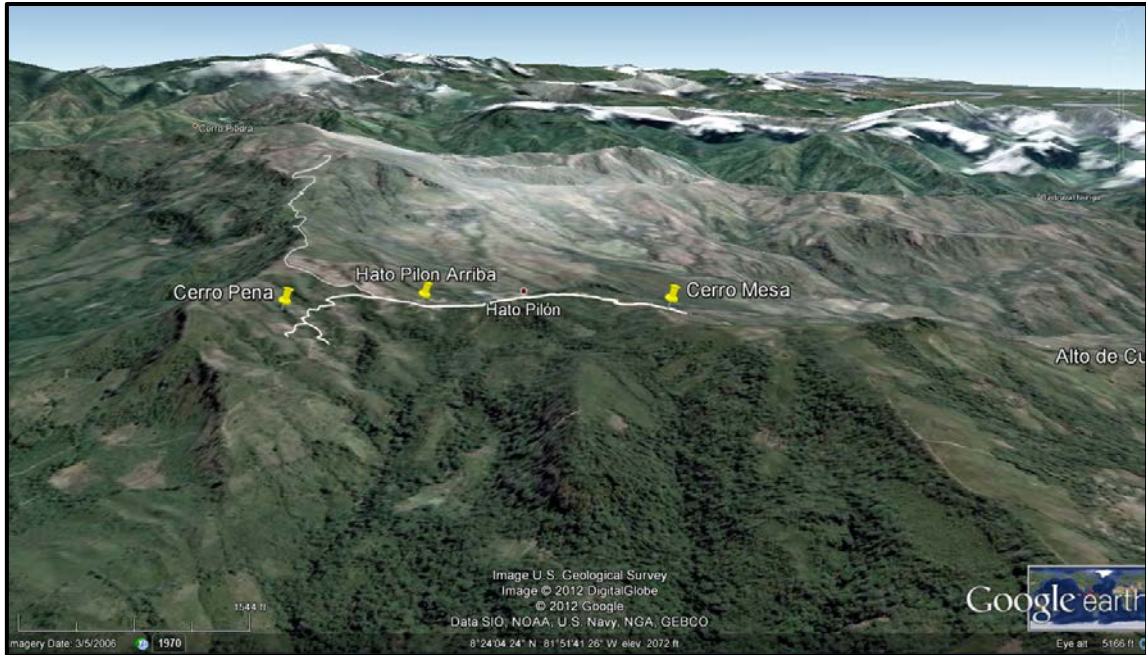


Figure 2 Location and topography of Cerro Peña, Hato Pílon and Cerro Mesa. Courtesy of Google Earth Pro

## Design Purpose

The purpose of this project is to provide the three communities of Cerro Mesa, Hato Pilón Arriba, and Cerro Peña with a feasible and sustainable design. A gravity-fed water distribution system is proposed to meet these needs. This design must be economically feasible in a region of limited financial resources, maintainable and sustainable for future use, have sufficient supply in the dry and rainy season, have low environmental impact and above all the water must be safe for consumption.

Currently, those without access to water in streams or creeks near their homes may walk up to twenty minutes carrying water back in five gallon buckets for domestic use. The streams and creeks are also utilized for bathing, open to animals, and sometimes for the community members to relieve themselves (although this is becoming less frequent as most homes have latrines nearby). The team noticed that during the afternoon when it rained, these waters ran murky as the clay foot trails washed downhill. The quality of these waters is not reliable and often people are stricken with stomach ailments.

There are several challenges the community may incur with a project of this size. Economic limitations of the community must be taken into consideration, given the low incomes of the people as well as the availability of skilled laborers. To reduce the need for a costly and complex water system, the source of water must be relatively clean. The system must be inexpensive to operate, simple to construct and maintain, so the local people may sustain the system on their own.

A sustainable, clean water supply can lead to a higher quality of life through improved health and convenience. This is the aspiration for each family expected to be serviced by this system.

## Community Background

In the sixteenth century, the indigenous people of Panama struggled with the same situation the Native Americans faced here in the United States. Spanish explorers brought new diseases wiping out much of the population. Fleeing development and fearing disease they were forced to settle in the foothills of the Chiriquí Mountains. In 1972, reservations known as “comarcas” were established to protect their land from mining and development projects. The Ngöbe Bugle people are comprised of two separate ethnic-linguistic groups (the Ngöbe and the Bugle); they were granted their own Comarca in 1997. Currently, they reside in the Chiriquí Providence of western Panama in small communities clustered among lush mountains at elevations between 3280 and 5560 feet above mean sea level.

Hato Pilon is one of these communities, a political center in which a mayor presides loosely over the small family groups that comprise their social matrix. Within this community, there are local organizational groups that address agriculture, community events, and water issues. The majority of people work in subsistence farming of rice, beans, maize, and yucca on their own property. There is a primary school that attracts many students from miles around, some walking from as far as two hours away. Many young people commute to the nearby town of San Felix to attend high school or work or less commonly to David, two hours away. During the dry season (December –May) some residents travel to nearby Costa Rica to harvest coffee beans. Many women of the community make hand sewn bags known as “chakras”. They use a variety of materials including agave plants, thin strips of tree bark, or recycled plastics and market them in Hato Pilon’s central store.

## Sociology

From Cerro Peña to Cerro Mesa, there is an estimated 256 people in about 47 homes. The population growth is estimated to be 1.4% annually (Central Intelligence Agency, 2012), and the team observed a large number of youth in the community. Most of the native women have their first child before 25 years of age, and family sizes vary most commonly between 6 and 9 people. Grandparents, parents, and extended family were seen interacting amongst each other and with the children frequently, even though the traditional Ngöbe Bugle manner of living consists of smaller, more widely spaced family groups.

There are several small convenience stores, one church pavilion, one restaurant, and one bar in the center of Hato Pilon Arriba. In Hato Pilon Abajo, there is a more modern municipal building where community meetings are held. This building has a series of solar panels installed on the roof, providing enough energy for several lights and a number of electrical outlets for charging cell phones. Wood is both the primary source of energy (used as cooking fuel) and the most common building material. A typical building is comprised of a dirt floor, a palm frond or zinc corrugated roof, and semi-enclosed walls latticed by branches and rope (Figure 3).





**Figure 3 A Typical 4- 8 person home in the community of Hato Pilón. The billowing smoke is commonly seen as the homes are not designed with any type of chimneys. Photo taken by Team Hard Body**

The Peace Corps currently maintains a presence in the community of Hato Pilón Abajo and the encompassing region. While in the field, Team Hard Body was assisted by volunteers Peter and Kelli Brands, Erica Jones, and Jordan VanSickle. It is assumed that they, if not other Peace Corps volunteers, will make the necessary preparations for the project and be present for consultation during the construction. Peter and Kelli Brands began their service last spring and were assigned to the Hato Pilón region. Peter is an environmental volunteer, while his wife Kelli is working to promote sustainable practice of agriculture. Erica Jones is a Peace Corps Master’s International (PCMI) student in environmental engineering, with a specialty in surface and groundwater behavior. She is entering the second year of her assignment. Jordan VanSickle is also a PCMI Volunteer with a focus in geohydrology. They have all agreed to offer support in the procurement of funds and the logistics necessary for the initial construction and use of this water distribution system.

## Methods of Data Collection

### Topographical Surveying

Starting at the water source, the land survey was begun in order to estimate the elevation change for the proposed water supply line. The team used two Abney levels, braced at an equal height relative to the ground surface by two sticks of equal length. Angle measures were taken in each direction, foreshot and backshot, and confirmed to be within 0.4 degrees of one another. A 100 foot measuring tape was used to measure the hypotenuse distance by pulling it taught between these two points, referred to as the line of sight (Figure 4). Using this hypotenuse distance ( $h$ ) and the angle of measurement from the abney levels ( $\theta$ ), the vertical height change ( $x$ ) was calculated from the following equation:

$$x = h * \sin\theta$$

The survey extended from the spring source to the furthest reaches of the three neighborhoods to be included in the design; this took place over the course of several days. All surveying data was recorded in a waterproof notebook and later transferred to Microsoft Excel for complete analysis. Collecting survey data was the most time consuming portion of data collection, due to the necessary accuracy of final elevations and pipeline route.

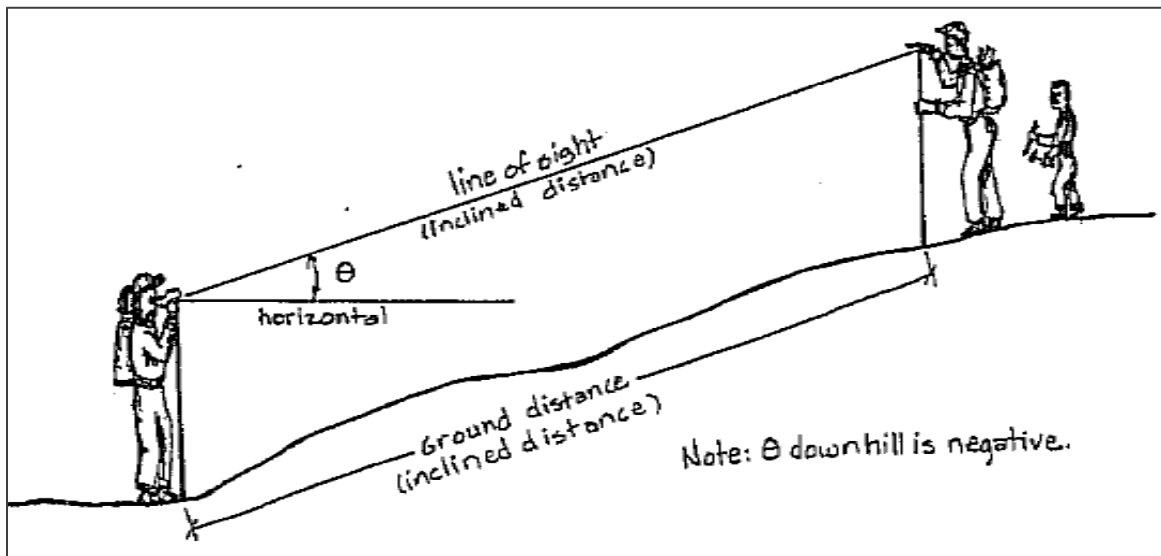


Figure 4 Example of how survey data was collected using Abney levels and tape measure (Thomas D. Jordan, 1980)

Using a handheld GPS, coordinate points were collected for each survey point and each potential tap location. The initial GPS elevation at the water source was used for the starting elevation, and the survey data was then used to calculate the elevation at each point along the route. A summary of the collected surveying data, as well as the GPS coordinates taken at each point, is shown in Appendix A. This also shows the location for every spigot, or *pluma*, designed for in the system. The GPS coordinates were plotted into Goggle Earth Pro, which shows a satellite view of our data points. This was a beneficial visual aid while considering the route of the final pipeline. Detailed images of the GPS routes plotted in Google Earth Pro are shown in Appendix B.



Figure 5 Example of the type of topography surveyed in a surveying shot. Photo taken by Team Hard Body

From the survey data, a graph showing the elevation of the main pipeline was produced and compared to the collected GPS data (Figure 6). The data in the GPS varies slightly due to atmospheric pressure changes from day to day, thus the Abney level survey data was determined to be more accurate despite the slight human error. From the survey data it can be seen that there are several peaks and valleys in the potential pipeline route. For the design, it is important that there is sufficient pressure from the source water to the storage tank to overcome the first major peak (Peak A) as well as from the tank to the end of the line to overcome the second peak (Peak B). These constraints were taken into consideration in the final design to ensure the functionality of the system.

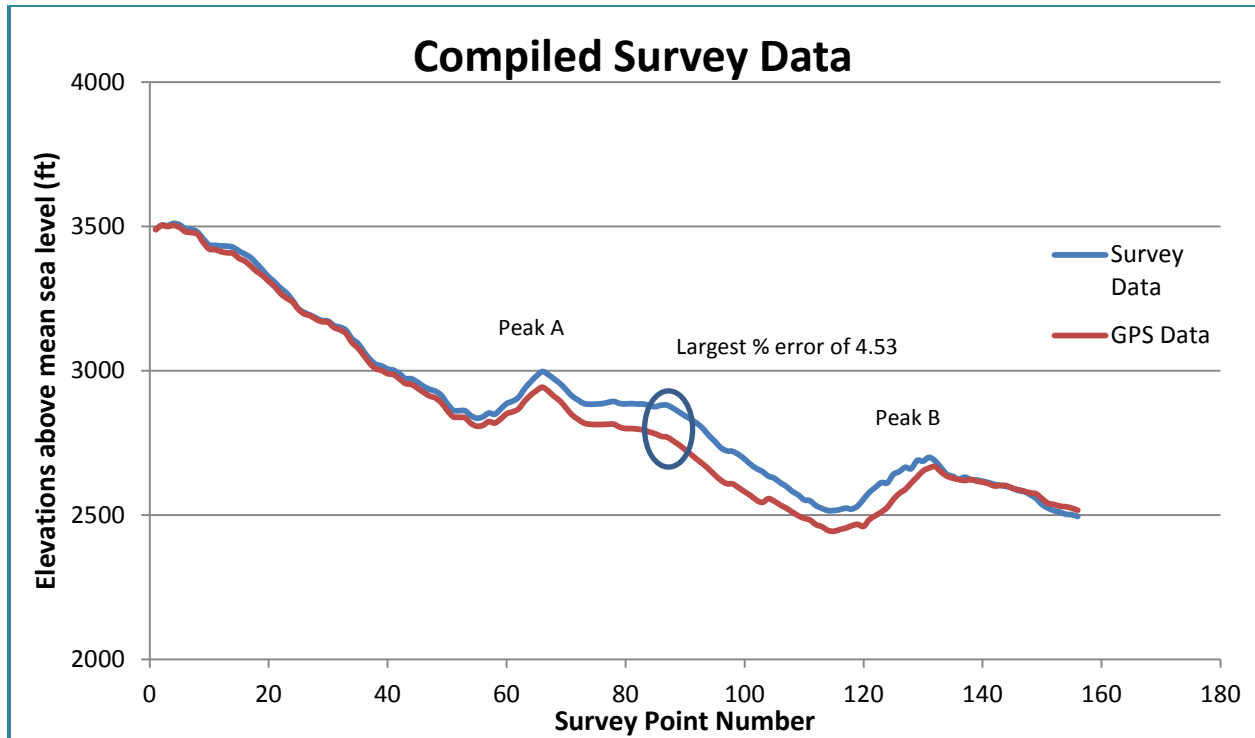


Figure 6 Elevation data along main pipeline with surveying data in blue and GPS data in red. The largest percent difference that occurs in the above data is 4.53% at point 91 marked above.

## Water Quality Testing

The identified water source flows from a rock face on the property of Emilio Quintero located 10,000 feet from the community of Cerro Peña. The spring source flows into a man-made reservoir, where the outflow is released through a pipe. Water quality samples at the spring source showed 0 *E. Coli*, 22 total coliform, and 20 colony forming units (CFU) per 100 mL of aerobic bacteria, with a turbidity of 1 -2 NTU (See Appendix C). It is important to note that the lack of controlled incubation of the count plates may have had an effect on the number of CFU's, therefore estimates should be considered with a margin of error. Apart from biological samples, the flow rate of the source water is an important factor in the design. Due to the spring source being recessed in a rock face, the outflow from the reservoir discharge pipe was used to measure flow from the source. Using a five gallon bucket and a stopwatch, the flow was measured to be approximately 24 gallons per minute (gpm).

## Current Water Usage

It is important to understand the dynamics of the community in order to design any type of development project. In order to estimate what the potential demands of this proposed system might be, population and current use data were collected from each home in the communities. The team interviewed a representative from every house asking how much water they use in a day and how many people resided in their home.

Most households stated that they used between 2 and 15 five gallon buckets of water in a day, depending on the family size. The average daily use was calculated to be about 3.5 gallons per person per day for drinking and cooking. Nearly all agreed that they did laundry and bathed directly in nearby streams and creeks. These water sources are commonly used not only by community members, but also livestock. The current use of these water sources leads to contamination and health hazards. It was also noted that several homes already have a rainwater catchment system in place, in addition to water collected from nearby sources. A summary of the survey data is shown in Appendix D.



Figure 7 Example of rain water collection noted by the team at the store in Hato Pilón

Water use data was also collected for Hato Pilón Abajo, a community with an existing water supply system. Estimates were given that each person uses one bucket a day for cleaning and hygiene, and a typical family says they use roughly 30 gallons per day in the kitchen for cooking and cleaning. There were several different answers for the current use, as can be expected given the various family sizes and lifestyle patterns. It can be assumed that once all of the residents have access to water near their homes, they will use the water for all of their necessary purposes, such as cleaning and bathing, whereas

they currently perform these tasks in the river. This assumption is based on the current use habits in the community of Hato Pilon Abajo.

## **Contingency Water Source Design**

In the event that this project is unable to be developed in the near future, Team Hard Body has compiled the following short term recommendations. These recommendations provide a temporary water solution, and can be used in conjunction with any water supply system that may be installed, at the discretion of the communities.

A possible option to supply individual families without a water source closer to their home would be to implement water catchment systems similar to that shown above (Figure 7). This is already being implemented by a few homes, as noted in Appendix C. An improved design would consist of 4" PVC pipe cut in half lengthwise to be used for gutters on the edge of the roofs. The rain water would then be funneled into collection basins, which would store water for future use. The recommended collection basin is a 50 gallon plastic drum, if they are available. Smaller five gallon buckets can also be used for collection, as they are less expensive and more readily available. Maintenance for water catchment systems would include cleaning the roof before implementation and on a biannual basis, and ensuring gutters remain clear of debris.

To ensure that the water is potable, the water from the catchment system can be treated in two different fashions. The first would be to boil the water over a fire. Due to the fact that many of the cook fires are placed inside the homes, the smoke from the fire causes additional harm to the health of the community members. Another option would be to add low doses of chlorine to the collected water.

This recommendation does not provide a long-term solution to the peoples need for accessible potable water. This should not be considered as a design alternative, and merely provides an additional idea for the utilization of available resources.

## Proposed Engineering Design

The recommended design solution is a gravity-fed water distribution system that would provide potable water to every home in the three aforementioned communities that currently lack a clean water source. The design begins at the home of Emilio Quintero, where the geology of the land is such that the faults have created geologic controls favoring the formation of a spring source that outputs approximately 24 gpm of clear water. The following engineering design was developed taking into consideration feasibility, sustainability, construction constraints, ease of maintenance, and potential environmental impacts to the region caused by diversion of the spring water.

To capture this water a general spring box constructed of masonry has been designed which includes an overflow pipe, cleaning drain and a valve to halt flow for maintenance operations on the proposed pipeline to follow. To reduce environmental impacts the diversion of water from the overflow pipe should be placed to allow for flow to continue where the stream occurs naturally. From the spring box the pipeline travels 1,870 feet to a pressure break tank. The break tank design is also suggested to be constructed of masonry. The storage tank for the water supply is designed to be located 6,506.5 feet from the pressure break tank and constructed of masonry reinforced with rebar. The tank design is a volume of 6414 gallons consisting of an overflow pipe, cleaning drain, inlet, outlet, and manhole access. In order to ensure proper treatment the water inflowing will be passed through a chlorinator for cleansing. From the storage tank, the pipeline continues 982 feet before it branches west to Cerro Peña and continues south to Hato Pilón Arriba and Cerro Mesa. In Cerro Peña a second pressure relief is suggested due to the high pressures that may occur at various valleys within the community. Along the route seven maintenance valves are suggested in the event that a pipe breaks and requires repair. In following the topography the route incurs many elevation changes that may lead to air build up in the line. Provided is a design for air relief valves that can be constructed on site and are recommended in locations of local maximum. The following sections include detail on each aspect of the design components described above while the construction details and recommendations can be found in Appendices E-J.

## Water Collection

At the spring source identified for use in the proposed engineering design, several water samples were tested and confirmed to contain zero *E. Coli*, 22 colony forming units (CFU) of total coliforms and 20 CFU of aerobic bacteria. Additional testing concluded turbidity to be less than 1 NTU. With a source as clear as this the water can be piped directly down the line without the need of a sand filter.

The water itself flows directly out of a rocky basin in a small cove. It is suggested to build the spring box directly in this cove with the overflow pipe diverting any unused water back to the stream that it forms. The spring box is designed to protect the water from sedimentation, insects, and any other type of contamination as it emerges from the rock. No foundation or rear wall is required because the water seeps up from the ground and the facing of the rock provides adequate protection from contamination before it emerges.

The design consists of two wing walls buried into the ground for stability; see Appendix E for detailed sizing and construction recommendations. A removable manhole cover allows access to the box for cleaning and maintenance as necessary. The overflow pipe allows unused water to flow back into the stream. There is a second smaller outlet where water enters the distribution line through a one inch diameter pipe.

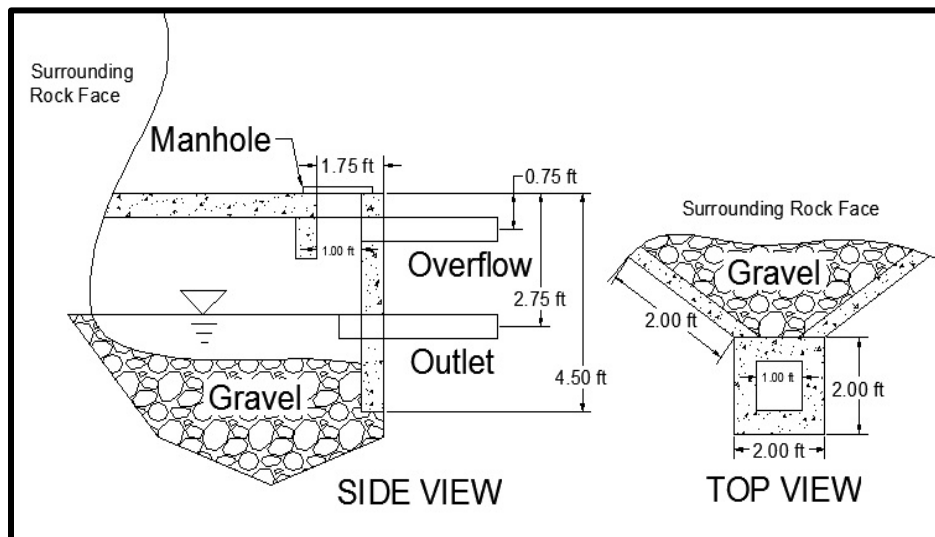


Figure 8 Proposed spring box design created by Rebecca Bender. Note that due to the clarity there is no need for a sedimentation basin or sand filter



## Pressure Break Tank

Following the spring box, 1,870 linear feet down the pipeline, is the highly recommended location of the first pressure break tank. This tank is intended to bring the water back to atmospheric pressure and the location is absolutely critical in this proposed design. If the pressure relief is to be located any lower the water will not gain the required kinetic energy on its downward descend to overcome the 1,100 foot hill that occurs before the location of the storage tank. Additional details are in Appendix L as well as in the section on EPANET hydraulic analysis. The break tank is lined with sealant to protect the structure from saturation and the component is essentially a small storage tank.

A second pressure relief is suggested to be an HDP tank, see Appendix H for detailed design. This is to be located in Cerro Peña between elevation points of 2513 and 2510 feet (Figure 9). This location will allow for adequate supply to the homes located uphill while decreasing the chance of bursting pipes downhill from this basin location.

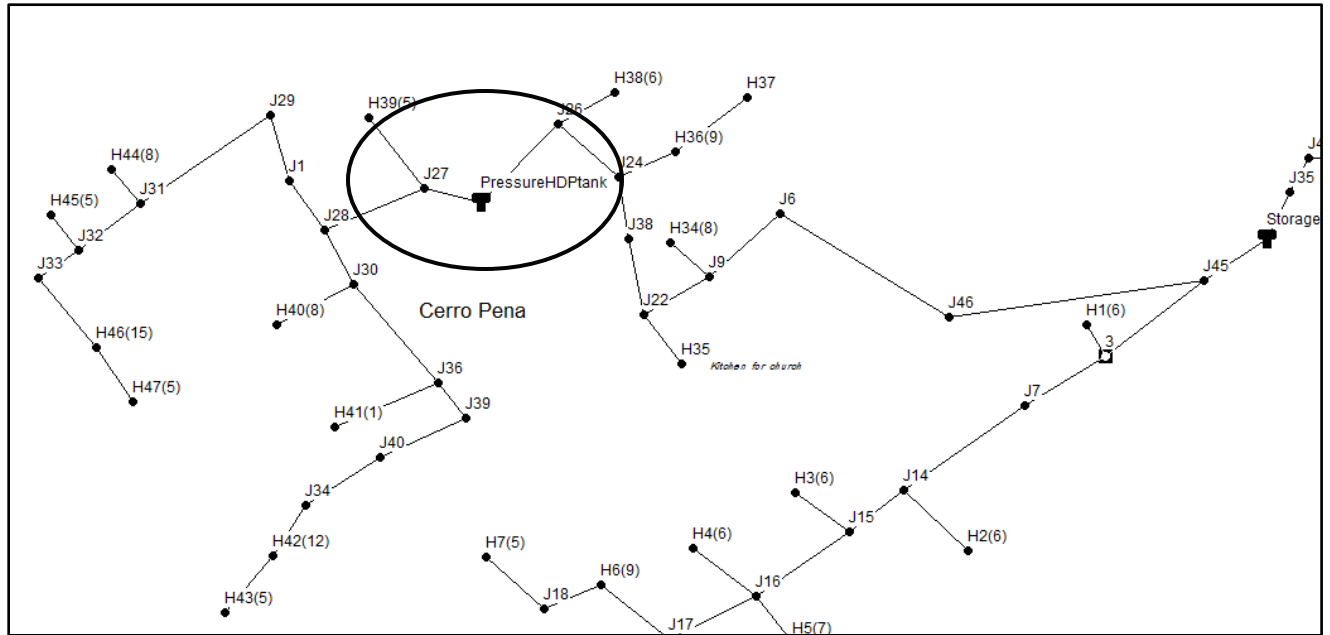


Figure 9 Proposed location of section relief basin, an HDP tank. The elevations correspond to survey data points (180-181 and 181-182) located in Appendix A.

## Water Storage Tank

The storage tank is suggested to be located 6506.5 feet from the first pressure break tank (8,476.5 feet from the spring), in order for the water to have enough head to reach all homes online. The piping at the inlet to the tank includes an expander so the pipe may go from one to four inch diameter. The expansion is to connect the chlorinator assembly that is recommended to be attached before the inlet so as to allow for the proper residence time of 50 minutes. See section on water treatment and Appendix K for further details on the chlorinator assembly. The storage tank has been designed for a capacity of 6400 gallons, allowing for enough water for a 1.4% population increase, 20 gallons day per capita (gpcd) and a peaking factor of 4.

In order to keep costs low the construction of the tank should be of a concrete foundation, and masonry walls reinforced with 3/8" rebar for internal support. A manhole is designed for on the top of the tank with a rebar ladder for entering and exiting as well as access to insert the chlorinator tablets. Two outlets are in the design, one for the water exiting to the communities and one for cleansing. Due to the high pressures that may occur in the pipeline before the tank a shutoff valve is not recommended to be installed prior to the tank entrance. To clean the tank, community members can open the drain valve located on the bottom and allow the inflow to flush the tank while scrubbing the inside. For details and recommendations on the construction and cleaning of the storage tank, as well as calculations of water consumption and estimated usage please refer to Appendix G.

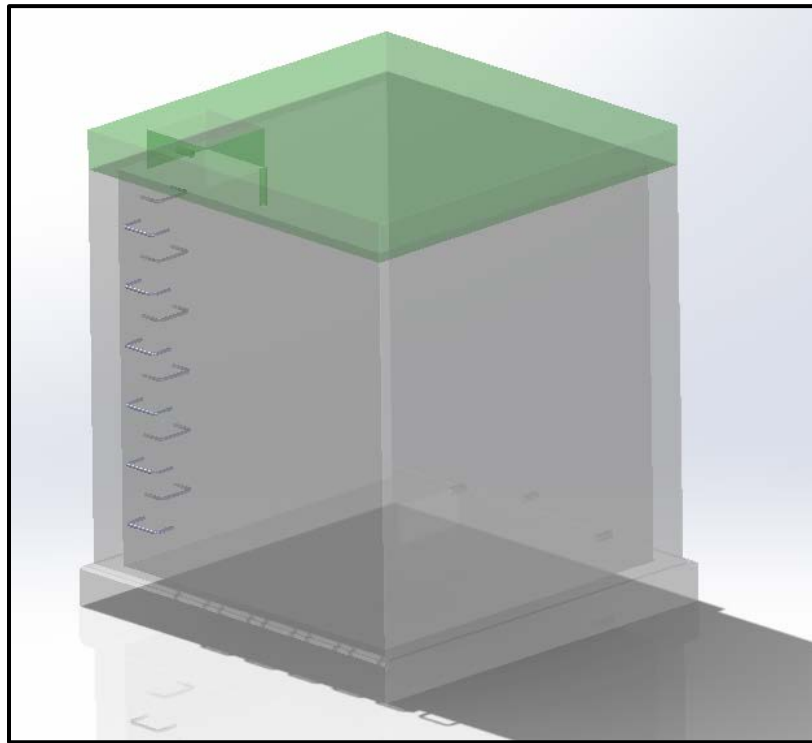


Figure 10 Conceptual model of the proposed storage tank created by Angella Mickowski

## Distribution Lines

Water exits the storage tank through a two inch diameter pipe, changing to a one inch on the branch to Cerro Peña. One of the checks made in this design was whether there would be an adequate to supply to Cerro Peña because the community is built into a hillside and some of the homes are at elevations above the main distribution line. Analysis in EPANET also showed that if the junction to Cerro Peña begins at a point higher than originally surveyed it will provide a more adequate supply to the community and decrease length of piping in the design. The suggested route is shown below (Figure 12), located at survey points 101 to 162, and details on its exact location are noted in Appendix A.

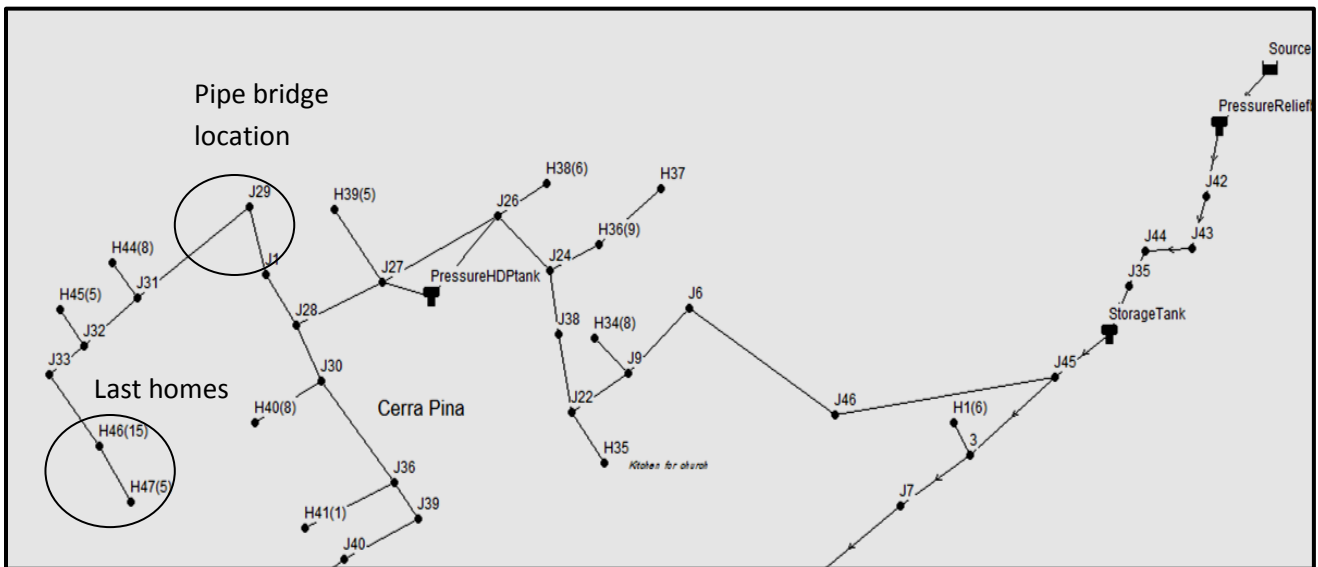


Figure 11 Conceptual layout of Cerro Peña not the junction that splits the route is higher than the original surveyed location

In Cerro Peña there is a steep ravine 80 feet across that must be overcome for the pipeline to continue to the last of the homes (shown in Figure 11 as H46 and H47). To address this challenge a cable bridge has been designed. The design is similar to one observed in Hato Pilón Abajo during data collection. Details are included in Appendix I.

From the main distribution line each branch to a home that was surveyed is designed to be one half inch pipe that distributes the clean water from a standpipe design detailed in Appendix J. The standpipe design includes a cement base that aids in reducing erosion around the faucet, and a ball valve.

Each component has been designed in order to be constructed as simple as possible, taking into consideration a wide variety of external factors that may arise during construction. Each component is scalable in volume or size and has been designed to be constructed with local materials under methods suggested by Peace Corps volunteers in the region.

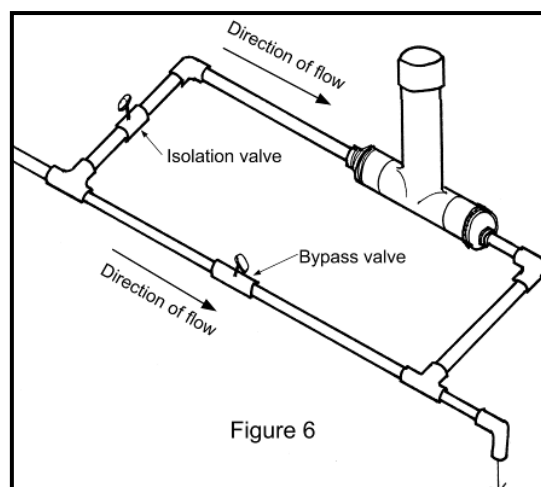


Figure 12 Courtesy of Google Earth Pro. Topographical layout of the suggested shortcut to Cerro Peña in order to provide adequate supply, and reduce piping cost.

## Water Treatment

One of the more important aspects of designing a system to deliver drinking water is the biological quality. Due to the presence of aerobic bacteria and total coliforms a chlorinator is highly recommended for this system. It is important to note that total coliforms are not the same as fecal coliforms. Total coliforms are a collection of different types of bacteria, they occur, along with aerobic bacteria, naturally in the environment. Generally they are harmless but if total coliforms can enter a water supply it is likely that pathogens can enter as well.

Team Hard Body has researched an inexpensive in-line chlorinator that can be assembled in the field and requires little maintenance after implementation. It is called the CTI 8 Chlorinator designed by Fred Jacobs and Charles Taflin of Compatible Technologies International (CTI), a non-profit non-governmental (NGO) headquartered in St. Paul, Minnesota (Figure 13). The estimated cost of this particular chlorinator assembly is approximately \$64 minus the chlorine tablets which run around \$10 a month. The assembly price is based on prices obtained at the general store in San Felix. The full chlorinator maintenance and assembly manual can be found in Appendix K.



**Figure 13** In-line chlorinator design courtesy of Compatible Technology International (CTI). There is an isolation valve to allow for adjustment of concentration.

Placement of the chlorinator is essential to proper disinfection of the water. It is recommended to be placed at the inlet to the storage tank away from human and animal interactions. Placement before the storage tank will provide for a residence time of over approximately over 11 hours<sup>1</sup>, well above the recommended 50 minutes from CTI. Upon implantation of the chlorinator, the outlet water must be tested to ensure the proper concentration of chlorine is being delivered. The United States Environmental Protection Agency (USEPA) approved “SenSafe-Free Chlorine Water Check” test strips from Industrial Test Systems, Inc. are recommended and may be purchased online through [www.sensafe.com](http://www.sensafe.com). A box of 50 strips costs \$17.99 and each strip takes 40 second to complete testing.

<sup>1</sup> Due to the predicted unsteady flowrate exiting the tank, this residence time is approximate.

## EPANET Hydraulics Analysis

After survey data was brought back to the United States it was put into EPANET, a public-domain program available online through the USEPA. EPANET models hydraulic flow and water quality throughout a piping system.

To study pressure extremes, the model was first run under a scenario that all taps are closed and no water is exiting the system (simulated as zero demand in EPANET). This scenario, while unlikely, is one in which the highest pressure within the pipes would occur. Figure 14 below shows the pressures calculated from EPANET along the surveyed path, they are also available in Appendix L. The first pressure relief is a pressure break tank with a suggested location of 1,870 feet downstream from the spring source. This is to relieve high pressures developed during the initial pipeline descent, while still allowing enough energy to overcome uphill climbs that occur later in the path. The second pressure relief is designed to be located in Cerro Peña, where a very steep elevation decline could otherwise lead to very high pressure. For detailed design of the HDP pressure break tank and suggested construction refer to Appendix H.

EPANET also utilized in determining the change in pressures in the system throughout the day based on expected water demand or usage. Utilizing the design goal of 20 gdpc over a period of 18 hours with variance dependent upon on the number of residents in each home, an estimate of a demand per minute can be calculated. Please see Appendix M for equations and tabulated demand data. Inputting these values into the model indicates that with a tank of only 6400 gallons, there would not be a sufficient volume of water stored if every home leaves their tap open and allows water to flow continuously. Based on observations made of abandoned leaking taps in Hato Pilón Abajo, there are system recommendations to discourage this from happening.

While the modeling software provides a quick and effective measure of whether this type of system is plausible, it does have its limitations and one needs to understand the calculations behind the answers. Team Hard Body has done a parallel analysis by hand using Bernoulli's equations confirming the results from EPANET. The software can be used to model real-life systems but do not take into account every aspect in a system. It is simply a tool to develop a broader understanding of the hydraulics behind water flow through a pipe and spot any potential oversights early on. One of the more important aspects the model does not account for is the minor friction losses due to joints, valves, and couplings. The model also did not account for transient flow as in valves opening and closing. Additions of these friction losses will lead to decreased pressures than what is reported. Even with the additional losses not account for the estimated results are still credible and are able to be applied to a real-life system because the design by Team Hard Body takes into account a safety factor on the pipeline pressure. The design allows for no pressure to be within 10% of the maximum pipe allowance.

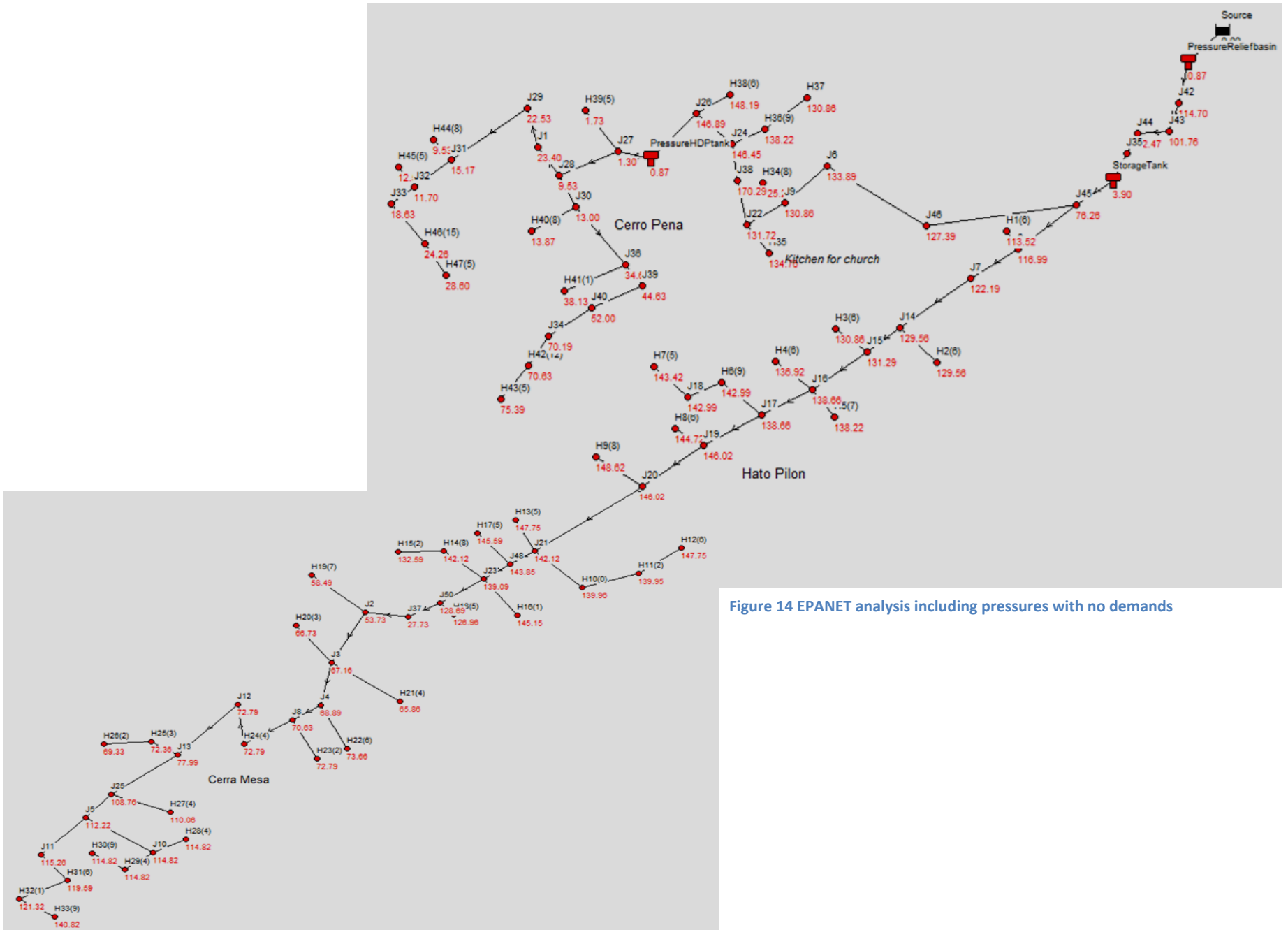


Figure 14 EPANET analysis including pressures with no demands

## Piping System

A major component of the system is the distribution network carrying the water from the source, to the storage basin, and distributing it to each home throughout the communities. There are many considerations and design constraints that must be accounted for to ensure the success of the pipe network. A complete list of recommendations is included in Appendix N. These recommendations are specific to this design and to ensure it functions at its best they should be followed.

From the survey data, it was determined that approximately 20,000 ft of pipe is required for this design. The exact locations of storage tank and pressure relief structures that have been recommended should be followed, as specific pressure calculations were performed to determine these locations. The pressure of the entire system as a whole is dependent upon the elevation location for these structures, and moving them may result in an increase in pressure that may lead to pipe failure or a decrease resulting in some homes receiving no water.

In order to decrease the cost of piping, the path for the pipeline should follow the collected GPS data but take shortcuts as deemed appropriate. The route should be developed allowing for accessibility and maintenance of the system, also taking into consideration ease of installation. Due to length of the pipeline, a skilled laborer should oversee the implementation of the system to ensure that it is correctly assembled. Incorrectly assembled pipes and valves can lead to failure in the system, increase in friction losses and may lead to unnecessary expenses. The connections between the pipe segments may be adjusted to the desired angle by thermoforming; heating the pipe and molding it. For any direction changes greater than 45 degrees a joint should be used. Pipeline should be buried 2-3 feet below ground, to minimize the possibility of damage due to sunlight and foot traffic. Any exposed pipe that must be laid above ground should be coated with a UV resistant paint to prevent degradation.

When implementing a gravity fed system, it is important to evaluate the pressure in the pipeline along the entire system. Pressures will build up as the pipe moves downhill, and decrease as it moves uphill. Fortunately, the topography allows for sufficient pressures that will distribute the water over the whole terrain, and a mechanical pump is not necessary in this design. Pressure relief basins are installed to relieve the buildup of high pressures, as previously described. However, there are still locations in the system with significantly high pressure, as detailed in the EPANET analysis in Appendix L. Due to these high pressures, pipe schedule is crucial in the design. The main pipeline must consist of at least an SDR 26 pipe, withstanding up to 160 PSI. Whereas the branch that extends towards Cerro Peña must use SDR 21 or SCH 40 pipe, withstanding pressures up to 250 PSI. Even with the HDP relief, there is a location with pressure above 160 PSI, but it is suggested this pressure remain or the water will not be able to ascend the hills in the community. Therefore a higher schedule at a smaller diameter is suggested for use that will also reduce cost. A diagram detailing what type of pipe should be selected for each part of the system is shown in Figure 15.



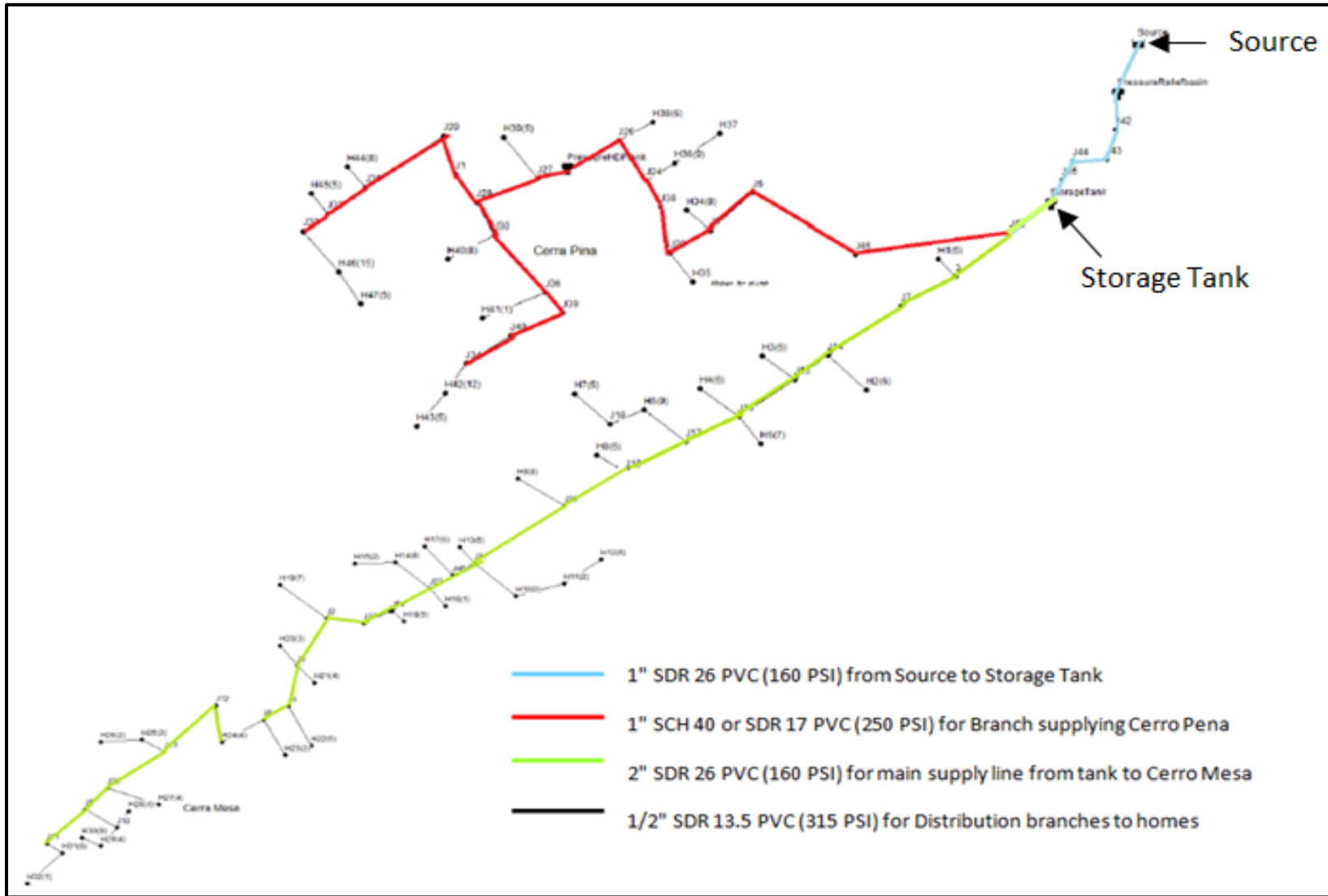


Figure 15 Map of water distribution line indicating pipe size and strength for each section. Using one inch pipe in Cerro Pena reduces cost and allows for higher pressures

Another design consideration is the location of maintenance and air release valves. Due to the varying elevations along the route, it is necessary to install air release devices throughout the line. A buildup of air in the system can lead to blockages, which may prevent the supply of water. Any high points must be fitted with air release valves, to ensure that any trapped air will have an escape. Team Hard Body recommends a design that can be built in the field and is cost effective. Detailed design of the air relief valves can be found in Appendix O.

Maintenance valves are essential in any design to halt the flow to certain areas of the system in the event that a repair needs to be done. It is recommended that valves are placed directly after the spring box, immediately before the pressure relief basins, directly after the storage tank, one on each branch after the pipe splits towards Cerro Peña, and also as the pipeline enters Cerro Mesa. As mentioned in the proposed design, it is not recommended to place valves before the storage tank due to the possibility of pressure increasing above the pipeline allowance. These recommendations are made keeping in mind the possibility of water hammer, as these locations will not exceed the maximum pressure of the pipe if the valve is instantaneously closed. To avoid the effects of water hammer, it is recommended that at any time these valves are closed, it is done so over a period of ten seconds. The type of valve accounted for in the cost estimate is a standard ball valve.

Each branch off of the mainline to a home is recommended to be of 1/2" diameter PVC, as these lines do not require as much flow as the main 2" distribution line. Flow reducers should also be placed on each of these 1/2" branches to limit the supply in the case that a spigot is left open or bursts. Flow reducers also keep one spigot from using a large quantity of water diminishing the supply to homes further down the line. The spigots should protrude above ground, on a concrete base to prevent erosion, and be supported with a metal or wooden post. For a complete guide of recommendations for the installation of the pipe network, including the aforementioned constraints, please see Appendix N.

## Cost Estimate

One of the most universally limiting constraints in development projects is a constrictive budget. In past projects, the municipal government has granted funds to the Ngöbe people and provided professional support for infrastructure development. This project has not been allotted any funding, so the budget and construction schedule have been prepared with the utmost frugality. The cost estimate for each system component is included in Appendix R while a summarized version is included in table one below.

Regardless of whatever sources of funding might arise, the budget currently presumes that the unskilled labor will be an in-kind service, one of several ways for the community to invest in their water project. The skilled labor is currently estimated at a wage of \$3.50 per hour, which amounts to \$28 per eight hour workday. For small masonry projects, it was assumed that one professional could work with one Peace Corps volunteer. For larger building projects, one skilled worker could lead a team of three other people. For the largest labor crews, those laying the pipeline, one skilled leader can be responsible for a team of five volunteers. Material costs and labor costs were calculated independently to allow for appropriate reconfiguration as more design restraints and project opportunities arise.

Table 1 Cost estimates for each component in the proposed design

Structure	Component	Cost
<b>Spring Box</b>	Materials	\$121
	Skilled Labor	\$84
	Unskilled Labor	\$0
	<b>Spring Box Total</b>	<b>\$205</b>
<b>Main Pipeline</b>	Materials	\$4,552
	Skilled Labor	\$388
	Unskilled Labor	\$0
	<b>Main Pipeline Total</b>	<b>\$4,940</b>
<b>Pressure Break Tank</b>	Materials	\$84
	Skilled Labor	\$15
	Unskilled Labor	\$0
	<b>Pressure Break Total</b>	<b>\$99</b>
<b>Storage Tank</b>	Materials	\$745
	Skilled Labor	\$388
	Unskilled Labor	\$0
	<b>Storage Tank Total</b>	<b>\$1,133</b>
<b>HDP Pressure Relief</b>	Materials	\$103
	Skilled Labor	\$30
	Unskilled Labor	\$0
	<b>HDP Relief Total</b>	<b>\$133</b>
<b>Distribution Branches</b>	Materials	\$1,933
	Skilled Labor	\$336
	Unskilled Labor	\$0
	<b>Distribution Total</b>	<b>\$2,269</b>
<b>In-Line Chlorinator</b>	Materials	\$64
	Skilled Labor	\$10
	Unskilled Labor	\$0
	<b>Chlorinator Total</b>	<b>\$74</b>
<b>Air Release Valves</b>	Materials	\$364
	Skilled Labor	\$2
	Unskilled Labor	\$0
	<b>Air Release Total</b>	<b>\$367</b>
<b>Total</b>	Materials	\$7,965
	Skilled Labor	\$1,254
	Unskilled Labor	\$0
	<b>All included</b>	<b>\$9,219</b>

## Construction Schedule

The construction schedule is based on estimated man hours and of practical construction knowledge. The construction begins at the most remote extreme, the spring box. After the construction crew develops knowledge of the construction style, the storage tank should be started as it is the largest masonry structure in the whole design. Because of its tremendous weight, the slab should be given a week to cure before the bricks are placed.

While the storage tank is being built by one professional and a team of three other volunteers, another professional and a team of five can begin digging the trench and laying down the pipeline. The trench is recommended to be 2-3 ft deep, and because of the challenging terrain, this time estimate doubles the calculated number of man-hours.

The masonry team can begin on the smaller pressure basin and HDP break tank components while the pipeline team continues working. The distribution lines are the last elements to be installed both for practical reasons, and because the community enthusiasm and participation in the project may be maintained throughout the entirety. Below is a condensed overview of the proposed design schedule, while a more detailed version is available in Appendix S.

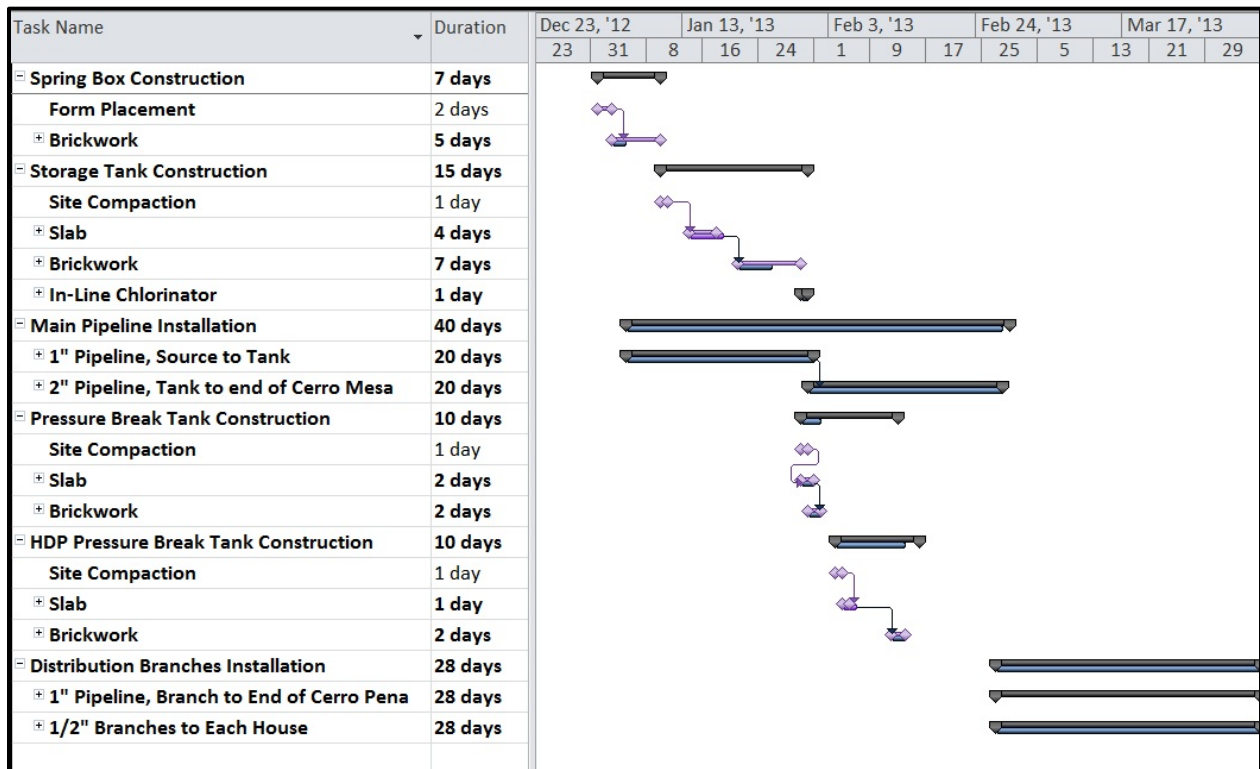


Figure 16 Condensed view of construction schedule created by Rebecca Bender.

## Environmental Impact

In order to reduce any possible environmental degradation that may occur during use and construction, Team Hard Body has developed recommendations. The largest possible impact is the diversion of water from the stream; the overflow is suggested to be diverted back to the nearest stream of river to preserve the available resources. The second potential impact is to the land. When digging to bury pipeline, restoration of the land back to original if not improved state should be done. If the land is not compacted back it is likely erosion of the soil will occur putting the pipeline at risk. As the overflow from the storage tank will be chlorinated water it should be confirmed, not only for the people but the environment that the chlorine level is not above 5 mg /L. High chlorine concentrations can destroy crops if the water is allowed to run uncontrolled, and can be hazardous to human and animal health. Any overflow is highly suggested to be diverted to the nearest source of naturally occurring water except water that has been chlorinated. Overflow of chlorinated water should be collected into a barrel for use in the dry season or for those unable to be online with the system.

It is unclear whether a development project within indigenous regions is subject to the general environmental law of Panama. In the case that it is, an environmental impact assessment has been completed and is included in Appendix T. The regulation that was utilized for this assessment was the general environmental law of Panama executive decrees number 123 and 155. The assessment has been completed based on the general knowledge obtained while in the communities for one week and is subject to variability. Regulations should be further confirmed and researched.

## Conclusion

Part of the nature of infrastructure development projects is that there is no end to what can be added, moved, adapted, or readjusted. Even as this design proposal comes to a close, there is no limit to what Team Hard Body could continue to reassess, and its submission is only the beginning of the evaluation process for those in the Hato Pilon region.

To have clean water brought to each home was the design challenge, and to make that design feasible, it is most important that the system is comprehensive, taking into consideration every aspect of human use, the local topography, the availability of materials, and the limited technical knowledge and financial ability of the residents.

The engineering feasibility is the first task that Team Hard Body considered in this design. Given the topographical data, the volumetric flow of the spring source, and the resilience of materials, the design is focused in many ways on the physical constraints of head loss, and water pressure. The structures within the design are scaled to accommodate adequate water collection at the spring box, enough storage for the people's needs, and simple but effective means of relieving air and water pressure.

A great part of this design, however, is focused on the sustainability of the system. All system components are intended to be easily understood by a diverse audience. The maintenance, which includes periodic chlorine tablet replacement, occasional sediment removal from tanks, and valve checks, is both minimal and simple, with the intention that the local water committee and its constituents can easily maintain the distribution lines for years to come.

What this report comprises is the best estimate of how the communities in Cerro Mesa, Cerro Peña and Hato Pilon can all come to enjoy the benefits of clean water, year-round. From spring box to spigot, and from pressure relief to flowrates, this collection of data, estimation, analysis, and recommendations is Team Hard Body's best design, and it is submitted to Michigan Technological University through the iDesign program with our thanks and our hopes.

## Acknowledgements

### Pete and Kelly Brands

To the fabulous couple who introduced us to the locals, showed us around every neighborhood, arranged for every meal, stood with us in the rain, and entertained us with stories and card games deep into the Panamanian night, we give our sincerest thanks and our warmest good wishes.



### Erica Jones

A comrade from our own university and a sage resource for all of our engineering and Peace Corps methodology questions, Erica Jones proved to be a charismatic, intelligent, dedicated, indispensable mentor and friend. Her wisdom and practicality were invaluable during our data collection and we are eager to see them applied to her graduate work and career.



Jordan VanSickle

During his brief stay with us, Jordan's zeal and sharp intellect proved a valuable resource from an analytical and a social aspect. As a relatively new Peace Corps volunteer in the comarca region, Jordan's stay is bound to be a legendary one, and we wish for him all the best.



Dr. David Watkins (P.E.), Mike Drewyor (P.E.) and Dr. Brian Barkdoll (P.E.)

While international design implies a strong intent to look outside one's borders, this project would have been impossible to complete without the guidance of our human resources at Michigan Technological University. Mike Drewyor's leadership and project experience during and after our trip was much appreciated and gave a certain air of possibility even in times of trial. Dr. Brian Barkdoll, as well, lent a steady assistance that made our modeling comprehensible and our thought process comprehensive. His understanding of rural development and learning methods was a gracious presence.

The single most tremendous thank you is owed to Dr. David Watkins for his infinite patience and unwavering energy for iDesign at Michigan Tech. He consistently offered consultation and guidance in what were often very uncertain times, and in a persistently good-natured manner, exemplified the international development ideals that we have come to know.

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## Appendix A: Collected survey data and GPS locations

Table 1. List of collected survey data points and corresponding GPS locations. Average elevation change is calculated from Abney level surveying shots, and used to calculate the total elevation. Locations highlighted in blue indicate a location for a spigot, and items highlighted in red indicate a major point of construction along the pipeline.

GPS Point	Distance Between Points (ft)	Compass Reading	Average Elevation Change (ft)	Calculated Survey Elevation	GPS Coordinates	Notes
1				3490.0	N8 25.146 W81 51.319	Source of Water
2	74	15 NoE	14.18	3504.2	N8 25.136 W81 51.319	
3	74	14 WoN	-1.29	3502.9	N8 25.122 W81 51.318	
4	58	20 WoS	7.82	3510.7	N8 25.113 W81 51.322	
5	100	60 WoS	-4.36	3506.4	N8 25.105 W81 51.335	
6	100	66 WoS	-14.35	3492.0	N8 25.096 W81 51.349	
7	100	75 WoS	-2.36	3489.6	N8 25.091 W81 51.364	
8	64	78 WoS	-8.08	3481.6	N8 25.087 W81 51.374	
9	100	83 WoS	-24.19	3457.4	N8 25.084 W81 51.391	
10	100	90 WoS	-21.22	3436.2	N8 25.083 W81 51.406	
11	100	82 WoS	-1.31	3434.9	N8 25.077 W81 51.422	
12	100	58 WoS	-2.18	3432.7	N8 25.070 W81 51.438	
13	100	82 WoS	-0.61	3432.1	N8 25.065 W81 51.453	
14	100	84 WoS	-3.93	3428.1	N8 25.063 W81 51.471	
15	100	4 NoW	-12.62	3415.5	N8 25.063 W81 51.487	
16	100	4 NoW	-11.32	3404.2	N8 25.065 W81 51.503	
17	100	0 NoW	-12.19	3392.0	N8 25.066 W81 51.520	
18	100	83 WoN	-21.22	3370.8	N8 25.069 W81 51.536	
19	100	87 WoN	-22.07	3348.7	N8 25.071 W81 51.551	
20	100	(-)w	-23.34	3325.4	N8 25.066 W81 51.568	
21	100	5 WoS	-17.79	3307.6	N8 25.056 W81 51.579	Pressure Break Tank
22	100	65 E Os	-21.05	3286.5	N8 25.047 W81 51.567	
23	100	70 EoS	-16.93	3269.6	N8 25.039 W81 51.553	
24	100	57 EoS	-25.04	3244.6	N8 25.024 W81 51.540	
25	100	63 EoS	-29.24	3215.3	N8 25.019 W81 51.525	
26	100	52 WoS	-13.48	3201.8	N8 25.009 W81 51.537	
27	100	50 WoS	-8.72	3193.1	N8 24.998 W81 51.550	
28	100	26 WoS	-10.45	3182.7	N8 24.988 W81 51.563	
29	100	62 WoS	-8.72	3174.0	N8 24.982 W81 51.576	
30	100	85 WoS	-1.75	3172.2	N8 24.980 W81 51.594	
31	100	73 WoS	-15.64	3156.6	N8 24.983 W81 51.610	
32	100	53 WoS	-5.23	3151.3	N8 24.974 W81 51.625	
33	100	83 WoS	-10.63	3140.7	N8 24.972 W81 51.640	
34	87	(-) W	-29.68	3111.0	N8 24.971 W81 51.654	
35	32.5	74 WoS	-15.88	3095.1	N8 24.969 W81 51.659	
36	100	10 EoS	-28.82	3066.3	N8 24.951 W81 51.662	
37	100	85 WoS	-25.88	3040.4	N8 24.955 W81 51.678	
38	100	67 WoS	-17.79	3022.6	N8 24.949 W81 51.693	
39	46	66 WoS	-5.61	3017.0	N8 24.946 W81 51.700	
40	100	(-)W	-10.89	3006.2	N8 24.945 W81 51.717	
41	71.5	64 WoS	-4.12	3002.0	N8 24.942 W81 51.728	
42	65.5	50 WoS	-12.22	2989.8	N8 24.929 W81 51.739	
43	100	84 WoS	-16.93	2972.9	N8 24.932 W81 51.753	
44	100	18 WoS	-0.52	2972.4	N8 24.917 W81 51.760	

45	75	18 WoS	-11.67	2960.7	N8 24.906 W81 51.769	
46	70	45 WoS	-14.02	2946.7	N8 24.897 W81 51.774	
47	100	55 WoS	-10.45	2936.2	N8 24.888 W81 51.786	
48	64	33 WoS	-6.69	2929.5	N8 24.880 W81 51.796	
49	100	(-)S	-13.92	2915.6	N8 24.863 W81 51.794	
50	100	62 WoS	-28.82	2886.8	N8 24.858 W81 51.810	
51	67	82 WoS	-23.03	2863.8	N8 24.855 W81 51.820	
52	100	20 WoS	-2.18	2861.6	N8 24.840 W81 51.824	
53	78	(-)S	0.00	2861.6	N8 24.828 W81 51.823	
54	78	6 EoS	-16.88	2844.7	N8 24.816 W81 51.824	
55	100	43 WoS	-9.06	2835.6	N8 24.804 W81 51.836	
56	100	72 WoS	4.80	2840.4	N8 24.798 W81 51.852	
57	72	72 WoS	13.12	2853.6	N8 24.793 W81 51.862	Possible Air Release Valve Location
58	100	70 WoS	-4.10	2849.5	N8 24.789 W81 51.877	
59	100	60 WoS	18.22	2867.7	N8 24.781 W81 51.894	
60	100	70 WoS	18.65	2886.3	N8 24.773 W81 51.910	
61	100	74 WoS	8.37	2894.7	N8 24.768 W81 51.924	
62	100	66 WoS	13.23	2907.9	N8 24.762 W81 51.938	
63	100	48 WoS	29.40	2937.3	N8 24.750 W81 51.950	
64	100	50 WoS	23.43	2960.8	N8 24.742 W81 51.964	
65	100	40 WoS	20.79	2981.6	N8 24.730 W81 51.975	
66	100	32 WoS	15.82	2997.4	N8 24.717 W81 51.983	Possible Air Release Valve Location
67	100	34 WoS	-10.45	2986.9	N8 24.704 W81 51.994	
68	100	50 WoS	-15.47	2971.5	N8 24.692 W81 52.006	
69	100	45 WoS	-16.07	2955.4	N8 24.680 W81 52.018	
70	100	32 WoS	-20.88	2934.5	N8 24.669 W81 52.024	
71	100	34 WoS	-22.15	2912.3	N8 24.654 W81 52.035	
72	100	40 WoS	-13.48	2898.9	N8 24.639 W81 52.046	
73	100	35 WoS	-12.19	2886.7	N8 24.627 W81 52.057	
74	100	40 WoS	-2.62	2884.1	N8 24.617 W81 52.070	
75	100	56 WoS	0.87	2884.9	N8 24.607 W81 52.082	
76	100	51 WoS	1.13	2886.1	N8 24.597 W81 52.096	
77	100	35 WoS	4.36	2890.4	N8 24.587 W81 52.106	
78	100	43 WoS	3.49	2893.9	N8 24.572 W81 52.118	Possible Air Release Valve Location
79	100	60 WoS	-6.98	2886.9	N8 24.564 W81 52.132	
80	100	74 WoS	-1.83	2885.1	N8 24.560 W81 52.148	
81	100	(-)W	1.31	2886.4	N8 24.558 W81 52.165	
82	100	(-)W	-1.57	2884.8	N8 24.558 W81 52.181	
83	100	78 WoS	0.00	2884.8	N8 24.556 W81 52.197	
84	100	60 WoS	-5.23	2879.6	N8 24.548 W81 52.213	
85	100	60 WoS	-3.93	2875.7	N8 24.541 W81 52.226	
86	100	55 WoS	5.23	2880.9	N8 24.530 W81 52.240	
87	100	58 WoS	-0.17	2880.7	N8 24.524 W81 52.254	
88	100	52 WoS	-10.63	2870.1	N8 24.516 W81 52.268	
89	100	50 WoS	-13.05	2857.1	N8 24.504 W81 52.280	
90	100	43 WoS	-13.48	2843.6	N8 24.490 W81 52.289	Storage Tank
91	100	25 WoS	-11.67	2831.9	N8 24.476 W81 52.300	
92	100	(-)S	-14.09	2817.8	N8 24.461 W81 52.300	Short cut trail
93	100	5 EoS	-17.88	2799.9	N8 24.445 W81 52.300	
94	100	10 WoS	-24.19	2775.8	N8 24.429 W81 52.303	
95	82	(-)S	-20.18	2755.6	N8 24.416 W81 52.306	
96	100	15 WoS	-22.07	2733.5	N8 24.402 W81 52.313	
97	100	25 WoS	-10.80	2722.7	N8 24.387 W81 52.319	

98	100	23 WoS	-1.92	2720.8	N8 24.373 W81 52.327	
99	100	20 WoS	-11.06	2709.7	N8 24.355 W81 52.330	
100	100	11 WoS	-15.38	2694.3	N8 24.340 W81 52.332	
101	100	1 EoS	-18.40	2675.9	N8 24.323 W81 52.333	Potential Branch to Cerro Pena
102	100	52 EoS	-14.78	2661.2	N8 24.313 W81 52.320	
103	100	60 EoS	-10.02	2651.1	N8 24.305 W81 52.306	
104	100	32 WoS	-16.07	2635.1	N8 24.291 W81 52.314	
105	100	30 WoS	-7.15	2627.9	N8 24.278 W81 52.325	
106	100	10 WoS	-15.82	2612.1	N8 24.261 W81 52.326	
107	100	13 WoS	-12.36	2599.7	N8 24.245 W81 52.329	
108	100	38 WoS	-17.36	2582.4	N8 24.231 W81 52.338	
H01 HP	29	50 WoN	8.53	2590.9	N8 24.235 W81 52.341	Hato Pilon Arriba House 1
109	64	28 WoS	-12.32	2570.1	N8 24.222 W81 52.342	Path to Cerro Pena
110	100	25 EoS	-16.93	2553.1	N8 24.210 W81 52.338	
H02 HP	69	80 EoS	0.00	2553.1	N8 24.208 W81 52.325	Hato Pilon Arriba House 2
111	33	25 EoS	-3.59	2549.5	N8 24.202 W81 52.336	
H03 HP	73	65 WoS	1.27	2550.8	N8 24.199 W81 52.347	Hato Pilon Arriba House 3
112	96	15 EoS	-16.84	2532.7	N8 24.188 W81 52.332	
H04 HP	65.5	5 NoW	4.28	2537.0	N8 24.186 W81 52.344	Hato Pilon Arriba House 4
H05 HP	46	65 EoS	0.60	2533.3	N8 24.184 W81 52.326	Hato Pilon Arriba House 5
113	78	20 EoS	-9.30	2523.4	N8 24.174 W81 52.332	
H06 HP	85	15 SoW	-1.11	2522.3	N8 24.175 W81 52.345	Hato Pilon Arriba House 6
H07 HP	60	10 NoW	-0.31	2522.0	N8 24.173 W81 52.353	Hato Pilon Arriba House 7
114	77	10 EoS	-7.71	2515.7	N8 24.162 W81 52.329	
H08 HP	58	75 WoS	3.14	2518.8	N8 24.158 W81 52.338	Hato Pilon Arriba House 8
115	100	S	0.00	2515.7	N8 24.144 W81 52.331	
H09 HP	86	W	-6.52	2509.2	N8 24.145 W81 52.346	Hato Pilon Arriba House 9
116	100	30 WoS	3.40	2519.1	N8 24.129 W81 52.336	
117	71	10 WoS	4.95	2524.0	N8 24.117 W81 52.337	
H10-12 HP	35	W	5.60	2529.6	N8 24.119 W81 52.332	Restaurant and two homes, 3 spigots 10 feet apart
H13 HP	67	80 WoS	-12.09	2511.9	N8 24.115 W81 52.349	Hato Pilon Arriba House 13
118	100	5 EoS	-3.05	2521.0	N8 24.100 W81 52.333	Path towards Hato Pilon Abajo
119	83	20 EoS	10.19	2531.2	N8 24.087 W81 52.330	
H14 HP	62	50 WoS	-6.21	2525.0	N8 24.080 W81 52.335	Hato Pilon Arriba House 14
H15 HP	100	S	21.64	2546.6	N8 24.063 W81 52.337	Hato Pilon Arriba House 15
H16 HP	85	35 EoS	-13.59	2517.6	N8 24.100 W81 52.323	Hato Pilon Arriba House 16
H17 HP	47.5	70 WoS	-4.76	2516.2	N8 24.097 W81 52.344	Tienda
120	100	20 EoS	24.19	2555.4	N8 24.075 W81 52.324	
H18 HP	38	74 EoS	3.64	2559.0	N8 24.073 W81 52.319	Hato Pilon Arriba House 18
121	100	N	23.77	2579.1	N8 24.058 W81 52.322	
122	100	30 EoS	17.11	2596.2	N8 24.043 W81 52.327	
123	100	20 EoS	16.33	2595.5	N8 24.027 W81 52.331	
124	100	20 EoS	16.25	2611.7	N8 24.013 W81 52.338	
125	100	21 EoS	29.32	2624.8	N8 23.997 W81 52.343	
126	100	22 EoS	25.97	2650.7	N8 23.981 W81 52.348	
127	100	S	14.95	2639.7	N8 23.967 W81 52.345	
128	100	30WoN	21.13	2660.9	N8 23.953 W81 52.335	
129	100	20 EoS	28.40	2668.1	N8 23.937 W81 52.338	
130	100	2 EoS	19.00	2687.1	N8 23.921 W81 52.340	
131	100	2 WoN	12.62	2680.8	N8 23.905 W81 52.339	
132	100	10WoN	7.85	2688.6	N8 23.890 W81 52.335	Top of Hill Towards Cerro Mesa, Possible Air Release Valve Location
133	100	55 WoN	-24.02	2656.7	N8 23.879 W81 52.320	
134	100	65 WoN	-15.30	2641.4	N8 23.874 W81 52.308	

135	100	53	WoN	-6.98	2634.5	N8 23.863 W81 52.294	
136	100	40	WoN	-10.02	2624.4	N8 23.849 W81 52.284	
137	47	35	WoN	-2.95	2631.5	N8 23.847 W81 52.277	
H01 CM	99	50	EoN	-10.86	2620.6	N8 23.831 W81 52.289	Cerro Mesa House 1
138	100	40	WoN	-8.19	2623.3	N8 23.831 W81 52.268	
139	100	40	WoN	-1.66	2621.7	N8 23.820 W81 52.257	
140	100	5	WoN	-5.84	2617.5	N8 23.802 W81 52.256	
141	100	2	EoN	-4.80	2612.7	N8 23.785 W81 52.256	
142	100	10	EoN	-10.89	2606.6	N8 23.769 W81 52.260	
H02 CM	50	75	EoN	1.31	2607.9	N8 23.769 W81 52.266	Cerro Mesa House 2
H03 CM	53.5	E		2.66	2609.2	N8 23.773 W81 52.248	Tienda
143	100	20	WoN	-4.01	2602.6	N8 23.754 W81 52.253	
H04 CM	51	50	WoN	-10.78	2591.8	N8 23.750 W81 52.245	Cerro Mesa House 4
144	85	20	EoN	-3.41	2599.2	N8 23.740 W81 52.256	
H05 CM	35	10	WoN	-5.08	2594.1	N8 23.736 W81 52.255	Cerro Mesa House 5
145	74	W		-5.29	2593.9	N8 23.743 W81 52.269	
H06 CM						N8 23.740 W81 52.261	Cerro Mesa House 6, offset by 20 ft from point 145
146	100	10	EoN	-8.72	2585.1	N8 23.727 W81 52.270	
147	100	35	EoS	-3.93	2581.2	N8 23.711 W81 52.263	
H07 CM	30.5	50	EoN	13.42	2594.6	N8 23.709 W81 52.266	Cerro Mesa House 7
H08 CM	49	10	WoN	6.27	2600.9	N8 23.703 W81 52.264	Cerro Mesa House 8
148	100	20	EoS	-10.45	2570.8	N8 23.699 W81 52.249	
149	100	35	WoN	-13.23	2557.5	N8 23.691 W81 52.237	
150	80.5	30	WoN	-20.83	2536.7	N8 23.682 W81 52.231	
151	100	30	EoN	-12.45	2524.3	N8 23.669 W81 52.239	
152	100	10	WoN	-8.54	2515.7	N8 23.652 W81 52.235	
153	57.5	S		-5.26	2510.5	N8 23.643 W81 52.235	
H09 CM	64	80	EoS	-2.29	2508.2	N8 23.643 W81 52.224	Cerro Mesa House 9
154	80	20	EoW	-7.46	2503.0	N8 23.629 W81 52.237	
H10-11 CM	77	W		-6.38	2496.6	N8 23.631 W81 52.225	Cerro Mesa House 10 and 11, 20 feet apart
H12 CM						N8 23.621 W81 52.228	Cerro Mesa House 12
155	66	15	EoN	-1.61	2501.4	N8 23.618 W81 52.240	
156	76	80	WoN	-6.16	2495.2	N8 23.615 W81 52.226	
H13 CM	55	40	WoN	-9.55	2485.7	N8 23.608 W81 52.220	Cerro Mesa House 13
H14-1 CM	100	S		-3.40	2482.3	N8 23.593 W81 52.225	Cerro Mesa House 14
H14-2 CM	56	20	WoN	-1.03	2481.2	N8 23.584 W81 52.220	Cerro Mesa House 14, second spigot
H15 CM	100	50	WoN	-37.86	2444.4	N8 23.574 W81 52.210	Cerro Mesa House 15
H15-2 CM	93	40	WoN	-8.11	2436.3	N8 23.565 W81 52.199	Cerro Mesa House 15, second spigot
157	71	40	EoN	11.05	2581.1	N8 24.230 W81 52.350	Start of branch towards Cerro Pena, from GPS point 109
158	100	N		-13.66	2567.4	N8 24.248 W81 52.351	
159	100	N		-15.99	2551.5	N8 24.263 W81 52.352	
160	100	50	EoN	0.00	2551.5	N8 24.274 W81 52.362	
161	100	40	EoN	6.98	2558.4	N8 24.287 W81 52.374	Possible Air Release Valve Location
162	100	55	EoN	-7.50	2550.9	N8 24.296 W81 52.388	
163	95	75	EoN	-7.37	2543.6	N8 24.299 W81 52.405	
164	100	20	EoS	7.06	2550.6	N8 24.283 W81 52.406	
H01 CP	46	20	WoN	13.18	2563.8	N8 24.285 W81 52.415	Cerro Pena House 1
165	100	40	EoN	-2.53	2548.1	N8 24.269 W81 52.417	
H02 CP	41	30	WoN	-6.34	2541.8	N8 24.265 W81 52.414	Cerro Pena House 2



166	100	70 EoN	-13.83	2534.3	N8 24.261 W81 52.431	GPS Point not used
167	100	60 EoN	-6.10	2528.2	N8 24.252 W81 52.444	GPS Point not used
168	100	30 EoN	-6.98	2521.2	N8 24.238 W81 52.453	GPS Point not used
169	55	50 EoS	5.75	2553.8	N8 24.277 W81 52.424	Start of trail, from GPS point 165
170	69	50EoS	-24.67	2529.2	N8 24.282 W81 52.433	
171	86	50 EoS	-16.41	2512.8	N8 24.288 W81 52.438	
172	83	55 WoS	-8.32	2504.4	N8 24.281 W81 52.453	
173	40	70 WoS	-11.49	2493.0	N8 24.279 W81 52.459	
174	56	N	-14.68	2478.3	N8 24.288 W81 52.460	
175	47	20 WoN	-19.12	2459.2	N8 24.293 W81 52.465	
176	70	65 WoS	13.60	2472.7	N8 24.290 W81 52.473	
177	59	45 WoS	11.26	2484.0	N8 24.284 W81 52.481	
178	28	60 WoS	5.70	2489.7	N8 24.282 W81 52.484	
179	86	40 WoS	15.08	2504.8	N8 24.271 W81 52.494	
180	50	80 WoN	9.75	2514.5	N8 24.272 W81 52.501	Possible Air Release Valve Location
H03 CP	72	40 WoN	18.51	2533.1	N8 24.282 W81 52.507	Cerro Pena House 3
H03-2 CP	70.5	7 WoS	17.06	2550.1	N8 24.294 W81 52.512	Cerro Pena House 3, spigto for Church
181	80	50 WoS	-1.05	2513.5	N8 24.272 W81 52.515	
H04 CP	29	24 EoS	-3.48	2510.0	N8 24.266 W81 52.518	Cerro Pena House 4
182	34	30 WoS	-3.91	2509.6	N8 24.262 W81 52.520	
H05 CP	28	75 WoN	-0.12	2509.5	N8 24.263 W81 52.523	Cerro Pena House 5
183	71	40 WoS	-18.08	2491.5	N8 24.250 W81 52.527	
184	100	75 EoS	-7.24	2484.3	N8 24.257 W81 52.545	
185	78	W	-24.56	2459.7	N8 24.256 W81 52.555	Cable bridge across creek
186	87	40 WoS	1.82	2461.5	N8 24.244 W81 52.566	
187	100	67 WoS	17.11	2478.6	N8 24.237 W81 52.579	
H06 CP	62	10 EoS	12.36	2491.0	N8 24.229 W81 52.580	Cerro Pena House 6
188	100	74 EoS	7.85	2486.5	N8 24.243 W81 52.596	Possible Air Release Valve Location
H07 CP	54	W	-1.55	2484.9	N8 24.242 W81 52.604	Cerro Pena House 7
189	85	35EoS	-15.85	2470.6	N8 24.230 W81 52.602	
H08 CP	77	15 EoN	-13.44	2457.2	N8 24.219 W81 52.604	Cerro Pena House 8
H09 CP	62	15 EoN	-9.32	2447.9	N8 24.207 W81 52.608	Cerro Pena House 9
190	69	10 WoS	-7.81	2483.7	N8 24.239 W81 52.527	Second Branch in Cerro Pena, from GPS Point 183
H10 CP	29	75 EoS	-1.72	2482.0	N8 24.238 W81 52.523	Cerro Pena House 10
191	100	20 EoS	-29.82	2453.9	N8 24.222 W81 52.532	
192	100	35 WoS	-20.36	2433.5	N8 24.210 W81 52.540	
H11 CP	28	70 WoN	-8.35	2425.2	N8 24.211 W81 52.544	Tienda
193	100	30 EoN	-23.00	2410.5	N8 24.198 W81 52.551	
194	115	W	-17.49	2393.0	N8 24.196 W81 52.566	
195	78	40 EoS	-27.63	2365.4	N8 24.183 W81 52.563	
196	100	10 WoS	-13.48	2351.9	N8 24.167 W81 52.569	
H12 CP	32.5	30 EoN	-1.73	2350.2	N8 24.164 W81 52.573	Cerro Pena House 12
H13 CP	66	30 EoN	-11.12	2339.1	N8 24.156 W81 52.579	Cerro Pena House 13

## Appendix B: Google Earth Pro Images



**Figure 1. The three communities under consideration for development of the main water distribution line.  
Note: no branches off main distribution are shown**



Figure 2. The spigots in Cerro Peña along the main distribution line. Note: no branches off main distribution are shown



Figure 3. The spigots of Hato Pilón along the main distribution line. Note: no branches off main distribution are shown



Figure 4. The spigots in Cerro Mesa along the main distribution line. Note no branches off main distribution are shown



Figure 5. Suggested locations of recommended pressure relief basins, storage tank, and air relief valves

## Appendix C: Water quality data

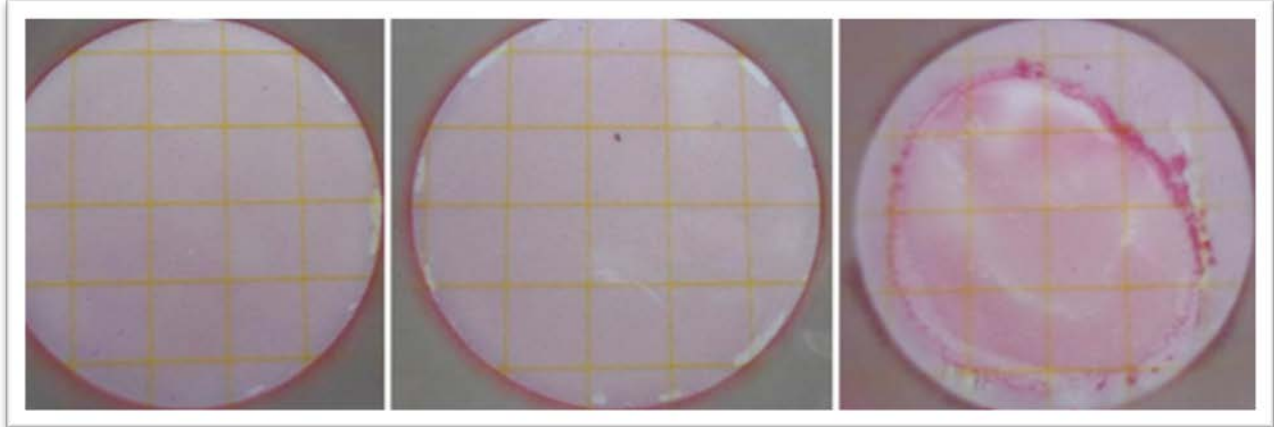


Figure 6. *E-Coli* and total coliform 3M Petrifilms sampled with water taken directly from proposed water source. There are 0 *E-Coli* present and 22 CFU (colony forming units) of coliform, shown by the purple dots within the testing circle.

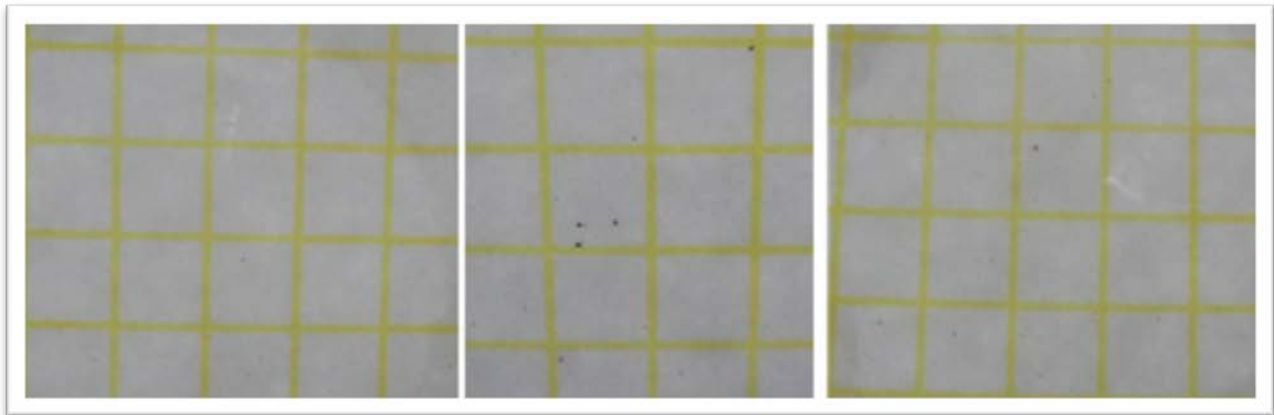


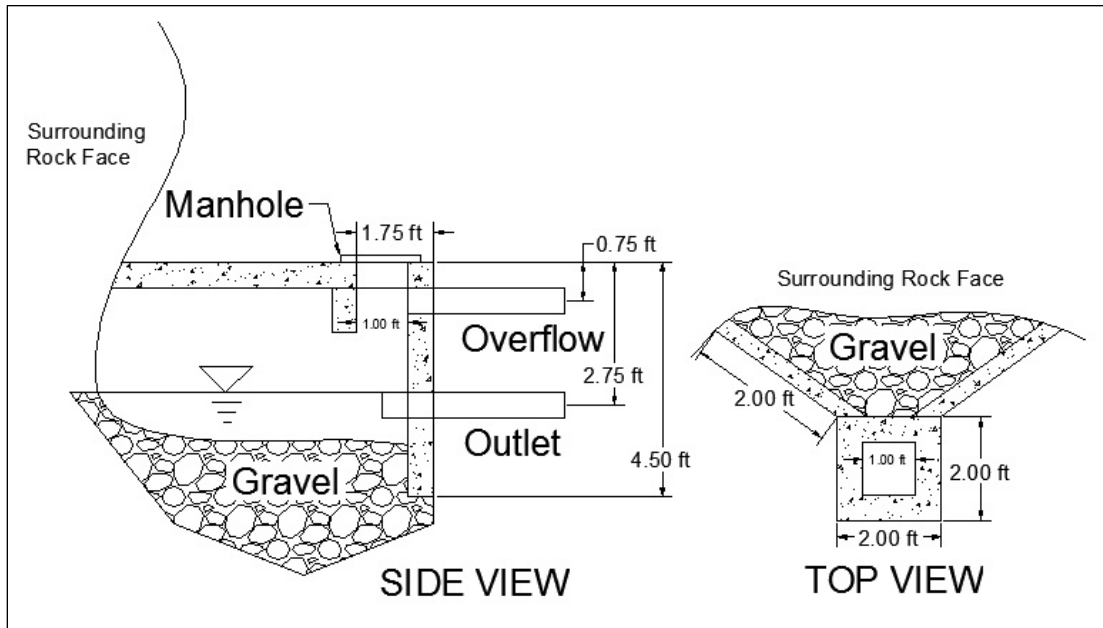
Figure 7. Aerobic bacteria 3M Petrifilms sampled with water directly from proposed water source. There are 20 CFU of aerobic bacteria present, as indicated by the red dots in the testing area.

## Appendix D: Current water use data

Table 2. Population data for the communities of Cerro Mesa, Hato Pilon Arriba, and Cerro Peña, showing the GPS location corresponding with GPS data in Appendix A, the number of people living at each requested tap location, and also the daily use of these community members.

Location	GPS Label	Type	People	Daily use, gallons	How far to current water	Water Catchment
Cerro Mesa	H01 CM	House	7	10	5 min	N
Cerro Mesa	H02 CM	House to be built	3		20-30 min	N
Cerro Mesa	H03 CM	House	4	20	20-30 min	N
Cerro Mesa	H04 CM	House	6		20-30 min	N
Cerro Mesa	H05 CM	House	2	7	20-30 min	N
Cerro Mesa	H06 CM	House	6	20	20-30 min	N
Cerro Mesa	H07 CM	Store and House	3	70	2 min	Y
Cerro Mesa	H08 CM	For Horses	2		2 min	N
Cerro Mesa	H09 CM	House	4	10	5 min	Y
Cerro Mesa	H10 CM	House	4	10	5 min	N
Cerro Mesa	H11 CM	House	4	10	5 min	N
Cerro Mesa	H12 CM	House	9	12	5 min	Y
Cerro Mesa	H13 CM	House	6	12	5 min	N
Cerro Mesa	H14 CM	House	6	15	5 min	N
Cerro Mesa	H15 CM	House	9	15	10 min	N
Hato Pilon Arriba	H01 HP	House	6		15 min	N
Hato Pilon Arriba	H02 HP	House	6		15 min	N
Hato Pilon Arriba	H03 HP	House	6		15 min	N
Hato Pilon Arriba	H04 HP	House	6		15 min	N
Hato Pilon Arriba	H05 HP	House	7		15 min	N
Hato Pilon Arriba	H06 HP	House	10		15 min	N
Hato Pilon Arriba	H07 HP	House	5		15 min	N
Hato Pilon Arriba	H08 HP	House	6		15 min	N
Hato Pilon Arriba	H09 HP	House	8		15 min	N
Hato Pilon Arriba	H10 HP	House	6		10 min	N
Hato Pilon Arriba	H11 HP	Restaurant			10 min	N
Hato Pilon Arriba	H12 HP	House	2		10 min	Y
Hato Pilon Arriba	H13 HP	House	5		15 min	N
Hato Pilon Arriba	H14 HP	House	8		15 min	N
Hato Pilon Arriba	H15 HP	House	2		15 min	N
Hato Pilon Arriba	H16 HP	House	1		15 min	N
Hato Pilon Arriba	H17 HP	Store and House	5		15 min	N
Hato Pilon Arriba	H18 HP	House	5		15 min	N
Cerro Pena	H01 CP	House	8	20	5 min	N
Cerro Pena	H02 CP	Church			5 min	N
Cerro Pena	H03 CP	House	9	20	5 min	N
Cerro Pena	H03-2 CP	Church Kitchen			5 min	N
Cerro Pena	H04 CP	House	6	20	5 min	N
Cerro Pena	H05 CP	House	5	20	5 min	N
Cerro Pena	H06 CP	House	8	20	5 min	Y
Cerro Pena	H07 CP	House	5	15	5 min	N
Cerro Pena	H08 CP	House	15	20	5 min	N
Cerro Pena	H09 CP	House	5	15	5 min	Y
Cerro Pena	H10 CP	House	8	25	5 min	N
Cerro Pena	H11 CP	Store and House	1		5 min	N
Cerro Pena	H12 CP	House	5	15	5 min	Y
Cerro Pena	H13 CP	House	12	20	5 min	Y
Total Population:			256	Average Daily use per person: 3.5 gallons		

## Appendix E: Spring box



**Figure 8. Recommended construction of the spring box, with wing walls and water permeable foundation.**

The spring box is to be built adjacent to the existing rock face that surrounds the spring source. There is no concrete foundation, as the water is seeping up through the ground. Instead, there are wing-walls which gather the seepage into a collection box, from which a 1" outlet pipe leads down to the distribution system and an overflow allows redirection of unused water. The overflow outlet should be covered with a mesh screen, to prevent contaminants from entering the system. The supply outlet pipe should be fitted with a valve directly as it leaves the spring box.

A trough is prepared along the outer perimeter of the seepage area, and wing-wall frames are installed. Then, a 6" by 6" grid of 3/8" diameter rebar is held in the center of each mold. Concrete is poured in the mold to a width of 4". The concrete mix is composed of 1/2 gravel, 1/6 cement, and 2/6 screened sand, by volume.

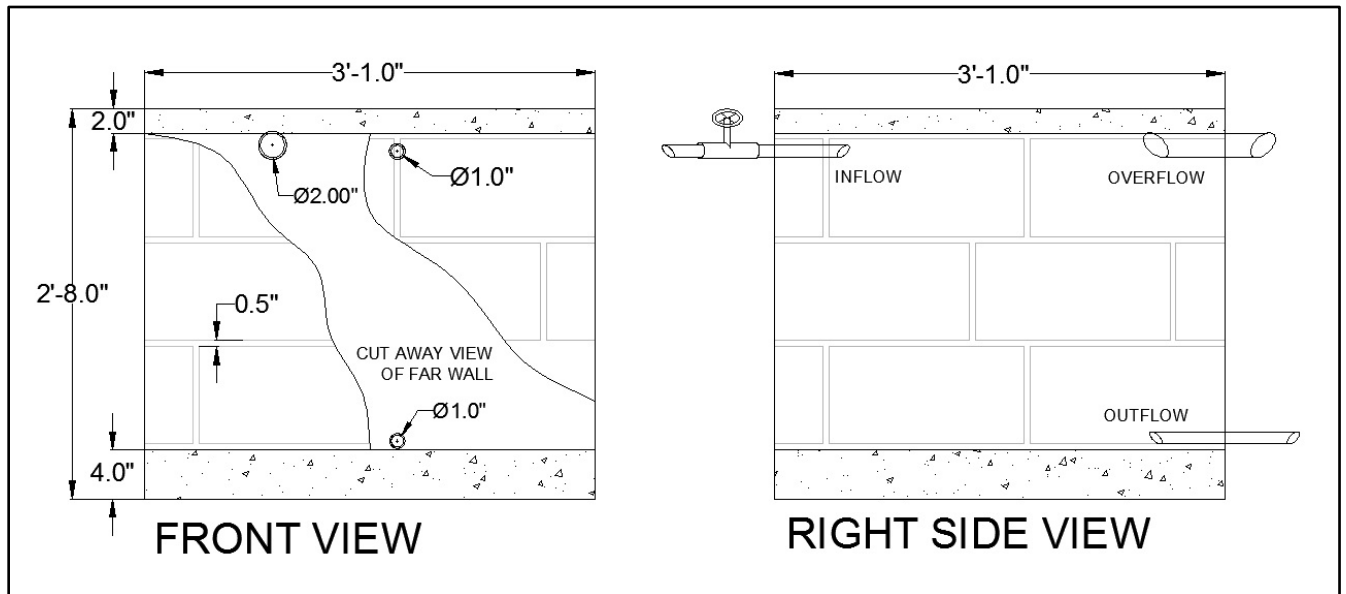
Another slab, 2 ft<sup>2</sup> and 2" in depth, can be built at the same time as the first on a non-stick surface, surrounded by a wooden board frame. This thin slab can be prepared on a non-stick surface for later use as a lift-able cover for the collection box. The collection box is then built from 4" by 8" by 16" masonry bricks surrounded by a 1/2" mortar. The mortar mix is one part cement to two parts sand.

The basin will plaster on the inside with a concrete mixture that includes the Sika 1 additive, a measure that will make the cement impermeable to water. The additive will be mixed at a ratio of 1 kg to every 11 kg of water. <sup>1</sup>The water quantity is assumed to be 3 kg for every cubic foot of cement mixture. The mix can be applied to a thickness of 1/2".

<sup>1</sup> Sika is sold in 4 kilogram quantities, mixing ratio (1:11) is equal in pounds.



## Appendix F: Break pressure tank



**Figure 9. Recommended construction of the first pressure break tank in the system, this type of break tank is where water enters and returns to atmospheric pressure then exits.**

The pressure relief basin is built on a 4" foundation of concrete. After clearing and compacting the ground surface, the edge boards are laid in a 3' by 3' square. Rebar of 3/8" diameter is arranged in a grid pattern to form a 6" by 6" mesh, suspended one inches above the ground. Through this mesh, a concrete mix, by volume, of 1/2 gravel, 1/6 cement, and 2/6 screened sand is applied.

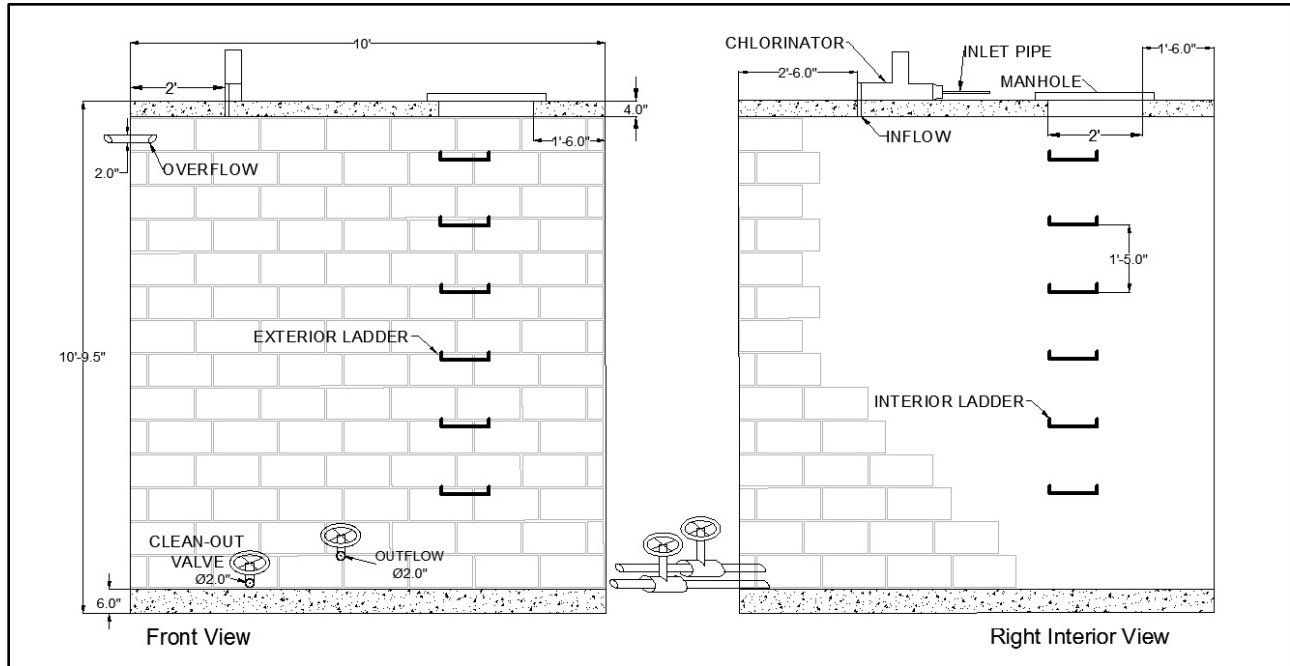
Another slab, equal in side dimensions and 2" in depth, can be built at the same time as the first. This thin slab can be prepared on a nonstick surface for later use as a lift-able cover for the basin.

After allowing the foundation slab to cure for seven days, the baseboards are removed and the walls constructed. A mortar mix of one part cement to two parts sand (by volume) is used between standard 4" x 8" x 16" concrete blocks. There is no need for rebar reinforcement in walls of this size.

The tank will be plastered to 1/2" thickness on the inside with a concrete mixture that includes the Sika 1 additive, a measure that will make the cement impermeable to water. The additive will be mixed at a ratio of 1 kg to every 11 kg of water. The water quantity is assumed to be 3 kg for every cubic foot of cement mixture.

A maintenance valve should be placed directly before the break pressure tank, so that the tank can be emptied if necessary. The overflow pipe should be covered with a mesh screen to prevent unwanted contamination from entering the system. The overflow can be directed to another water supply, such as a nearby creek, to prevent the waste of water that can be used for other needs.

## Appendix G: Storage tank construction



**Figure 10. Recommended construction of the storage tank. The chlorinator is to be located before the water enters to provide proper residence time of chlorine in the tank.**

The storage tank is built on a 6" foundation of concrete. After clearing and compacting the ground surface, the edge boards are laid in a 10' by 10' square. Rebar of 3/8" diameter is arranged in a grid pattern to form a 6" by 6" mesh, suspended 4" above the ground. Through this mesh, a concrete mix, 1/2 gravel, 1/6 cement, and 2/6 screened sand by volume, is applied.

After allowing the foundation slab to cure for seven days, the mold is removed and the superstructure is begun. A mortar mix of one part cement to two parts sand (by volume) was used between standard 4" x 8" x 16" concrete blocks. Within these walls will be 3/8" rebar reinforcement running vertically through the center holes in each brick.

The tank will be plastered on the inside with a concrete mixture that includes the Sika 1 additive, a measure that will make the cement impermeable to water. The additive will be mixed at a ratio of 1 kg to every 11 kg of water. The water quantity is assumed to be 3 kg for every cubic foot of cement mixture. The mix can be applied to a thickness of 1/2".

After completing the inside of the tank, the roof slab must be undertaken. Using plywood or another flat surface a platform is constructed on the inside of the four walls to hold up the tank roof. Concrete is poured over the 6" x 6" grid of 3/8" diameter rebar leaving space for manhole access.

A maintenance valve should be placed directly after the storage tank, on both the cleaning outlet and also on the water supply outlet. The cleaning outlet should be placed flush with the tank bottom. The

supply outlet should be higher than that, whereas the overflow outlet should be placed towards the top of the structure. The overflow outlet should be connected to a 90 degree elbow and faced downward in order to prevent rainwater or other debris from entering the system after the water has been treated. This outlet should also be covered with a mesh screen to prevent contamination.

In order to determine the size of the storage tank, calculations were performed below shown below.

$$P_N = P_O * \left( \frac{r * N}{100} + 1 \right)$$

Projected population growth (r) = 1.4% (USA CIA)

Project Design Life (N) = 20 YRS

Po= Population

$$P_N = 256 \text{ ppl} * \left( \frac{1.4 * 20 \text{ yr}}{100} + 1 \right) = 328 \text{ ppl}$$

$P_N$  = Projected population in N years (20yrs)

$\omega$  = per capita water consumption (20 gallons per person per day<sup>2</sup>)

$$\text{Average Daily Use } V_{avg} = P_N * \omega = 328 \text{ ppl} * \frac{20 \frac{\text{gal}}{\text{person}}}{\text{day}} = 6560 \frac{\text{gallons}}{\text{day}}$$

$$\text{Maximum Daily Use } V_{max} = V_{avg} * \text{safety factor} = 6560 \frac{\text{gallons}}{\text{day}} * 1.25 = 8200 \frac{\text{gallons}}{\text{day}}$$

$$\text{Demand Flow rates } Q_{AVG} = 6560 \frac{\text{gallons}}{\text{day}} * \left( \frac{1 \text{ day}}{86400 \text{ s}} \right) = 0.0760 \frac{\text{gallons}}{\text{s}}$$

$$Q_{max} = 8200 \frac{\text{gallons}}{\text{day}} * \left( \frac{1 \text{ day}}{86400 \text{ s}} \right) = 0.0950 \frac{\text{gallons}}{\text{s}}$$

$$Q_{peak} = Q_{max} * 4 = 0.0950 \frac{\text{gallons}}{\text{s}} * (4) = 0.380 \frac{\text{gallons}}{\text{s}}$$

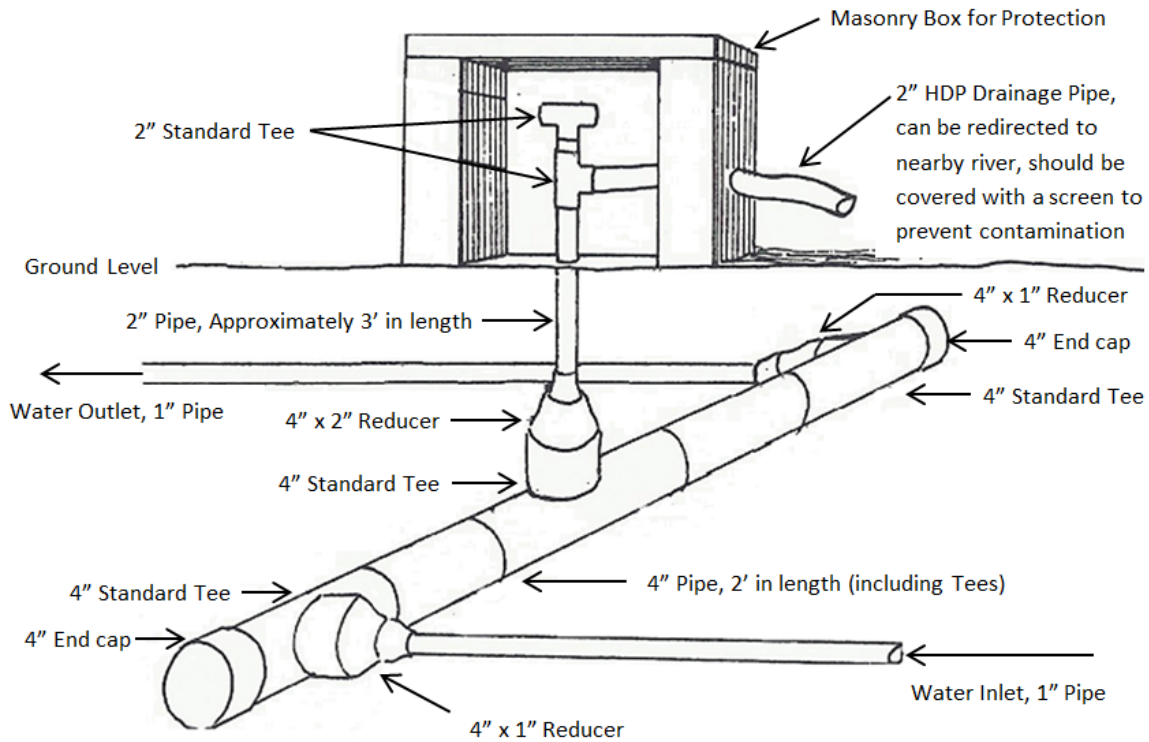
$$\tau_{peak} = \frac{V_{max}}{Q_{peak}} = \frac{8200 \text{ gallons}}{0.380 \frac{\text{gal}}{\text{s}}} = 21,578 \text{ s} = 6 \text{ hours}$$

$$\begin{aligned} V_{tank} &= (Q_{peak} - Q_{min-source}) * \tau_{peak} = \left( 0.380 \frac{\text{gallons}}{\text{s}} - 0.083 \frac{\text{gallons}}{\text{s}} \right) * 21,578 \text{ s} \\ &= 6408.6 \text{ gallon} \end{aligned}$$

<sup>2</sup> UN water suggests 5-13 gallons per person per day to ensure basic needs for cooking, drinking and cleaning.

<sup>3</sup> Estimate is if flow from the proposed spring source is 25% of what it runs now at 24 gpm (during dry season) Estimate is based on the lowest measure of flow data from the spring collected.

## Appendix H: HDP Pressure break tank construction



**Figure 11. HPD pressure break tank construction. Image courtesy of Thomas Jordan Jr.**

HPD tanks are beneficial due to their ease of construction and protection from contamination. The rate of flow out of the HDP tank is dependent on the downward pressure from the outlet pipe. The pressure is limited by the height of the upwardly protruding pipe, which is recommended to be at least 3' in length. The suggested pipe size for the components is shown above (Figure 11). The pipe is placed below ground for protection, with only a short segment protruding above the ground level. The protection of the masonry box is important to the design. A maintenance valve should be placed directly before this component. The overflow outlet should be connected to a 90 degree elbow and faced downward in order to prevent rainwater or other debris from entering the system after the water has been treated. This outlet should also be covered with a mesh screen to prevent contamination.

## Appendix I: Cable bridge construction

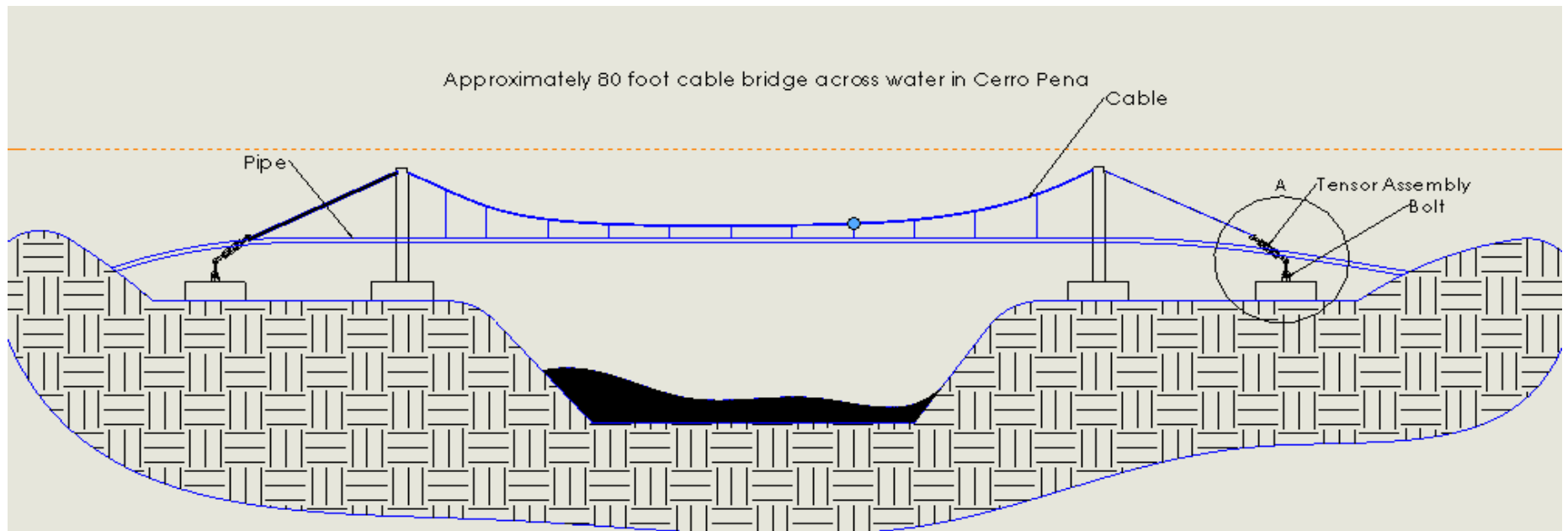
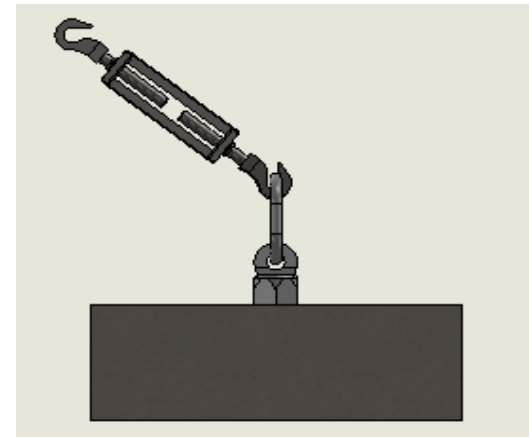
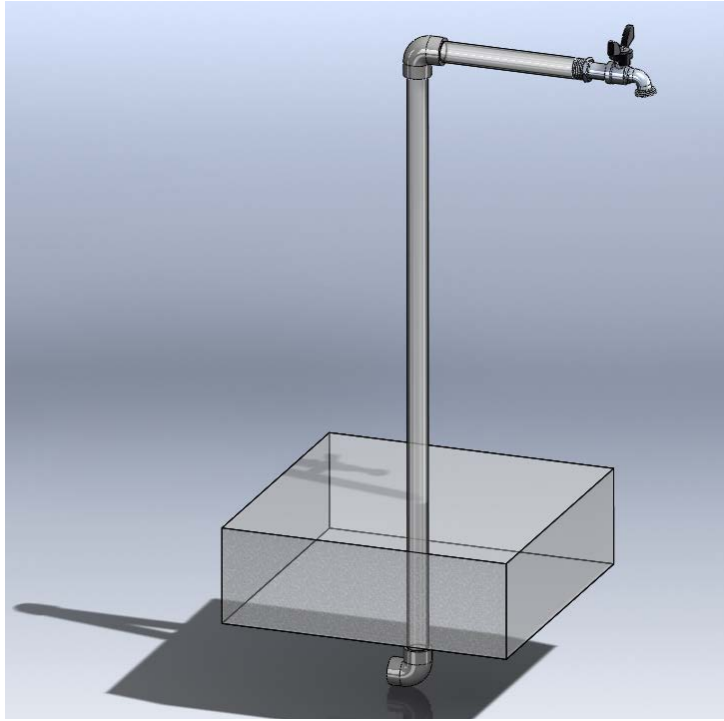


Figure 12. Cable bridge assembly recommended for ravine in Cerro Peña. Design adapted from assembly observed in Hato Pilón Abajo. Pipeline is bound with wire to suspension cable.

## Appendix J: Spigot construction



**Figure 13. Sample construction of supply spigot at a home. Concrete base supports pipe but additional support such as a piece of wood or metal pipe is recommended.**

To each of the homes that requested a tap, a ½" distribution branch will be laid, ending with a spigot. All spigots should be constructed with a 90 degree elbow protruding the pipe above ground 2-3 feet, followed by another 90 degree elbow connected to a spigot with a faucet. A concrete foundation, 2' by 2' will support the structure and prevent erosion around the base. All spigots should be supported by a wooden post, a steel post, or a concrete post (not shown in Figure 13). The faucet valve can be either plastic or metal. It is recommended that the family build the support for the spigot on their own; however it should be enforced by the standing water committee.

## Appendix K: In-line chlorinator manual

### THE CTI 8 WATER CHLORINATOR

## MANUAL OF INFORMATION, MAINTENANCE & OPERATION

by

Fred Jacob and Charles Taflin

Compatible Technology International (CTI)

CTI is a not for profit Non-Governmental Organization (NGO) headquartered in St. Paul, Minnesota, USA with a history of twenty-five years working in appropriate technology in developing countries. The vision and mission of CTI is to make a measurable difference in alleviating hunger and poverty in developing countries through simple, inexpensive, repeatable technology

### *The Chlorinator*

The chlorinator is shown fully assembled in Figure 1. It is built entirely from schedule 40 PVC pipe, fittings, and ¼-inch plate. The parts are easily constructed with simple tools and assembled with standard PVC cement and stainless-steel screws. The body of the unit is a 4-inch PVC tee, with a 9-cm nipple and coupling on each end. A 4-inch riser, 30-cm long, is fitted into the branch of the tee, and is closed on top by a cap. A tube containing the chlorine tablets is placed inside the riser.

A complete list of materials and tools is included with templates in the last section of this appendix

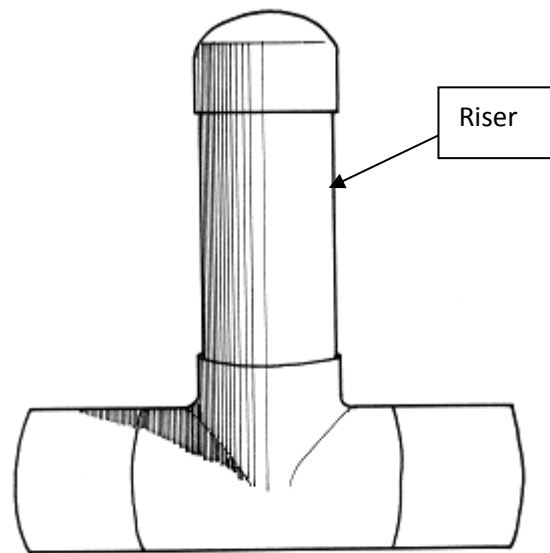
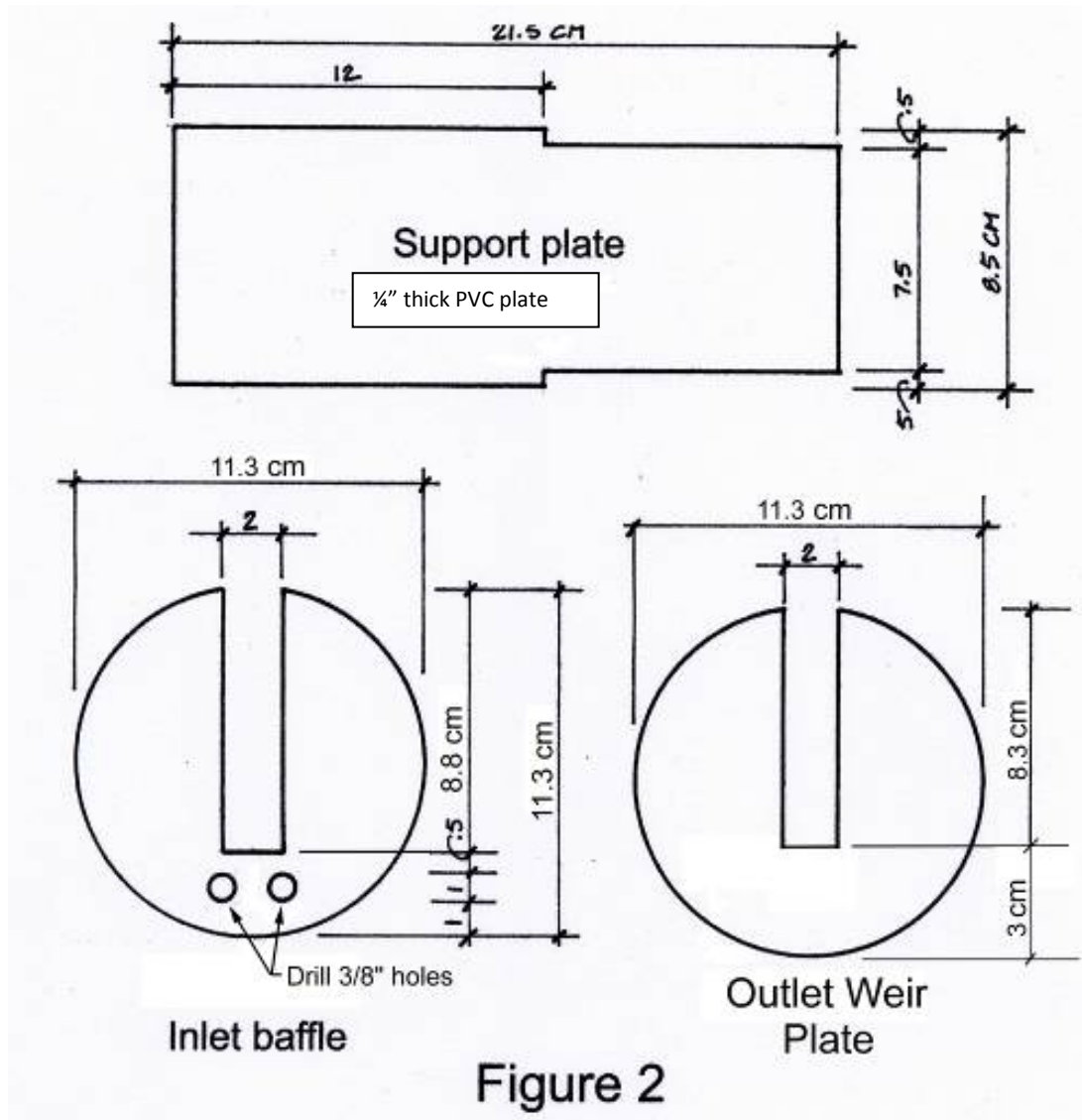


Figure 1

Inside the tee a ¼-inch plate supports the tablet tube. On the inlet end of the tee, between the nipple and the coupling, there is a baffle that directs the water flow. At the outlet end there is a weir plate that regulates the depth of flow through the chlorinator. The support plate, inlet baffle, and weir plate are shown in Figure 2. These, and all other flat parts, are cut from ¼" PVC plate.

**Dimensions for constructing the parts are shown on the included figures. To simplify the fabrication of the chlorinator, full-size templates for most of the flat parts are included at the back of this manual.**





The tablet tube is shown in Figure 3. It consists of a 3-inch pipe section that is slotted at the lower end. A circular plate is cemented to the bottom and secured with stainless steel sheet metal screws. Chlorine tablets are stacked in the tube before it is placed in the riser.

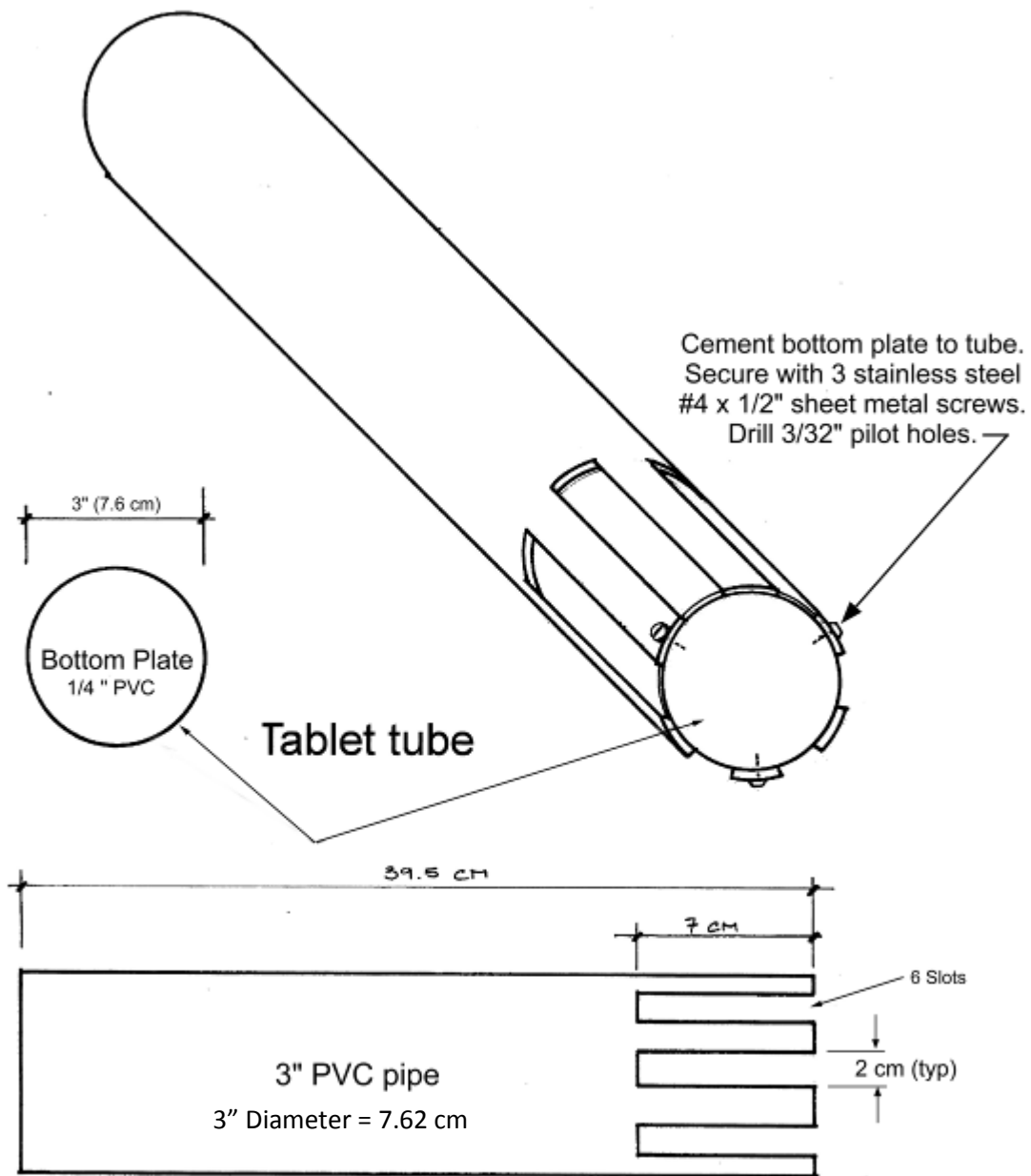


Figure 3

In some circumstances it may be necessary to stack the tablets on edge. For this purpose an adapter is placed into the tablet tube before the tablets are added. The upright adapter is shown in Figure 4.

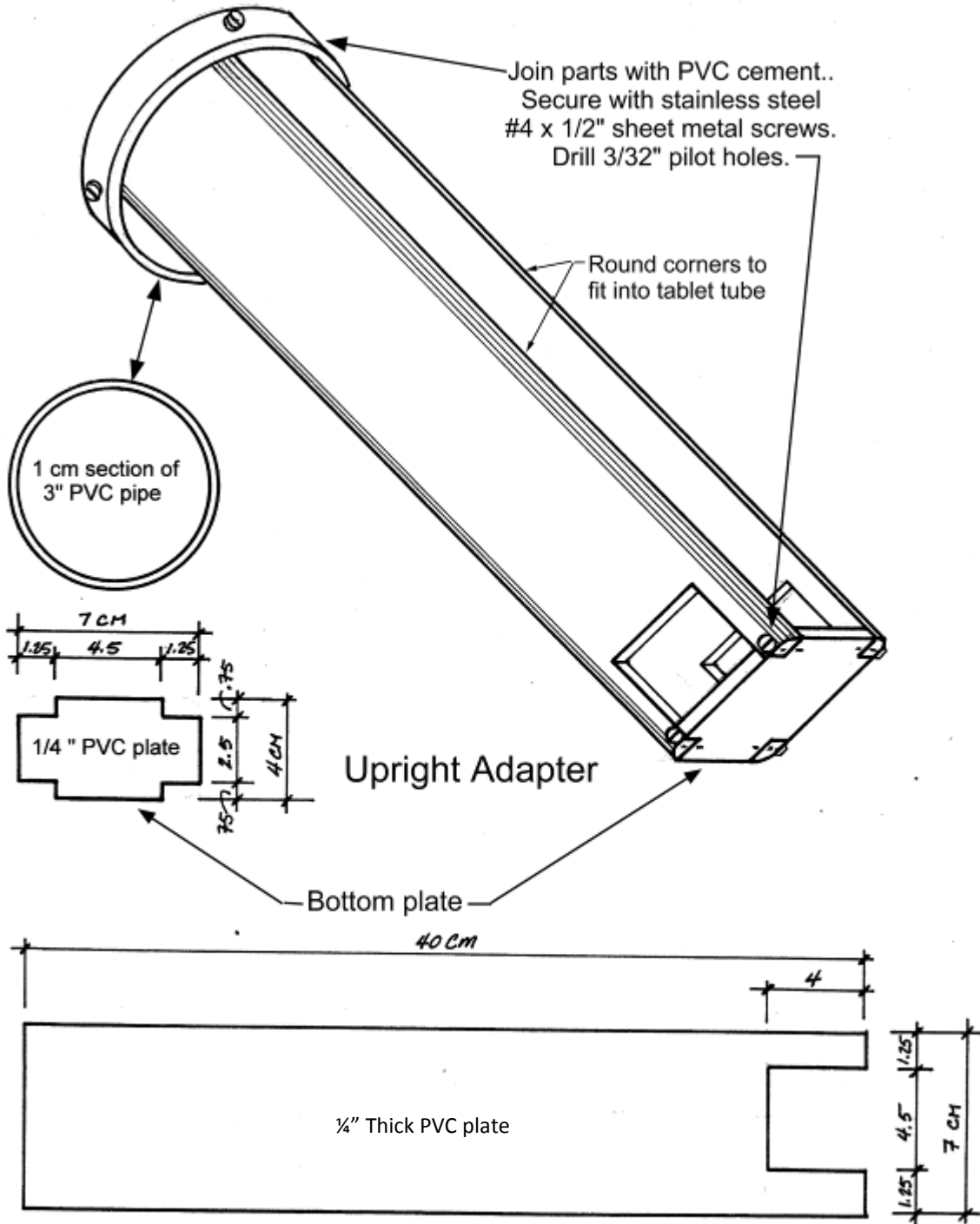


Figure 4

## Installation

The chlorinator should be assembled as shown in Figure 5. **For ease of maintenance and part replacement the tee, nipples, couplings, riser, cap, baffle and weir should not be cemented together. The best location for the chlorinator is on the inlet to a reservoir.** The reservoir will provide a buffer for chlorine dose variations and also will provide contact time for the chlorine to work. The unit should be installed with the tee level and the riser vertical. It should be installed as shown in Figure 6, so that a portion of the flow can bypass the chlorinator. A valve (bypass valve) should be installed on the bypass pipe and another (isolation valve) on the pipe to the chlorinator. If the influent flow is much greater than the needs of the community, it may be advisable to install another valve upstream of the assembly shown in Figure 6 that may be throttled to restrict the flow to the reservoir. The valves used should be of the type that won't restrict the flow very much, such as ball valves or gate valves.

During operation it will be necessary to take samples downstream of the chlorinator to check the chlorine residual.

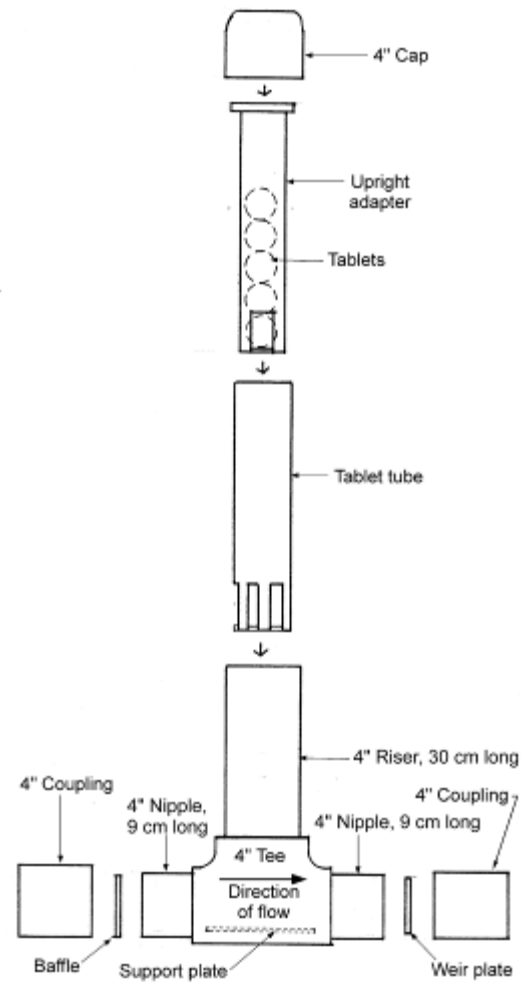


Figure 5  
Exploded View

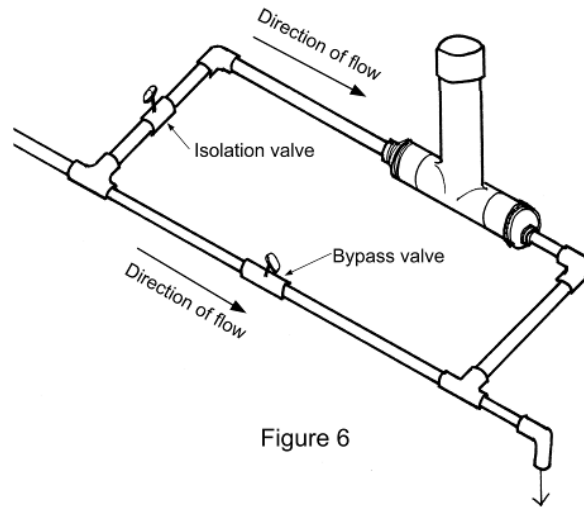


Figure 6

## Operation

In operation the water flows by gravity through the chlorinator, entering through the inlet baffle and exiting through the weir plate. The baffle directs most of the flow toward the center of the unit and directs a small portion of the flow under the support plate. The portion of the flow above the plate encounters the chlorine tablets in the tablet tube. The weir plate controls the level of water in the unit. The higher the flow, the higher the water level and the more tablet surface is exposed to the water. The dose should remain relatively constant regardless of the rate of flow. A cutaway view of the assembled chlorinator is shown in Figure 7.

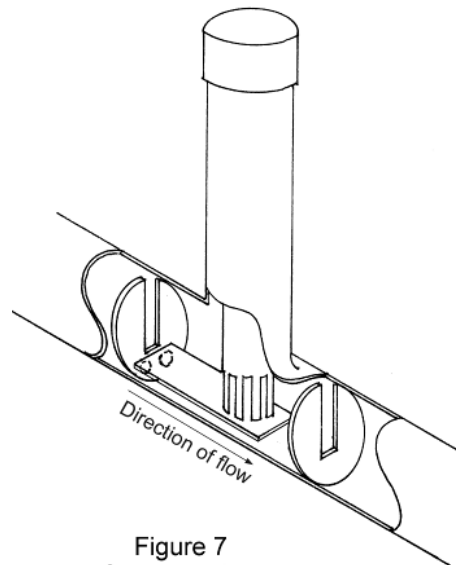


Figure 7  
Cutaway View

The chlorine dose should be sufficient to satisfy the chlorine demand and provide a residual level in the distribution system. The chlorinator may add more chlorine to the water than is needed for these purposes. The chlorine dose can be controlled two ways:

1. *By the amount of water bypassing the chlorinator. To increase or decrease the dose the bypass valve may be adjusted toward the closed or open positions to divert more or less water through the chlorinator. During operation the bypass valve will normally be throttled for flow control and the isolation valve will be wide open.*

2. *By the use of spacer discs. Figure 8 is a diagram of a spacer disc. One or more discs may be placed in the tablet tube under the tablet stack to raise the tablets so that less tablet surface will be submerged. **Caution: The spacer discs must not raise the tablets so much that they will be completely out of the water at minimum flow. Normally only one spacer disc may be used at a flow of 2 gpm. At higher flows more than one may be used. When the upright adapter is used, the spacer discs, if used, must be placed between it and the bottom of the tablet tube. Also, when the upright adapter is used it should be placed in the tablet tube and oriented so that the water flow strikes the edge of the bottom tablet, not the side.***

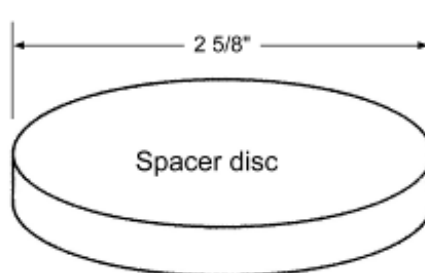


Figure 8

## ***Maintenance***

The chlorinator must be checked periodically to make sure that the tablets aren't hanging up in the tube and to add new tablets as needed. When the tube is replaced after maintenance it should be turned to present a new face to the flow. If the upright adapter is in use it must be rotated 180° or not rotated at all. During use the chlorinator may accumulate deposits from the water or the tablets themselves. It should be cleaned periodically. The isolation valve should be closed and the chlorinator disassembled as necessary for cleaning.

## ***Tools and Materials***

To construct one CTI 8 chlorinator the following are required:

### Materials:

<b>Item</b>	<b>Quantity</b>
PVC Tee, 4"x 4", Schedule 40	1
PVC Pipe, 4", Schedule 40	21"
PVC couplings, 4", Schedule 40	2
PVC cap, 4", Schedule 40	1
PVC Pipe, 3", Schedule 40	17"
PVC Plate, ¼"	1.3 sq.ft.
PVC cement	Small container
Sheet metal screws, #4 x ½", stainless steel	11

### Tools:

Handsaw or equivalent

Drill

Spirit level (for  
installation)

Coping saw, saber saw, or  
equivalent

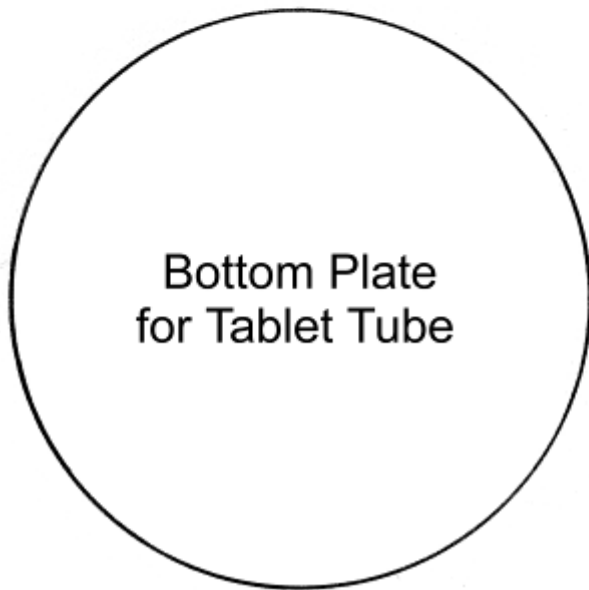
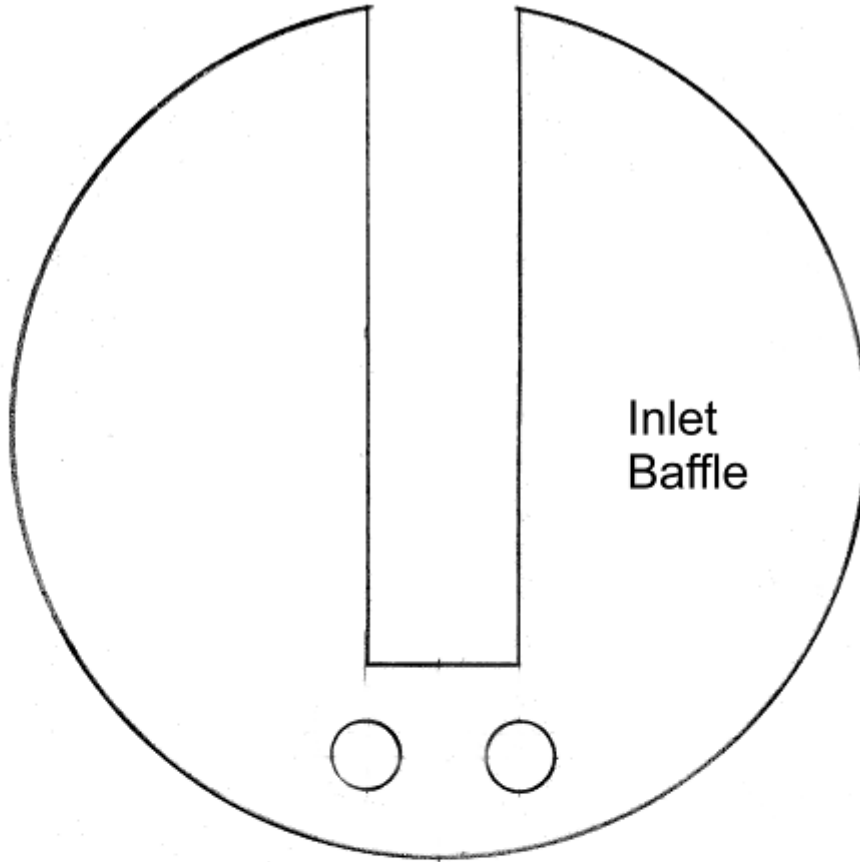
Drill bits 3/8" &  
3/32"

Wood rasp or coarse file

Wood chisel

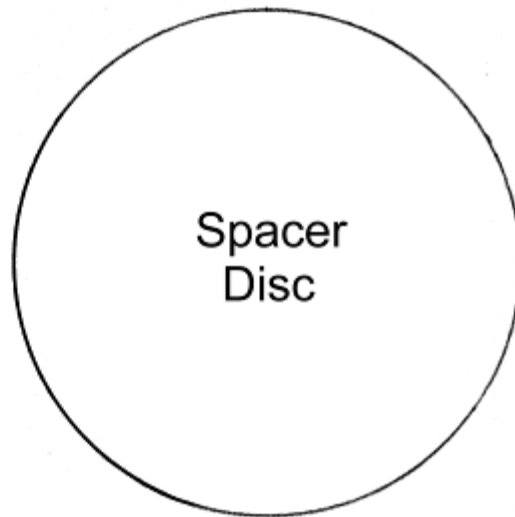
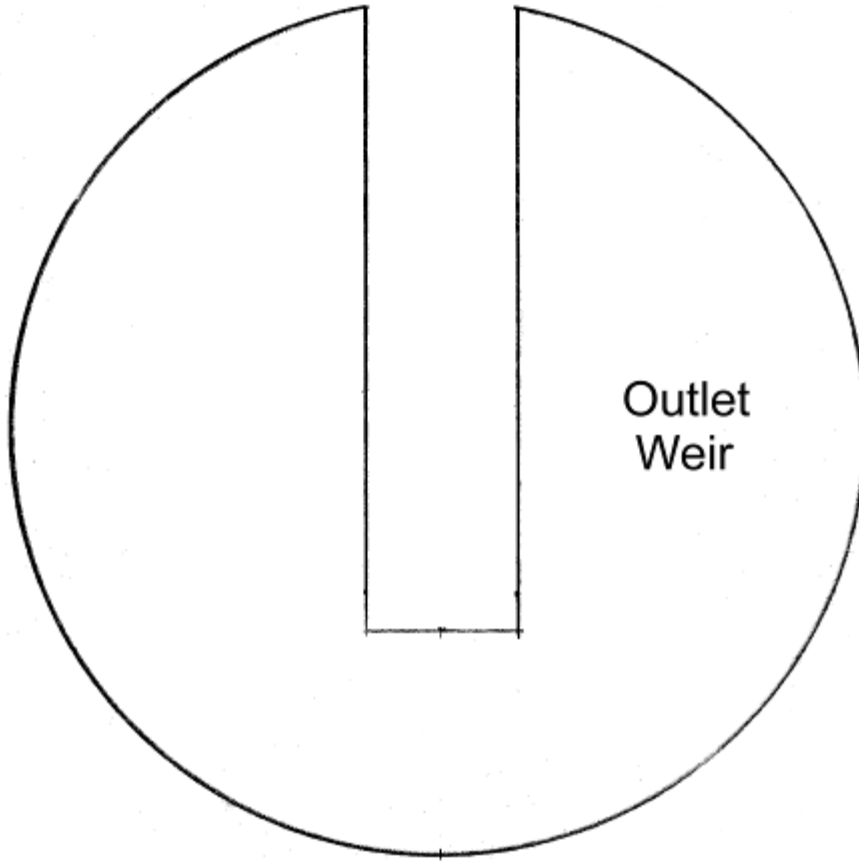
Sandpaper

Screwdriver



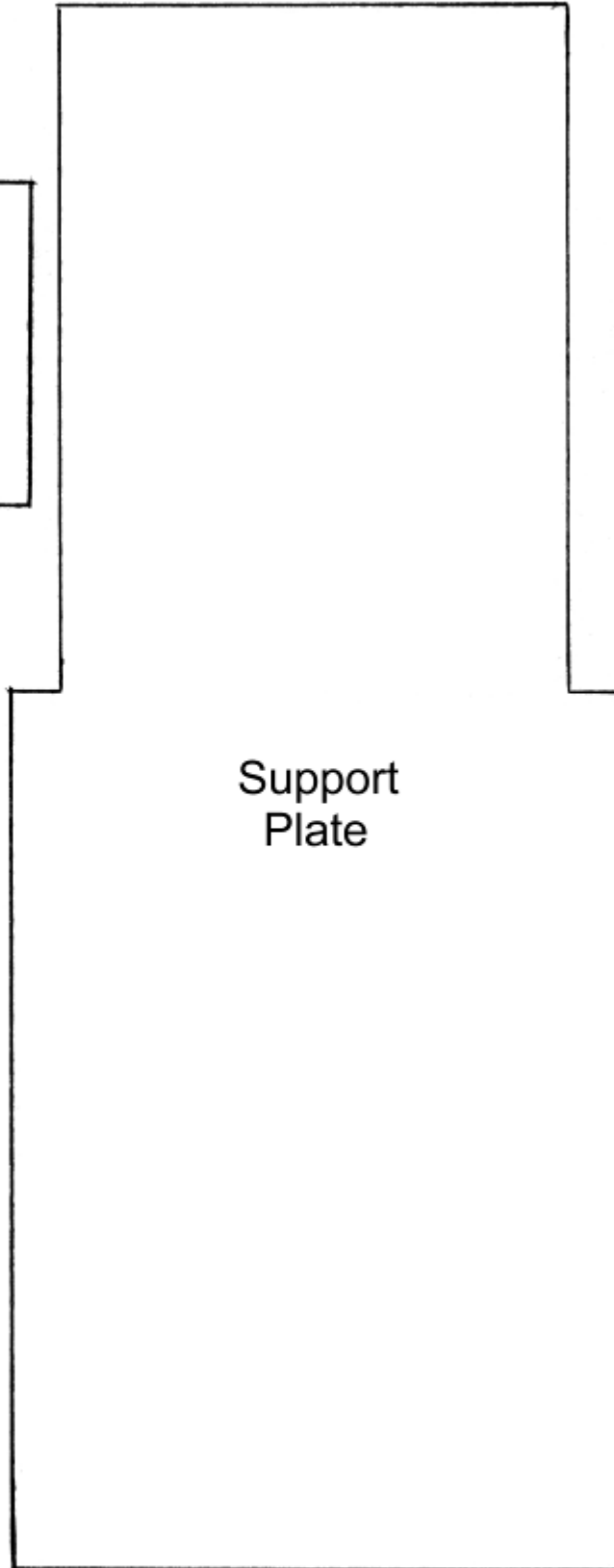
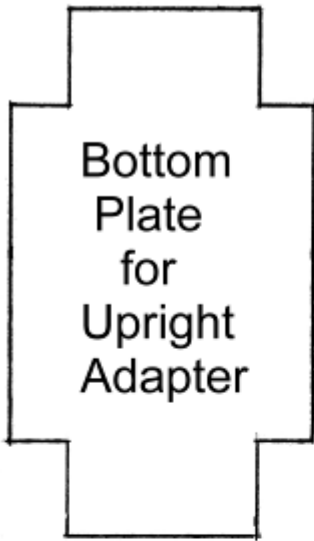
## Templates Sheet 1

***Double check templates are correctly scaled before cutting.  
Print as is with no scaling***



Templates  
Sheet 2





Templates  
Sheet 3

## Appendix L: EPANET pressure analysis

Table 3. Predicted pressure calculated when all spigots are closed, modeled in EPANET.

Node ID	Elevation ft	Head ft	Pressure psi	Node ID	Elevation ft	Head ft	Pressure psi
Junc 3	2582	2852	116.99	Junc H34(8)	2563	2852	125.22
Junc H1(6)	2590	2852	113.52	Junc H35	2541	2852	134.76
Junc H2(6)	2553	2852	129.56	Junc H36(9)	2533	2852	138.22
Junc H3(6)	2550	2852	130.86	Junc H38(6)	2510	2852	148.19
Junc H4(6)	2536	2852	136.92	Junc H39(5)	2509	2513	1.73
Junc H5(7)	2533	2852	138.22	Junc J36	2433	2513	34.66
Junc H6(9)	2522	2852	142.99	Junc H41(1)	2425	2513	38.13
Junc H7(5)	2521	2852	143.42	Junc J39	2410	2513	44.63
Junc H8(6)	2518	2852	144.72	Junc J40	2393	2513	52
Junc H9(8)	2509	2852	148.62	Junc H42(12)	2350	2513	70.63
Junc H13(5)	2511	2852	147.76	Junc H43(5)	2339	2513	75.39
Junc J14	2553	2852	129.56	Junc H40(8)	2481	2513	13.87
Junc J15	2549	2852	131.29	Junc H44(8)	2491	2513	9.53
Junc J16	2532	2852	138.66	Junc H45(5)	2484	2513	12.57
Junc J17	2532	2852	138.66	Junc H46(15)	2457	2513	24.26
Junc J18	2522	2852	142.99	Junc H47(5)	2447	2513	28.6
Junc J19	2515	2852	146.02	Junc H37	2550	2852	130.86
Junc J20	2515	2852	146.02	Junc H11(2)	2529	2852	139.96
Junc J21	2524	2852	142.12	Junc H17(5)	2516	2852	145.59
Junc H12(6)	2511	2852	147.76	Junc J48	2520	2852	143.86
Junc H10(0)	2529	2852	139.96	Junc H18(5)	2559	2852	126.96
Junc J23	2531	2852	139.09	Junc J50	2555	2852	128.69
Junc H14(8)	2524	2852	142.12	Junc J6	2543	2852	133.89
Junc H15(2)	2546	2852	132.59	Junc J7	2570	2852	122.19
Junc H16(1)	2517	2852	145.16	Junc J9	2550	2852	130.86
Junc J2	2728	2852	53.73	Junc J22	2548	2852	131.72
Junc J3	2697	2852	67.16	Junc J24	2514	2852	146.46
Junc J4	2693	2852	68.89	Junc J26	2513	2852	146.89
Junc H19(7)	2717	2852	58.5	Junc J27	2510	2513	1.3
Junc H20(3)	2698	2852	66.73	Junc J28	2491	2513	9.53
Junc H21(4)	2700	2852	65.86	Junc J29	2461	2513	22.53
Junc J8	2689	2852	70.63	Junc J30	2483	2513	13
Junc H22(6)	2682	2852	73.66	Junc J31	2478	2513	15.17
Junc H23(2)	2684	2852	72.79	Junc J32	2486	2513	11.7
Junc H24(4)	2684	2852	72.79	Junc J33	2470	2513	18.63
Junc J12	2684	2852	72.79	Junc J34	2351	2513	70.19

Junc J13	2672	2852	77.99	Junc J37	2788	2852	27.73
Junc H25(3)	2685	2852	72.36	Junc J38	2459	2852	170.29
Junc H26(2)	2692	2852	69.33	Junc J42	2835	3099.71	114.7
Junc J25	2601	2852	108.76	Junc J43	2853	3087.84	101.76
Junc H27(4)	2598	2852	110.06	Junc J44	2997	3025.78	12.47
Junc J5	2593	2852	112.22	Junc J45	2676	2852	76.26
Junc H28(4)	2587	2852	114.82	Junc J46	2558	2852	127.39
Junc H29(4)	2587	2852	114.82	Junc J1	2459	2513	23.4
Junc H30(9)	2587	2852	114.82	Junc J35	2847	2853.38	2.76
Junc J10	2587	2852	114.82	Resvr Source	3490	3490	0
Junc J11	2586	2852	115.26	Tank Storage Tank	2843	2852	3.9
Junc H31(6)	2576	2852	119.59	Tank PressureReliefbasin	3307	3309	0.87
Junc H32(1)	2572	2852	121.32	Tank PressureHDPtank	2511	2513	0.87
Junc H33(9)	2527	2852	140.82				

## Appendix M: Daily use pattern and supply calculations

Table 4. Estimated daily use patterns for use in EPANET model for the communities based on 20 gpc and a leakage factor of 15%

Junction	Estimated # of ppl in home	Estimated usage based on 20 gal/day/person/home = x gal/day/home	NonRevenueWater usage (15%)	For 18 hours per day and into gal/min/
H1	6	120	141.176	0.131
H2	6	120	141.176	0.131
H3	6	120	141.176	0.131
H4	6	120	141.176	0.131
H5	7	140	164.706	0.153
H6	10	200	235.294	0.218
H7	5	100	117.647	0.109
H8	6	120	141.176	0.131
H9	8	160	188.235	0.174
H10	1	20	23.529	0.022
H11	2	40	47.059	0.044
H12	6	120	141.176	0.131
H13	5	100	117.647	0.109
H14	8	160	188.235	0.174
H15	2	40	47.059	0.044
H16	1	20	23.529	0.022
H17	5	100	117.647	0.109
H18	5	100	117.647	0.109
H19	7	140	164.706	0.153
H20	3	60	70.588	0.065
H21	4	80	94.118	0.087
H22	6	120	141.176	0.131
H23	2	40	47.059	0.044
H24	4	80	94.118	0.087
H25	3	60	70.588	0.065
H26	2	40	47.059	0.044
H27	4	80	94.118	0.087
H28	4	80	94.118	0.087
H29	4	80	94.118	0.087
H30	9	180	211.765	0.196
H31	6	120	141.176	0.131
H32	1	20	23.529	0.022
H33	9	180	211.765	0.196
H34	8	160	188.235	0.174
H35	1	20	23.529	0.022
H36	9	180	211.765	0.196
H37	1	20	23.529	0.022
H38	6	120	141.176	0.131
H39	5	100	117.647	0.109
H40	8	160	188.235	0.174
H41	1	20	23.529	0.022
H42	12	240	282.353	0.261
H43	5	100	117.647	0.109
H44	8	160	188.235	0.174
H45	5	100	117.647	0.109
H46	15	300	352.941	0.327
H47	5	100	117.647	0.109
Total		5040	5929.411765	5.490196078

## Appendix N: Piping installation recommendations

The following are recommendations for laying the length of pipeline from the water source to each household spigot.

### Route

- The path of the survey data (Appendix A) does not need to be exactly followed, but provides a basis for any route that may be implemented.
- Directly from the spring box, the pipe should travel laterally downhill and meet the road when possible. The pipe *should not* follow the foot path immediately beside the home of Emilio Quintero, as this elevation change will prevent the water from flowing through the system.
- The pipeline should follow alongside main paths but not in the middle. If the pipe is buried in the middle of the path, this could lead to damage due to stress from traffic above ground.
- The most direct path for the pipeline should be taken. For example, if there is a curve in the road and a path that bypasses the curve, the path should be followed. This will decrease the amount of pipe necessary and reduce the total cost.
- Whenever possible, the pipe should continue on a downward slope. When laying the pipe, you should avoid areas where the pipe changes from travelling downhill to uphill than back downhill. This will prevent air blockages from forming in the pipe, which could halt the flow of water and limit the supply.
- For the branch of the system that extends towards Cerro Peña, it is recommended that a short cut is made. If the main path is followed, the branch will have to immediately travel uphill from the main pipeline, and this gravitational resistance will cause Cerro Peña to receive less water while the communities of Hato Pílon Arriba and Cerro Mesa will receive the majority of the supply. An outline of this shortcut is illustrated below.



Figure 14. Suggested shortcut route to Cerro Peña, extending from GPS point 101 to GPS point 162 (Appendix A)

## Protection

- All pipelines should be buried between 2'-3' below ground in order to protect the pipe from damage due exposure. The course of the pipe should be marked above ground with wooden stakes. In locations where it is not possible to run the pipe underground, it should be routed in a path where it is not likely to be damaged, where it is fully supported, and where it is visible in order to identify if repair is necessary. It should not be left lying over a gap unsupported, which may cause a break in the pipe, and if it is run through an area of woods, it should be clearly marked so that the line can be followed.
- Any pipe exposed to the sunlight should be painted or encased by a larger diameter pipe.

## Joints

- For locations where the lengths of pipe must be connected, 45 and 90 degree elbows will be necessary when the pipe is making a change in direction. If the pipe is only making a slight turn in direct (less than 30 degrees) the PVC pipe can be bowed slightly to accommodate these directional changes.
- The PVC pipe can also be heated and molded to the desired position, but this will weaken the pipe and should be avoided. Any joints that are molded by hand must be done skillfully. Due to the high pressures of the system, failure to successfully join the pipe may lead to failure.
- All pipe connections must be sealed with PVC glue in order to ensure the durability of the system after construction and to prevent leak.

## Pipe Selection

- Pipes are recommended to be sized accordingly:
  - 1" pipe (SDR 26, 160 PSI) extending from the spring source to the main storage basin
  - 2" pipe (SDR 26, 160 PSI) extending from the storage tank to the last branch in Cero Mesa
  - 1" pipe (SDR21, 200 PSI or SCH 40, 260 PSI) for the branch that extends towards Cerro Peña
  - 1/2" pipe (SDR 13.5, 315 PSI) for every branch leading to a spigot at a house.

If 1" pipe is unavailable, a similar pipe size ( $\pm 0.5$  inches) may be used, depending on the availability and cost. However, it is imperative to the design that the SDR 21 or SCH40 pipe is used for the branch towards Cerro Peña, as pipe of a lower pressure rating will be at risk of failing. The 1/2" branch was designed to be SDR 13.5. The 1/2" distribution branches only need to be durable up to 160 PSI.

- Due to the high pressures in the pipe, it is imperative that the pipe selected is of good quality and be properly installed. Using old pipe that has previously encountered wear may lead to failure in the system.

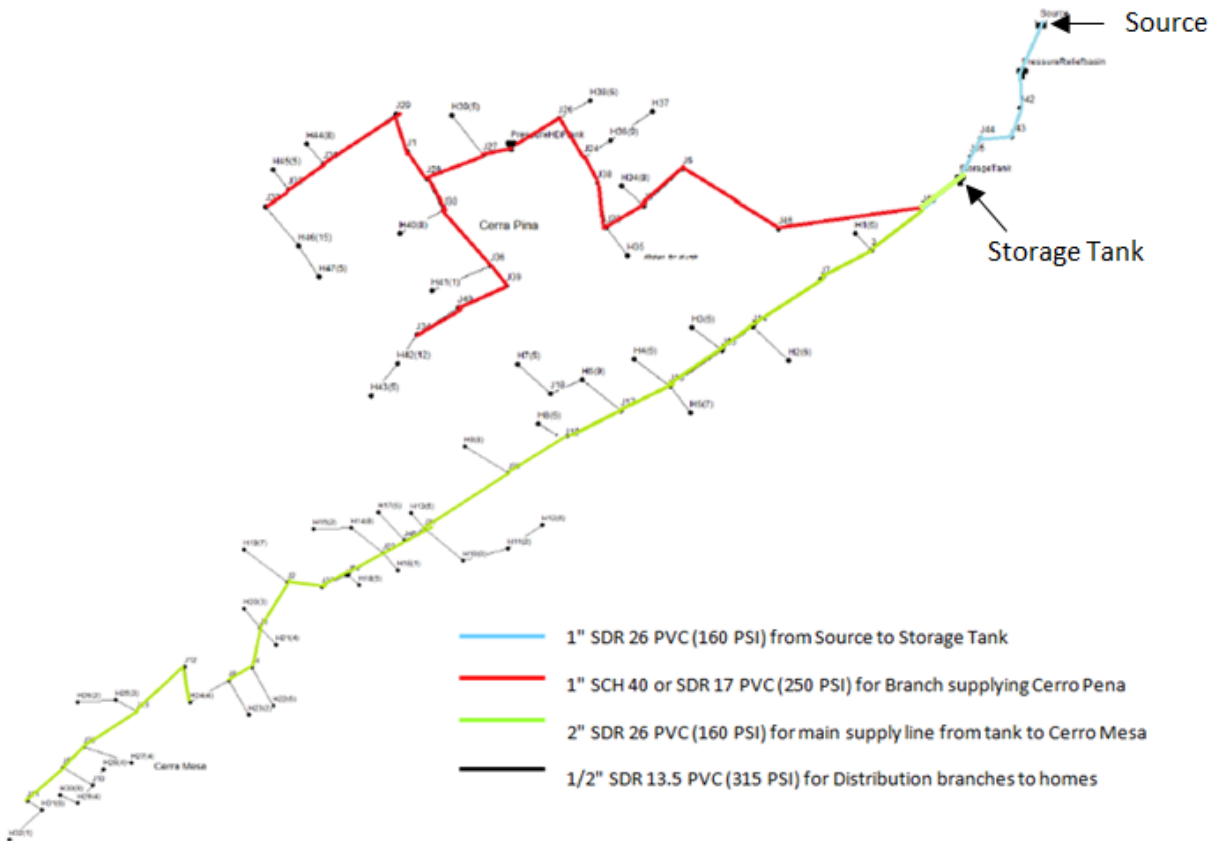


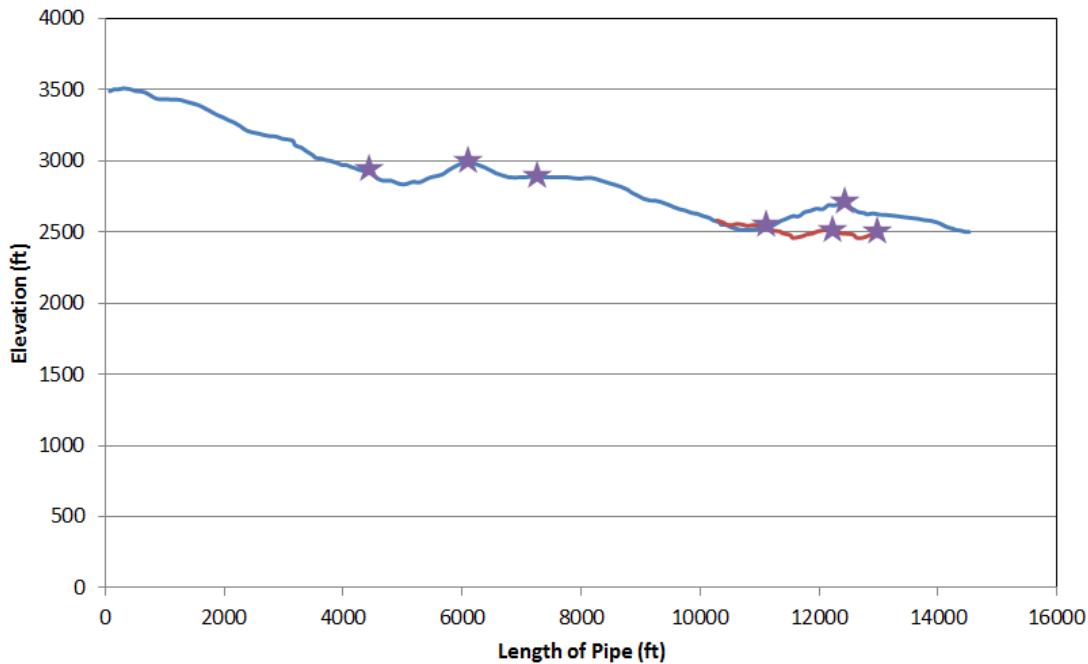
Figure 15. Map of water distribution branches, indicating recommended pipe size and strength for each section of pipe.

## Appendix O: Air release valves

Air release valves should be placed at any high points along the pipeline, where it travels downhill then uphill, and then back downhill. A buildup of air in the system can lead to blockages, so it is essential to the design that these be placed along the pipeline. A list of suggested locations for these valves is shown below (Table 5), as well as an image showing these locations along an elevation profile of the system.

**Table 5. Suggested locations for air release valves, based on collected survey data. Note: These locations are subject to change based on the final route of the implemented pipeline.**

GPS Point	Calculated Elevation (ft)	GPS Location	Notes
57	2853.57	N8 24.793 W81 51.862	Only Slight Elevation Change
66	2997.38	N8 24.717 W81 51.983	High Point on Hill
78	2893.92	N8 24.572 W81 52.118	Slight Elevation Increase along Plain
132	2688.60	N8 23.890 W81 52.335	On top of Hill Towards Cerro Mesa
161	2558.43	N8 24.287 W81 52.374	Branch Towards Cerro Peña
180	2514.55	N8 24.272 W81 52.501	Entering Cerro Peña
188	2486.50	N8 24.243 W81 52.596	Before last house on Cerro Peña Branch



**Figure 16. Locations for air release valves plotted on the elevation profile from the source to the first junction in Cerro Peña (shown in red) and down to Cerro Mesa**



For areas where there is only a short uphill inclination (less than 10 feet) a notch should be made in the pipe at the high point, so that air has a location where it can release from the system. Although water will also release from this point, the amount of water leaving the pipe is negligible to the overall system. The notch should be of minimal size, to prevent major contaminants from entering the system.

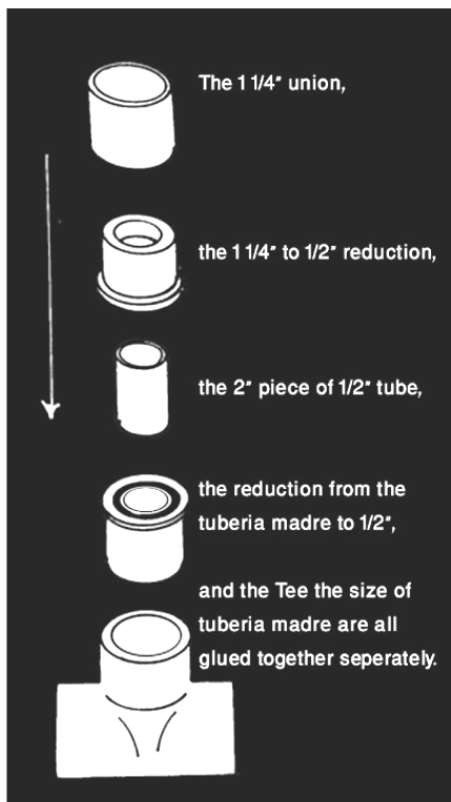
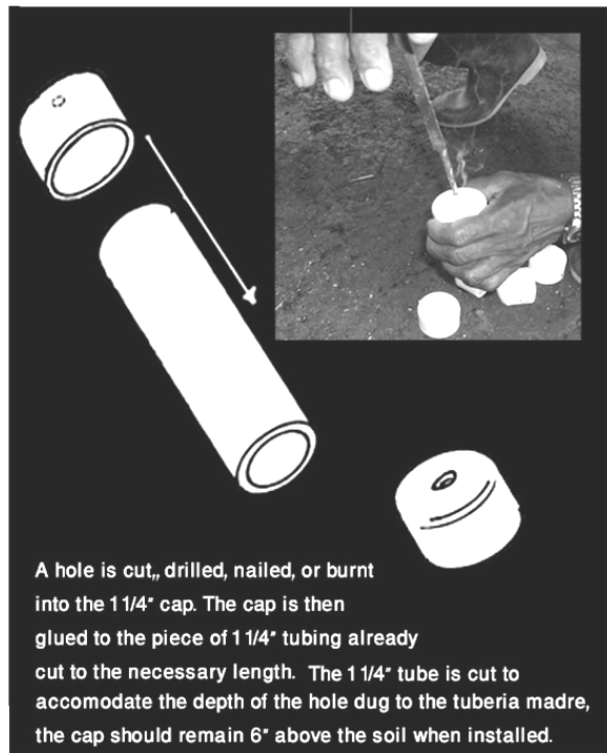
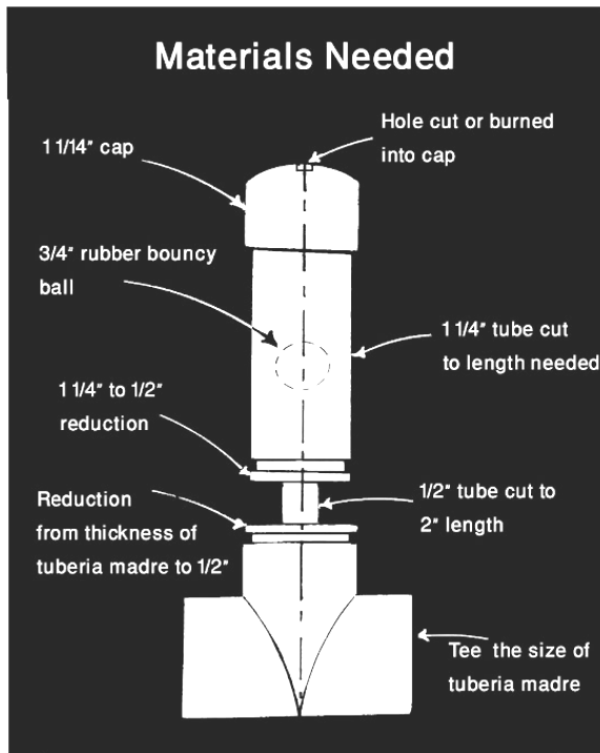
The air relief valve can be constructed on site by hand. It will be necessary to burn or cut a hole in the top cap of the release valve, allowing an escape for the air, with an internal ball that will close the valve when water is flowing through the system. A manual for construction of the proposed air release valve is described in further depth (Figure 17).

Air release valves must be placed above ground, so that the air has an escape path. The valve should be protected with concrete blocks, so that it is not damaged, which may hinder the effectiveness of the system as a whole, but still must be accessible.

It is important that the glue dries thoroughly before the internal ball is inserted, and that the ball does not become glued to the inside. Be sure to check and make sure the ball is loose before it is installed in the system.

The following materials are necessary for the construction of an air release valve. If the following pipe sizes are not available, another pipe size ( $\pm 0.25$  inches) may be select, however it is imperative that the valve is tested before it is installed, to ensure that the ball can completely cover the top hole and prevent the escape of water.

- 2" length of  $\frac{1}{2}$ " diameter PVC pipe
- 3" – 5" length of  $1\frac{1}{4}$ " diameter PVC Pipe
- Standard T Joint for the size of the main pipeline
- One reducer fitting the main pipeline to  $\frac{1}{2}$ " pipe
- One reducer fitting the  $\frac{1}{2}$ " pipe to the  $1\frac{1}{4}$ " pipe
- One  $1\frac{1}{4}$ " end cap
- One plastic ball,  $\frac{3}{4}$ " in diameter



## Air Valve/Respirador

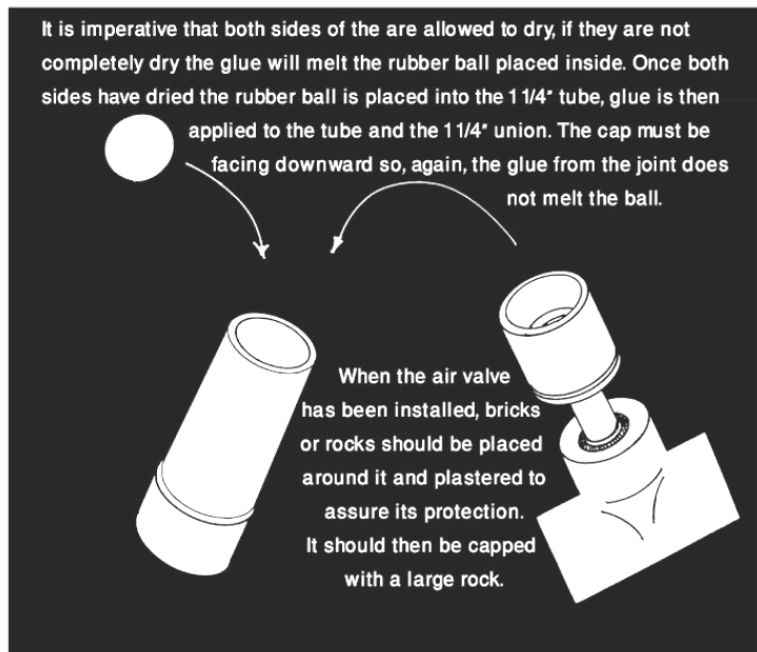


Figure 17. Air release valve construction manual built using PVC pipe.

## **Appendix P: Maintenance valves**

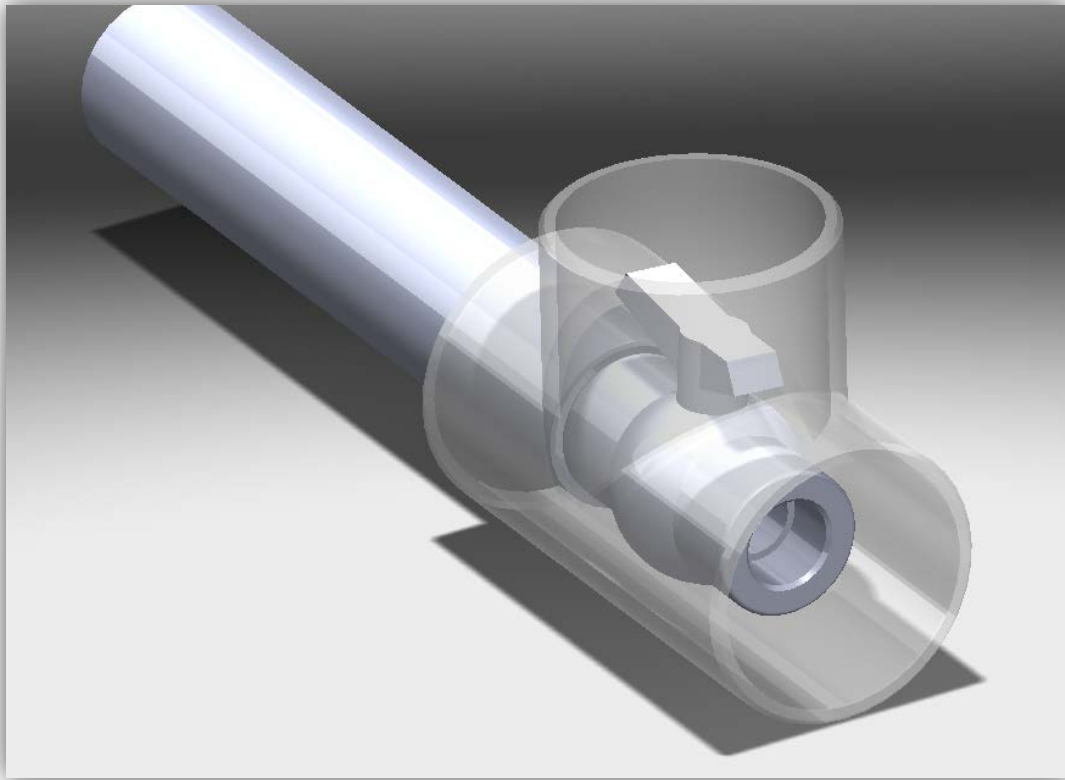
Maintenance valves should be placed in specified locations in the system that will not allow the pressures in the pipeline to become exceedingly high when closed. These maintenance valves will be useful in the event that the pipe breaks in one of the communities. This way, the supply of water can be shut off at the nearest maintenance valve, instead of shutting it off directly from the storage tank.

The type of valve selected can be whatever is most readily available to the community as well as cost effective. It is suggested that valves be placed in the following locations:

- Directly after the spring box
- Immediately before the pressure break tank
- Directly after the main storage tank
- On the beginning of the branch extending towards Cerro Peña
- Immediately before the HDP pressure break tank
- As the pipeline is entering Hato Pilón Arriba
- At the top of the hill before entering Cerro Mesa

These locations are suggested taking into the consideration of water hammer. If a valve is closed instantaneously, it will cause a shock in the system and lead to an increase in pressure directly before the valve. This pressure increase may cause the pipe to burst, however pressure calculations were performed to ensure that these locations will not cause a pressure higher than the strength of the pipe. Caution must still be used when closing valves.

Valves can be placed above ground or below ground, as long as they are sufficiently protected. If they are placed above ground, they must have a protection cover which can be constructed from cement blocks. If they are placed below ground, they can be made accessible with a larger PVC pipe surrounding the valves, as shown below. The large pipe will protrude above ground and be covered with a cap, so that you simply remove the cap and reach in to access the valve. If valves are placed below ground, the valve must be selected more carefully, as valves with large handles will not fit inside of the 4" pipe.



**Figure 18. Example of valve covering if placed underground. Shown here is a 2" pipe covered with a 4" pipe and a short handled ball valve.**

The standing water committee has the additional option of adding an extra valve with on each spigot branch. This could be used to turn off the water to one spigot if a family fails to pay their monthly water bill. The placement of these will be at the discretion of the community, as it is an additional cost to the overall project and was *not included* in the cost estimate.

## **Appendix Q: Flow reducers for distribution branches**

All 1/2" branches should include a flow reducer, as shown below. These flow reducers can be constructed by thermoforming the PVC pipe. These should be put in place to prevent the demand at one spigot from depleting supply at another spigot. For example, if one tap was left open all day another tap farther down the line may receive less water; however with a flow reducer in place it will ensure that it is not significantly less water.



**Figure 19. Example of flow reducer that would be placed on the system. These attachments can be handmade by melting PVC pipe, and may be placed on every 1/2" branch of the system.**

## Appendix R: Cost estimate

Table 6. Total cost estimate for the distribution system, broken down by each design component

Structure	Component	Cost
<b>Spring Box</b>	Materials	\$121
	Skilled Labor	\$84
	Unskilled Labor	\$0
	<b>Spring box total</b>	<b>\$205</b>
<b>Main Pipeline</b>	Materials	\$4,552
	Skilled Labor	\$388
	Unskilled Labor	\$0
	<b>Main pipeline total</b>	<b>\$4,940</b>
<b>Pressure Break Tank</b>	Materials	\$84
	Skilled Labor	\$15
	Unskilled Labor	\$0
	<b>Pressure break total</b>	<b>\$99</b>
<b>Storage Tank</b>	Materials	\$745
	Skilled Labor	\$388
	Unskilled Labor	\$0
	<b>Storage tank total</b>	<b>\$1,133</b>
<b>HDP Pressure Relief</b>	Materials	\$103
	Skilled Labor	\$30
	Unskilled Labor	\$0
	<b>HDP relief total</b>	<b>\$133</b>
<b>Distribution Branches</b>	Materials	\$1,933
	Skilled Labor	\$336
	Unskilled Labor	\$0
	<b>Distribution total</b>	<b>\$2,269</b>
<b>In-Line Chlorinator</b>	Materials	\$64
	Skilled Labor	\$10
	Unskilled Labor	\$0
	<b>Chlorinator total</b>	<b>\$74</b>
<b>Air Release Valves</b>	Materials	\$364
	Skilled Labor	\$2
	Unskilled Labor	\$0
	<b>Air release total</b>	<b>\$367</b>
<b>Total</b>	Materials	\$7,965
	Skilled Labor	\$1,254
	Unskilled Labor	\$0
	<b>All included</b>	<b>\$9,219</b>

**Table 7. Total cost estimate for the distribution system, broken down by each design component**

Proposed Cost Estimate		Materials				Labor								
Item	Quantity per Unit	Size	Unit Cost	Number of Units	Material Cost	Task	Unit MH	Unit measure	Calculated MH	Skilled MH	Skilled Worker Rate (\$/hour)	Unskilled Worker Rate (\$/hour)	Labor Cost	
<b>Detailed Materials List</b>														
<b>Spring Box</b>														
Cement Mix	100	lbs	\$8.95	0.56	\$5.01	Form Placement	10.1	100 ft <sup>2</sup>	2.273	0.758	\$3.50	\$0.00	\$2.65	
Sand	35	ft <sup>3</sup>	\$24.50	0.34	\$8.33	Brickwork								
Gravel	35	ft <sup>3</sup>	\$26.00	0.03	\$0.74	Cement mortar	18	15.3 ft <sup>3</sup>	21.176	7.059	\$3.50	\$0.00	\$24.71	
Rebar	30	ft	3/8"	\$9.00	1.33	\$12.00	Placing Blocks	18.1	100 ft <sup>2</sup>	48.870	16.290	\$3.50	\$0.00	\$57.02
Sika 1 Cement Coating	4	kg	\$12.50	0.25	\$3.13									
Wood Board	12	ft	2" x 4"	\$5.50	2.00	\$11.00								
Wood Board	12	ft	1" x 12"	\$7.80	2.00	\$15.60								
Concrete Blocks	1		4"x8"16"	\$0.53	0.00	\$0.00								
Concrete Blocks	1		6"x8"16"	\$0.73	67.00	\$48.91								
Cement Spade	1		\$5.00	2.00	\$10.00									
Cement Spreader	1		\$3.00	2.00	\$6.00									
<b>Total</b>					\$120.71				72.319				\$84.37	
<b>Main Pipeline</b>														
1" PVC Pipe, SDR 26 (8,377 ft)	20	ft	1"	\$4.25	420.00	\$1,785.00	Pipe installation, 1"	3.20	100 ft	268.800	44.800	\$3.50	\$0.00	\$156.80
90 or 45 degree Elbow	1		1"	\$1.00	42.00	\$42.00								
1" PVC Ball Valve	1		1"	\$4.50	2.00	\$9.00	Valves	0.28	each	0.560	0.093	\$3.50	\$0.00	\$0.33
2" PVC Pipe, SDR 26 (6150 ft)	20	ft	2"	\$7.25	315.00	\$2,283.75	Pipe installation 2"	5.5	100 ft	346.500	57.750	\$3.50	\$0.00	\$202.13
Standard T or Y	1		2"	\$1.50	52.00	\$78.00	"T" installation 2"	6	per 10	31.200	5.200	\$3.50	\$0.00	\$18.20
90 or 45 degree Elbow	1		2"	\$1.25	32.00	\$40.00								
Reducer	1		2" x 1/2"	\$0.95	35.00	\$33.25								
PVC Ball Valve	1		2"	\$7.75	5.00	\$38.75	Valves	0.28	each	1.400	0.233	\$3.50	\$0.00	\$0.82
PVC Glue	473	mL		\$7.25	3.00	\$21.75								
<b>Maintenance Valve Cover</b>						\$0.00								
4" PVC Pipe	20	ft	4"	\$16.00	1.00	\$16.00	Pipe installation, 4"	8	100 ft	1.600	0.400	\$3.50	\$0.00	\$1.40
Standard T or Y	1		4"	\$7.25	5.00	\$36.25	"T" installation 2"	6	per 10	3.000	0.750	\$3.50	\$0.00	\$2.63
End Cap	1		4"	\$3.25	5.00	\$16.25								
<b>Cable Bridge</b>						\$0.00								
Cable	1	lbs		\$1.25	80.00	\$100.00	Cable							
Protective PVC Pipe, SDR 26 (80 ft)	20	ft	2"	\$7.25	4.00	\$29.00	Pipe installation 2"	5.5	100 ft	4.400	0.733	\$3.50	\$0.00	\$2.57
Galvanized Steel Pipe	20	ft	2"	\$22.50	1.00	\$22.50	Steel pipe2"	1.9	10 ft	3.800	0.950	\$3.50	\$0.00	\$3.33
<b>Total</b>						\$4,551.50			661.260				\$388.19	

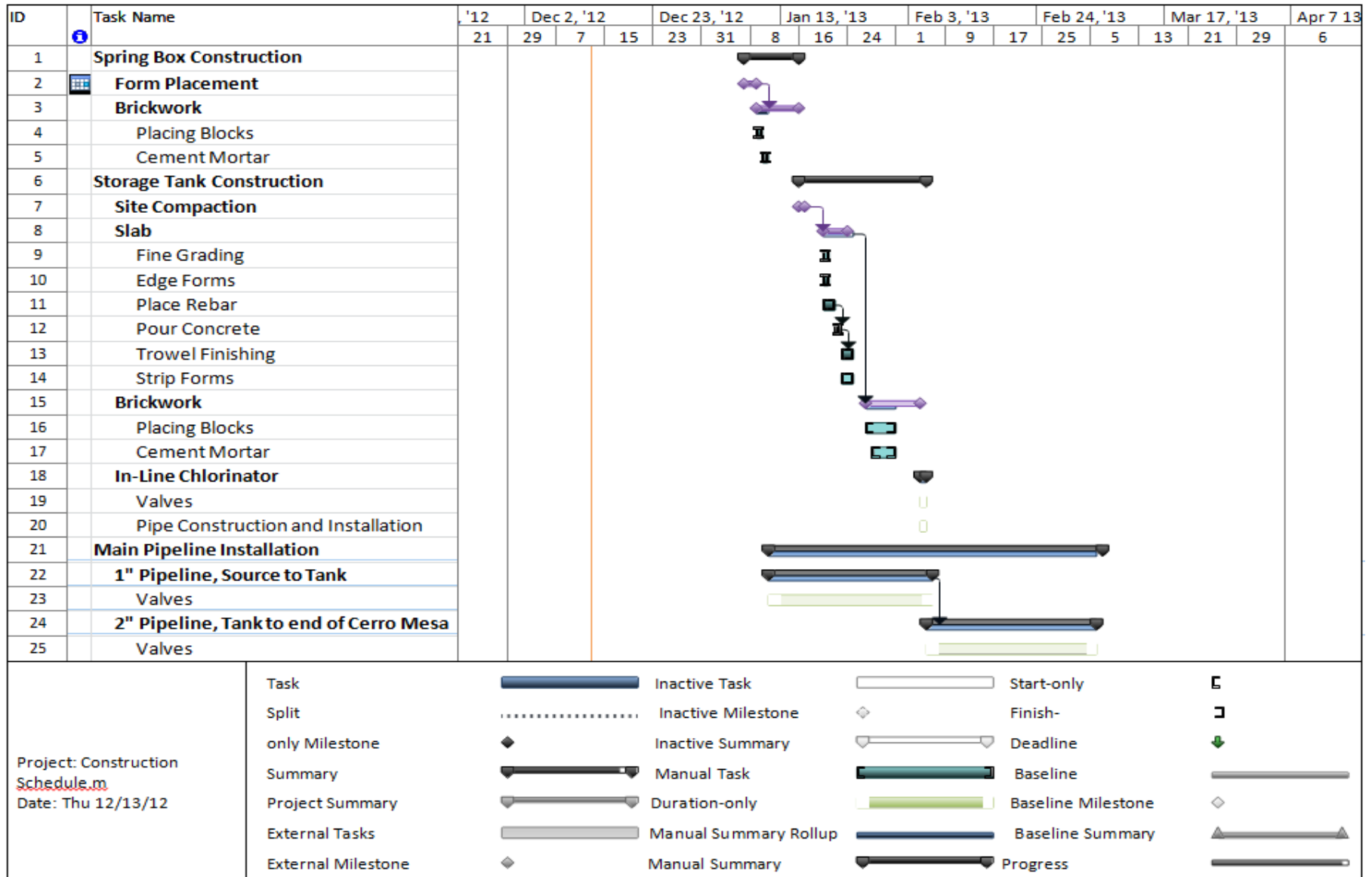
Item	Quantity per Unit		Size	Unit Cost	Number of Units	Material Cost	Task	Unit MH	Unit measure	Calculated MH	Skilled MH	Skilled Worker Rate (\$/hour)	Unskilled Worker Rate (\$/hour)	Labor Cost
<b>Pressure Break Tank</b>														
Cement Mix	100	ft		\$8.95	0.80	\$7.16	Site compaction	1	100 ft <sup>2</sup>	0.090	0.023	\$3.50	\$0.00	\$0.08
Sand	35	ft <sup>3</sup>		\$24.50	0.25	\$6.25	Slab							
Gravel	35	ft <sup>3</sup>		\$26.00	0.11	\$2.95	Fine grading	1	100 ft <sup>2</sup>	0.090	0.023	\$3.50	\$0.00	\$0.08
Rebar	30	ft	3/8"	\$9.00	1.40	\$12.60	Edge forms	4.5	100 ft	0.540	0.135	\$3.50	\$0.00	\$0.47
Sika 1 Cement Coating	4	kg		\$12.50	0.25	\$3.13	Place rebar	0.6	100 ft	0.252	0.063	\$3.50	\$0.00	\$0.22
Wood Board	12	ft	2" x 4"	\$5.50	3.00	\$16.50	Pour concrete	0.8	100 ft <sup>2</sup>	0.072	0.018	\$3.50	\$0.00	\$0.06
Wood Board	12	ft	1" x 12"	\$7.80	0.00	\$0.00	Trowel finishing	1.6	100 ft <sup>2</sup>	0.144	0.036	\$3.50	\$0.00	\$0.13
Concrete Blocks	1		4"	\$0.53	0.00	\$0.00	Strip forms	1.2	100 ft	0.144	0.036	\$3.50	\$0.00	\$0.13
Concrete Blocks	1		6"	\$0.73	26.00	\$18.98	Brickwork							
Cement Spade	1			\$5.00	2.00	\$10.00	Cement mortar	10.5	15.3 ft <sup>3</sup>	9.265	2.316	\$3.50	\$0.00	\$8.11
Cement Spreader	1			\$3.00	2.00	\$6.00	Placing Blocks	18.1	100 ft <sup>2</sup>	6.516	1.629	\$3.50	\$0.00	\$5.70
<b>Total</b>						\$83.56				17.113				\$14.97
<b>Storage Tank</b>														
Cement Mix	100	lbs		\$8.95	9.21	\$82.43	Site compaction	1	100 ft <sup>2</sup>	1.000	0.250	\$3.50	\$0.00	\$0.88
Sand	35	ft <sup>3</sup>		\$24.50	3.46	\$84.67	Slab							
Gravel	35	ft <sup>3</sup>		\$26.00	1.19	\$30.93	Fine grading	1	100 ft <sup>2</sup>	1.000	0.250	\$3.50	\$0.00	\$0.88
Rebar	30	ft	3/8"	\$9.00	14.00	\$126.00	Edge forms	4.5	100 ft	1.800	0.450	\$3.50	\$0.00	\$1.58
Sika 1 Cement Coating	4	kg		\$12.50	1.75	\$21.88	Place rebar	0.6	100 ft	2.520	0.630	\$3.50	\$0.00	\$2.21
Wood Board	12	ft	2" x 4"	\$5.50	4.00	\$22.00	Pour concrete	0.8	100 ft <sup>2</sup>	0.128	0.032	\$3.50	\$0.00	\$0.11
Wood Board	12	ft	1" x 12"	\$7.80	3.00	\$23.40	Trowel finishing	1.6	100 ft <sup>2</sup>	1.600	0.400	\$3.50	\$0.00	\$1.40
Concrete Blocks	1		4"	\$0.53	0.00	\$0.00	Strip forms	1.2	100 ft	0.480	0.120	\$3.50	\$0.00	\$0.42
Concrete Blocks	1		6"	\$0.73	440.00	\$321.20	Brickwork							
Cement Spade	1			\$5.00	4.00	\$20.00	Cement mortar	10.5	15.3 ft <sup>3</sup>	125.588	31.397	\$3.50	\$0.00	\$109.89
Cement Spreader	1			\$3.00	4.00	\$12.00	Placing Blocks	18.1	100 ft <sup>2</sup>	52.800	13.200	\$3.50	\$0.00	\$46.20
<b>Total</b>						\$744.51				186.916				\$163.55

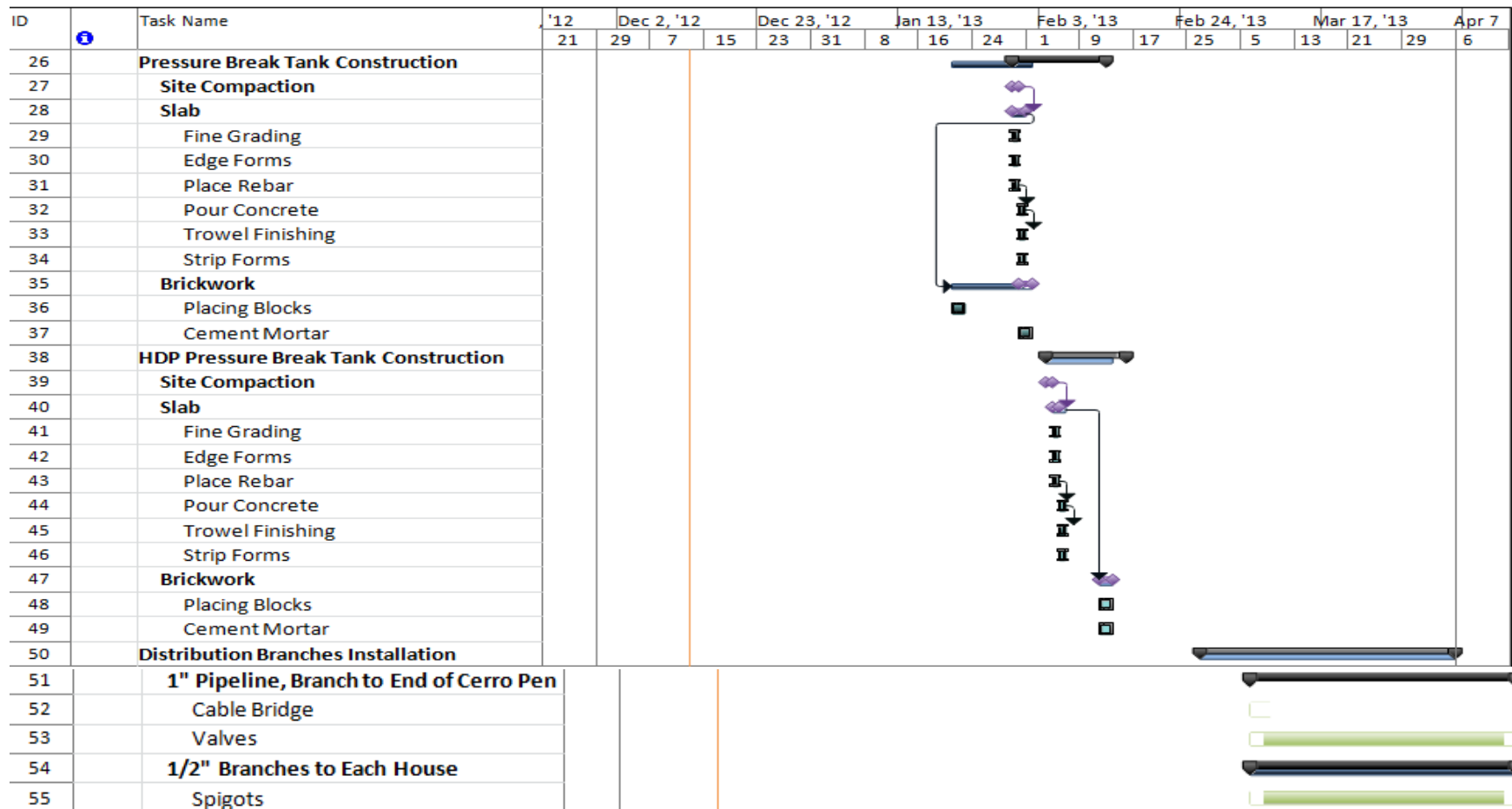


Item	Quantity per Unit		Size	Unit Cost	Number of Units	Material Cost	Task	Unit MH	Unit measure	Calculated MH	Skilled MH	Skilled Worker Rate (\$/hour)	Unskilled Worker Rate (\$/hour)	Labor Cost
<b>HDP Pressure Relief</b>														
<b>Cement Cover Box</b>														
Cement Mix	100	lbs		\$8.95	0.10	\$0.90	Site compaction	1	100 ft <sup>2</sup>	0.160	0.080	\$3.50	\$0.00	\$0.28
Sand	35	ft <sup>3</sup>		\$24.50	0.14	\$3.47	Slab							
Gravel	35	ft <sup>3</sup>		\$26.00	0.06	\$1.47	Fine grading	1	100 ft <sup>2</sup>	0.160	0.080	\$3.50	\$0.00	\$0.28
Rebar	30	ft	3/8"	\$9.00	0.80	\$7.20	Edge forms	4.5	100 ft	0.540	0.270	\$3.50	\$0.00	\$0.95
Sika 1 Cement Coating	4	kg					Place rebar	0.6	100 ft	0.144	0.072	\$3.50	\$0.00	\$0.25
Wood Board	12	ft	2" x 4"	\$5.50	1.00	\$5.50	Pour concrete	0.8	100 ft <sup>2</sup>	0.072	0.036	\$3.50	\$0.00	\$0.13
Wood Board	12	ft	1" x 12"	\$7.80	0.00	\$0.00	Trowel finishing	1.6	100 ft <sup>2</sup>	0.144	0.072	\$3.50	\$0.00	\$0.25
Concrete Blocks	1		4"	\$0.53	0.00	\$0.00	Strip forms	1.2	100 ft	0.144	0.072	\$3.50	\$0.00	\$0.25
Concrete Blocks	1		6"	\$0.73	26.00	\$18.98	Brickwork							
<b>Piping</b>														
							Cement mortar	10.5	15.3 ft <sup>3</sup>	3.431	1.716	\$3.50	\$0.00	\$6.00
1" PVC Pipe, SCH 40 (2,992 ft)	20	ft	1"	\$5.75	1.00	\$5.75	Placing Blocks	18.1	100 ft <sup>2</sup>	6.516	3.258	\$3.50	\$0.00	\$11.40
3" PVC Pipe	20	ft	4"	\$16.00	1.00	\$16.00	Pipe installation 3"	6.0	100 ft	1.200	0.600	\$3.50	\$0.00	\$2.10
Standard T	1		4"	\$7.25	3.00	\$21.75	"T" installation 4"	10	per 10	3.000	1.500	\$3.50	\$0.00	\$5.25
End Cap	1		4"	\$3.25	2.00	\$6.50								
Standard T or Y	1		2"	\$1.50	2.00	\$3.00	"T" installation 2"	6	per 10	1.200	0.600	\$3.50	\$0.00	\$2.10
Reducer	1		2" x 4"	\$1.50	3.00	\$4.50								
PVC Ball Valve	1		2"	\$7.75	1.00	\$7.75	Valves	0.28	each	0.560	0.280	\$3.50	\$0.00	\$0.98
Total						\$102.77				17.271				\$30.22
<b>Distribution Branches</b>														
1" PVC Pipe, SCH 40 (2,992 ft)	20	ft	1"	\$5.75	150.00	\$862.50	Pipe installation, 1"	16.1	100 ft	483.000	80.500	\$3.50	\$0.00	\$281.75
90 or 45 degree Elbow	1		1"	\$1.00	15.00	\$15.00								
1" PVC Ball Valve	1		1"	\$4.50	2.00	\$9.00	Valves	0.28	each	0.560	0.093	\$3.50	\$0.00	\$0.33
0.5" PVC Pipe (2620 ft)	20	ft	1/2"	\$2.75	140.00	\$385.00	Pipe installation, 0.5"	1.1	100 ft	30.800	5.133	\$3.50	\$0.00	\$17.97
Standard T or Y	1		1/2"	\$0.25	15.00	\$3.75	"T" installation 1/2"	1.6	per 10	2.400	0.400	\$3.50	\$0.00	\$1.40
90 degree Elbow	1		1/2"	\$0.25	100.00	\$25.00								
Coupling	1		1/2"	\$0.30	70.00	\$21.00								
PVC Glue	473	mL		\$7.25	2.00	\$14.50								
Metal Spigot with Valve	1		1/2"	\$2.50	50.00	\$125.00	Valves	0.28	each	14.000	2.333	\$3.50	\$0.00	\$8.17
Support stake, 2" Galvanized Pipe	20	ft	2"	\$22.50	12.50	\$281.25	Base							
Cement Mix	100	lbs		\$8.95	3.50	\$31.33	Edge forms	4.5	100 ft	18.000	4.500	\$3.50	\$0.00	\$15.75
Sand	35	ft <sup>3</sup>		\$24.50	0.62	\$15.27	Place rebar	0.6	100 ft	2.400	0.600	\$3.50	\$0.00	\$2.10
Gravel	35	ft <sup>3</sup>		\$26.00	0.95	\$24.67	Pour concrete	0.8	100 ft <sup>2</sup>	1.600	0.400	\$3.50	\$0.00	\$1.40
Rebar	30	ft	3/8"	\$9.00	13.33	\$120.00	Trowel finishing	1.6	100 ft <sup>2</sup>	3.200	0.800	\$3.50	\$0.00	\$2.80
							Strip forms	1.2	100 ft	4.800	1.200	\$3.50	\$0.00	\$4.20
Total						\$1,933.27				560.760				\$335.86

Item	Quantity per Unit		Size	Unit Cost	Number of Units	Material Cost	Task	Unit MH	Unit measure	Calculated MH	Skilled MH	Skilled Worker Rate (\$/hour)	Unskilled Worker Rate (\$/hour)	Labor Cost
<b>In-Line Chlorinator</b>														
1" PVC Pipe	20	ft	1"	\$4.25	1.00	\$4.25	Pipe installation, 1"	3.2	100 ft	0.640	0.320	\$3.50	\$0.00	\$1.12
90 or 45 degree Elbow	1		1"	\$1.00	4.00	\$4.00								
1" PVC Ball Valve	1		1"	\$4.50	2.00	\$9.00	Valves	0.28	each	0.560	0.280	\$3.50	\$0.00	\$0.98
Standard T or Y	1		1"	\$1.50	2.00	\$3.00	"T" installation 1"	2.4	per 10	0.480	0.240	\$3.50	\$0.00	\$0.84
3" PVC Pipe	20	ft	3"	\$12.00	1.00	\$12.00	Pipe installation, 3"	6	100 ft	1.200	0.600	\$3.50	\$0.00	\$2.10
4" PVC Pipe	20	ft	4"	\$16.00	1.00	\$16.00	Pipe installation, 4"	8	100 ft	1.600	0.800	\$3.50	\$0.00	\$2.80
Coupling	1		4"	\$2.75	2.00	\$5.50								
Standard T	1		4"	\$7.25	1.00	\$7.25	"T" installation 4"	10	per 10	1.000	0.500	\$3.50	\$0.00	\$1.75
End Cap	1		4"	\$3.25	1.00	\$3.25								
<b>Total</b>						\$64.25				5.480				\$9.59
<b>Additional Costs</b>														
Shovel	1			\$12.00	10.00	\$120.00								
Pick-ax	1			\$20.00	10.00	\$200.00								
<b>Air Release Valves</b>														
0.5" PVC Pipe	20	ft	1/2"	\$2.75	1.00	\$2.75	0.5"	1.1	100 ft	0.220	0.037	\$3.50	\$0.00	\$0.13
1.25" PVC Pipe	20	ft	1 1/4"	\$5.25	1.00	\$5.25	Pipe installation, 1.25"	4.5	100 ft	0.900	0.150	\$3.50	\$0.00	\$0.53
Standard T or Y	1		1"	\$1.00	3.00	\$3.00	"T" installation 1"	2.4	per 10	0.720	0.120	\$3.50	\$0.00	\$0.42
Standard T or Y	1		2"	\$1.50	4.00	\$6.00	"T" installation 2"	6	per 10	2.400	0.400	\$3.50	\$0.00	\$1.40
Reducer	1		1" x 1/2"	\$0.95	3.00	\$2.85								
Reducer	1		2" x 1/2"	\$0.95	4.00	\$3.80								
Reducer	1		1 1/4" x 1/2"	\$0.95	7.00	\$6.65								
End Cap	1		1 1/4"	\$1.00	7.00	\$7.00								
Rubber Ball	1		3/4"	\$1.00	7.00	\$7.00								
<b>Total</b>						\$364.30				4.240				\$2.47
<b>System Subtotal</b>						\$7,964.87			Total MH	1525.359			Wages	#####
<b>Total Cost</b>						\$8,994								

## Appendix S: Construction schedule





Project: Construction Schedule.m  
Date: Thu 12/13/12

48 Figure 20. Construction schedule created in Microsoft project the estimated total time for the project is approximately 4 months.

Table 8. RS means data used to approximate the necessary time for each design component construction.

<b>From RS Means</b>			
<b>Work Element</b>		<b>Unit</b>	<b>Per Unit</b>
<b>Pipe Installation</b>	1/2"	100 ft	1.10
	1"	100 ft	3.20
	1.25"	100 ft	4.50
	1.5"	100 ft	5.40
	2"	100 ft	5.50
	3"	100 ft	6.00
	4"	100 ft	8.00
<b>Elbow Installation</b>	0.5"	Per 10	1.20
	1"	Per 10	2.00
	2"	Per 10	4.00
	3"	Per 10	6.00
	4"	Per 10	10.00
<b>T</b>	0.5"	Per 10	1.60
	1"	Per 11	2.40
	2"	Per 12	6.00
	3"	Per 13	8.00
	4"	Per 14	10.00
<b>Valves</b>		each	0.28
<b>Site Compaction</b>		100 ft <sup>2</sup>	1
<b>Form Placement</b>		100 ft <sup>2</sup>	10.1
<b>Masonry Block Placement</b>	4" width	100 ft <sup>2</sup>	
	6" width	100 ft <sup>2</sup>	12.00
	12" width	100 ft <sup>2</sup>	18.10
<b>Cement Mortar</b>		15.3 ft <sup>3</sup>	10.5
Fine grading		100 ft <sup>2</sup>	1
Edge forms		100 ft	4.5
Place rebar		100 ft	0.6
Pour concrete		100 ft <sup>2</sup>	0.8
Trowel finishing		100 ft <sup>2</sup>	1.6
Strip forms		100 ft	1.2

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# Environmental Impact Assessment

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Aqueduct system  
Provincia de Chiriqui, Panama

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Prepared by Team Hard Body  
Michigan Technological University

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## Preface

In July 1, 1998, the General Environmental Law (Law No.1) of the Republic of Panama was established. Regulatory authorities that oversee key legislations include local municipalities, ministry of health, the District Attorney and the National Environment Authority (*Autoridad Nacional del Ambiente*) (ANAM).

Key legislation is comprised of three Titles, each serving a different purpose. Title I is comprised of objectives and basic definitions. Titles II & III pertain to the strategies and actions along with the creation of ANAM. The obligation of ANAM is to develop and sustain necessary actions to obtain results on the integrated triangle of sustainable development with its economic, social and environmental components (HERNANDEZ VIRVIESCAS). The agency's role includes the development of environmental impact assessments or studies, criminal codes for crimes against the environment, environmental adaption and management programs, as well as environmental audits. Currently many regulations are enforced on the largest polluters, and environmental impact study (EIS) are demanded from mining companies. Policies and regulations for the environment have been developed, but rules and implementations are still up for debate.

EIS are regulated through decree No.123 developed in August 2009 and modified by decree No.155 in 2011. These enforce the requirement to submit an EIS or assessment to ANAM for approval of activities, work or projects related to various activities found listed in the legislation. Certain activities also require a permit in addition to an EIS, amongst these is the use or discharge of water, and the treatment of sewage or potable water. When a project is proposed to be developed within an indigenous community, prior arrangements must be made ensuring the benefits are shared with the indigenous communities.

This document is an environmental impact assessment pertaining to the construction of an aqueduct system in Hato Pilón Arriba, Cerro Mesa, and Cerro Peña in Provincia de Chiriqui, Panama. The pipeline construction begins at the home of Emilio Quintero and continues to the last home in Cerro Mesa with an overall elevation change of 1,169 feet. In between there are much greater elevation dips and rises. The length of pipeline required is 20,135 feet total, including branches to each home. This document covers the type of construction that will be required and any potential environmental impacts, both positive and negative, that may result from this said construction. Suggestions are included on how to minimize any potential impacts and the benefit of doing so.

This report was prepared by the international senior design team of Hard Body Engineering at Michigan Technological University in Houghton Michigan. Comprised of Angella Mickowski, Kelsey Maijala, Rebecca Bender, and Cheriese Radionoff.

## **Project Overview**

The international senior design team, Hard Body Engineering, from Michigan Technological University in Houghton, Michigan travelled to Chiriqui Panama in order to collect data to design a water distribution system and develop a socioeconomic understanding of the Ngöbe Bugle tribes. The region is similar to an Indian Reservation in the United States and has little formal economy or political influence. The available skilled labor is minimally available from within the tribe and the majority of earned income comes from working outside of the region.

## **Location and Description**

The system is engineered as a gravity-fed water system from a spring source at the home of Emilio Quintero. The water source is clear with a turbidity of approximately 1 NTU. A chlorinator is included in the design. There are committees in each community that are to collect monies from each home for the use of the water. The funds are then allocated to the maintenance and upkeep of the system. With very little budget information, the team developed a system based on prices from the closest hardware store in San Felix.

## **Purpose and Need**

The indigenous population of the region is in no way unfamiliar with being stricken sick from ingesting unsafe water. Many accept it as a way of life as do their children. According to Minority Rights Group International, the Ngöbe-Bugle people are the most numerous of the indigenous people inhabiting the rural jungles of Panama. They have the least political leverage of all the indigenous groups though, leaving them extremely disconnected and possibly far from receiving government help. Living on isolated reserves leaves them on their own when it comes to medical care and supplies. Most are used to going without treatment when they are sick. While collecting data in the region, team Hard Body came across a young girl who was sick from stomach ailments. When asked by the translator, her mother says it occurs often. Water is not scarce in the region by any means, but clean water is very hard to find. Traditionally the streams are used to bathe and relieve themselves in as well as sources of water for household consumption. While the practice of relieving oneself in the nearby stream is fading, many of the older population still live by tradition and continue to do so. The uncertainty of the water conditions continues to be a struggle in the region, and children are often sick. A community nestled between the three has a running water system and can receive chlorinated water. This creates social inequality between the communities.



## **Alternatives**

The alternatives to developing a water distribution supply system for the three communities of Hato Pilón Arriba, Cerro Mesa and Cerro Peña are

- Not develop a system and leave them to continue collecting water as they currently do from rain and distant streams.
- Develop a rainwater harvesting system within the communities.

## **Environmental Effects and Recommendations**

### *Water*

The spring source for the proposed system flows from the side of a hill forming a stream. This stream is joined a few hundred feet down by another stream, the source of which is unknown. The proposed diversion of water from the spring source may cause degradation downstream before it is intersected by the second stream. Since the stream itself runs for thousands of feet, the environmental impact is small in comparison of what it could potentially be. Water will still flow within the stream with the ability to be used by animals and people living nearby that will not be online with the system.

The proposed design is a gravity fed system that will flow into a 6414 gallon storage tank. The tank is equipped with an overflow pipe that will divert water back to the nearby stream. This will allow for any lost water upstream to be replaced downstream rather than flowing uselessly onto the trail.

### *Air Quality*

During the any course of the construction phase that includes concrete mixing there is a potential inhalation hazard due to particulate matter. The amount of cement being used is miniscule, and the location is far away enough to negate any health effects that may occur in the communities, with the exception of those workers constructing the tank. There are no air quality regulations in the region that the construction must adhere to though and it is suggested that the cement dust be used with caution and not be allowed to accumulate in the water or on any nearby crops. Any and all mixing should be done in an open, well-ventilated area.

### *Land Degradation*

The water pipeline should be dug at least 1 meter below the ground surface, using shovels and pickaxes. The entire pipeline will be dug on a downward slope increasing the chances for erosion to occur after the line is placed. In order to prevent erosion it is recommended that the pipeline be dug and placed in the dry season, if this is not possible work should be done in the morning when there is no rain and the soil compacted after it is placed. Also recommended is to place the pipeline at least 3 feet inward off of the foot paths so as to decrease the chances of the foot paths eroding away and the pipeline becoming exposed. Exposed piping can lead to breaks and ultra violet degradation.

### *Socioeconomic Benefits*

The overall environment in the region is expected to benefit from the development of this system. With the construction of this system, the population will have direct access to a tap at their homes, thereby decreasing the dependency on the nearby streams for bathing and relieving themselves. Each home will experience a boost of economic status and it is hoped that with this there will be a desire for amenities such as latrines. Decreasing these hazardous inputs allows the stream to be cleaner for other uses downstream.

### **Works Cited for Environmental Impact Assessment**

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