Water for Honey Hill:
Supplying Water to the Community of Cerro Miel

iDesign 2012
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CERRO MIEL AQUEDUCT SYSTEM
Cerro Miel, Panama

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Uno Más Engineering is a not a professional engineering organization. Uno Más is a group of undergraduate engineering students from Michigan Technological University. This report was prepared as part of the 2012 International Senior Design course for the community of Cerro Miel, Panama. Its contents have not been reviewed and certified by a professional engineer and should be used only as design suggestions. This report is the property of Michigan Technological University.

Mission Statement:

Uno Más Engineering seeks to provide clean drinking water to developing communities in a sustainable, reliable, economical and environmentally friendly way. Uno Más is also committed to educating community members on proper sanitation, use regulation, and system maintenance.

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1.0 Executive Summary

Cerro Miel, located in the Comarca Ngöbe-Bugle of western Panama, is a community of approximately 300-400 people that currently does not have a reliable source of drinking water for the entire population. During August of 2012, Uno Más Engineering made an assessment trip to Cerro Miel to assess the existing infrastructure, gather data to expand and improve the systems, and learn more about the community, including their needs and wants in a drinking water supply system. Uno Más then returned to the United States to develop and design a system that would supply Cerro Miel with reliable and safe drinking water. The findings and recommendations from Uno Más are detailed in this report.

The community of Cerro Miel is a rural, indigenous community where many members partake in subsistence farming as a way of life. There are currently two drinking water systems in Cerro Miel. One of the systems is a small but reliable system that supplies the school and a few homes. Although the system is reliable, it does not have the capacity to meet the needs of the entire community. The second system is a government funded project that was not properly constructed, causing frequent periods when the system is not operable due to breaks in the pipeline. While Uno Más was in the community, data was collected including survey, water availability, water quality, material cost, and construction scheduling data.

After returning to the United States, Uno Más analyzed the collected data using elevation profiling, EPANET modeling, and mapping in Google Earth in order to make final design recommendations for a reliable and safe drinking water system. Through the analysis of the data it became evident that pressure within the pipes would cause the pipeline to break at lower elevations. To address this, Uno Más designed two pressure release tanks to decrease the pressure within the pipes at lower elevations. Three tanks are to be located within the community and another near the source for the newest system. There are also points along the proposed pipeline in the community where air blockages may occur. To prevent this, Uno Más recommends air release valves to be installed in the pipeline where the possibility of air blocks is high. By installing the recommended pressure release and air release components, the pipeline will not be damaged from pressure or air blockages within the pipeline.

Pressure and air blockages are not the only things that have the potential to damage the Cerro Miel aqueduct. During the assessment trip to Cerro Miel, Uno Más discovered that there are many gully crossings where the existing supply line is not properly supported. Breaks occur frequently at these points. Uno Más recommends these gully crossings to be properly supported using the method outline in this report. There are seven gully crossings that are currently not properly supported. Another threat to the pipe is UV rays in the sunlight. These UV rays can cause PVC pipe to become brittle and break. Methods to prevent UV damage include burying the pipeline, painting the pipeline, or encasing the pipeline in a larger diameter pipe. Uno Más recommends the pipeline to be buried when possible. When the pipeline is unable to be buried and is exposed to sunlight, the pipeline should be painted.

Uno Más has made all of the recommendations to provide the community of Cerro Miel with a safe and reliable drinking water system. The final cost to construct the project is $7.850. A maintenance plan has been included in this report to ensure the system works long past installation. The findings and recommendation presented in this report will be submitted to the Peace Corps.

2.0 Introduction

Cerro Miel is a small, rural community situated in Western Panama. Currently, the area has two gravity fed water supply systems. Uno Más Engineering has been working towards improving and expanding these. IPEADEHM has provided a grant of $5,000 available for this purpose.

2.1 Community Background

Cerro Miel is situated in a mountainous region that is home to the native Ngöbe people. The Ngöbes were relocated here from the coastal land. The Comarca Ngöbe-Bugle is a governmental unit established around fifteen years ago, thus all the challenges and opportunities that come with local government have not fully been discovered and worked out. Traditionally, the Ngöbes were a more nomadic people that operated in smaller family units. The current organization of larger communities is therefore not natural for them, and this can cause challenges, especially in regards to larger projects.

The inhabitants of Cerro Miel are generally impoverished, and the challenging topography and geology of the area does not improve on the situation. Subsistence farming or having family members working in larger cities are common ways of survival. Many people rely on a bi-monthly welfare check, but because of little education, the area has a problem of this money not being used wisely. The community has a school with grades one through six. A school with grades seven through twelve is located in the community of Chichica. Though many children start school, most will not complete a level of education higher than what would be the equivalent of middle school. The language taught and spoken in school is Spanish, while most people speak the indigenous language Ngöbe at home.

2.2 Project Background

Currently, there are two water distribution systems in Cerro Miel. The oldest one is from 1998, and it is a smaller system fed by a spring source located nearby. This system currently supplies a few houses as well as the school. Since it is a spring source, the water quality is relatively high, but the flow is not sufficient to meet a higher demand. Additionally, the elevation of the source and the nearby terrain makes it impossible to supply all of the community based on gravity alone. Seeing as this is a clean and reliable source, the community has expressed a wish for having this source supply only the school. Thus, they want to take the few houses that are already on this system and connect them to the other system.

This new system was built in 2008 and was the result of a large government project. Due to Cerro Miel's high elevation, the source chosen for this system is located in a community approximately 9 miles away called Tugri. The source is a small river which means that the water quality is not on par with the spring source. The water is collected though a 3 inch pipe covered by a mesh netting to keep debris out. Rivers are also generally more affected by seasonal changes than springs, but according to people in the community, the river supplies an adequate amount throughout the year. The water quality problem was tackled by installing two slow sand filters and an inline chlorination system in Tugri. This project had a cost of over $100,000, but functioned for less than a year. There are multiple reasons for the failure of this large scale project. First, it seems that the quality of the work decreased through the construction phase, so that the pipe closer to Tugri is better buried and supported when crossing gullies. As one moves closer to Cerro Miel, there is more exposed pipe, and it is not supported when crossing gullies. The problem with not burying the pipe is that it is exposed to human and animal traffic, as well as UV radiation, which degrade PVC. The communities in the area also have a habit of burning land to clear it for farming. Since the pipe running though the properties on the route from Tugri to Cerro Miel does not supply the families living there, the owners do not care about protecting the pipe. Another aspect the project lacked was proper training of the personnel in charge of maintenance of the system. Because of this, the man in charge of the water treatment had an accident involving the sand filters which caused him to route the pipe and water around both the filters and the chlorination. Third, because of the extreme elevation changes of the area, the pressure in the system exceeds the capacity of the pipe, resulting in breaks.

The community of Cerro Miel has a functioning water committee lead by Alfonzo Surdo. The water committee is currently in charge of operating and maintaining the system, as well as making sure people pay their water fee. The current monthly fee is either $0.50 or $0.25, depending of which of the two systems a household is connected to. The plan is to have people connected to either system pay $0.50 a month. This money is to be used for operations and maintenance of the systems. There is a representative from Tugri in charge of the operations and maintenance of the part of the system that is located there. This person and Alfonzo Surdo have never had the opportunity to sit down to talk and plan together, which has posed some challenges in regards to operating the system.

2.3 Project Objectives

The purpose of this project is to design a safe and reliable water distribution system that is feasible for the community of Cerro Miel. A few key characteristics that were chosen to accomplish this were: serviceability, economy, simplicity of construction, system security, and environmental impact. Serviceability was further broken down into components of reliability, ease of maintenance and durability. This means the team wants to design a water system that always provides a sufficient flow of safe drinking water to the community. It also means that the system will be simple enough to be maintained by community members with little education on how to do so. It will also have safety features built in so that no one hurts themselves trying to maintain it. Durability of the design would ensure that the system will last a long time. It will be well constructed so that heavy rain, cows walking across the pipe, and high pressures do not put the system out of commission. Another important aspect of this project was economy. This focuses on the fact that the team was working on a limited budget and that some design decisions would need to be based on expense. Simplicity of construction is a measure of how easily the project can be built. This is very important because a thoughtful design will not do much good for the community if they are not able to build it. The construction plan incorporates not only fitting pipe together, but also transporting materials to the community, acquiring tools and labor to complete the work, and making sure the project is reasonable based on existing conditions such as soil type. The next item that Uno Más wanted to highlight in their design is the security of the system. Valves and tanks should be secure so that community members, untrained in the water system, cannot tamper with it. Also, if parts of the system break, that line can be shut off so that water and pressure are not lost to the rest of the system. The final item that Uno Más wanted to address was environmental impacts. The most important environmental issue for this system was soil erosion along the route where the pipe is buried.

2.4 Project Funding

Funding will be important in the implementation of the aqueduct project in Cerro Miel. The community of Cerro Miel currently has a grant from the Instututo Panameño Desarrollo Humano Y Municipal (IPADEHM) for $5,000. This grant is a great starting point for the funding of the project, but it will not be able to cover the cost of the entire project. IPADEHM may be able to increase the amount of the grant, but other forms of funding may still need to be considered. Alternative forms of funding can include applying for other grants or community contributions.

3.0 Data Collection

In August 2012, the team travelled to Cerro Miel and collected data on topography, water availability, and water quality. Later, information regarding water usage, gulley crossings, material costs, and scheduling were also collected, mainly through the aid of Peace Corps Volunteers Christopher Kingsley and Chet Hopp.

3.1 Surveying

During the assessment trip to Cerro Miel, a topographical survey needed to be performed of the existing and proposed pipeline. Some of the options that were available were to use a Total Station, a theodolite survey, or an Abney level and GPS. Due to the rugged terrain of the region, Uno Más decided to employ the use of an Abney level and GPS to survey the existing and proposed pipeline. An example of an Abney level is presented in Figure 1.

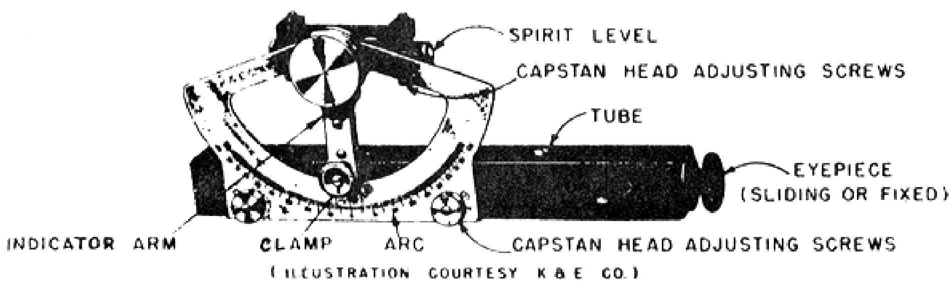

Figure 1: Abney Level Diagram
(fao.org)

The surveying was completed using the setup found in Figure 2. Each person in the figure makes a reading with the Abney level and a compass bearing. A GPS point is taken at each location. A total of 7 miles of surveying was completed within the community of Cerro Miel.

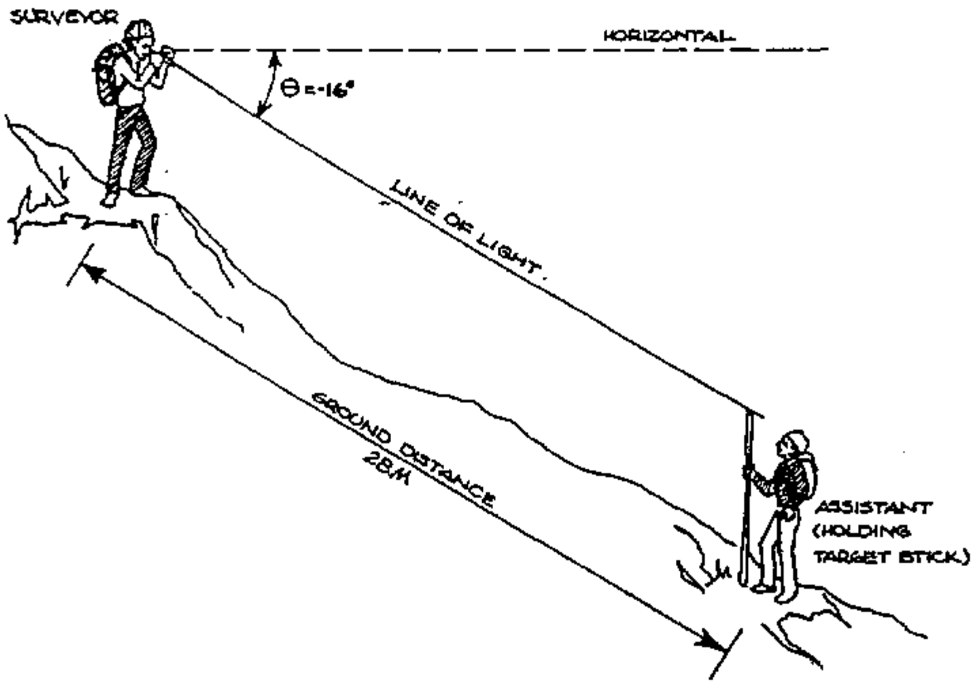

Figure 2: Abney Levey Surveying Method
(nzdl.org)

The surveying results from the assessment trip to Cerro Miel can be found in Appendix A. The GPS data from the assessment trip can be found in Appendix B.

3.2 Water Availability

Flow rate data was taken at both of the tanks to help determine the amount of water available from each source. The time-volume method was used to estimate the flow. A one liter water bottle was used for the old tank, and a five gallon bucket was used for the new tank in Tugri because of the higher flow rate. For each tank, the time to fill the container was measured and recorded. This test was performed multiple times and the final result was averaged. This data was only used as an indicator, due to the fact that the water came through the supply line from the source in cycles and was not a constant flow.

The flow from the old spring source to the tank was measured to be an average of 4.8 gal/min. The water level in the tank was very low, indicating that the supply might be insufficient for the current demand. The spring source box for the old system was also leaking, meaning that improvements could allow more water to be collected from this source. The source for the new system is located in a small stream above Tugri where there is plenty of water available from the stream to meet all current needs. The limiting factor is the 3 inch PVC pipe running from the stream to the tank in Tugri and onwards to the tank in Cerro Miel. The current flow rate from this source to the tank in Tugri is 50.7 gal/min. Flow rate data is found in Appendix C.

3.3 Water Quality

During the assessment trip in August, two types of water quality testing were conducted: coliform bacteria tests and aerobic bacteria tests. This was done using 3M Petrifilm plates. At each location where water quality information was considered useful, two samples of each test were taken to reduce the uncertainty of the sample results. The locations sampled were the spring box and tank of both the old and the new system. One ml of water was placed onto a biofilm using a clean disposable pipette before the biofilm was pressed and labeled. The samples were then incubated using body heat for 24 hours. The colonies of bacteria were then counted and recorded. The results from these tests are presented in Figure 3 for the coliform bacteria and Figure 4 for the aerobic bacteria.

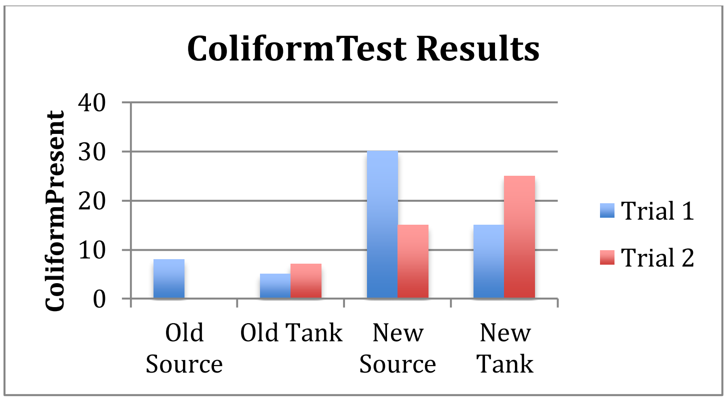

Figure 3: Coliform Bacteria Test Results

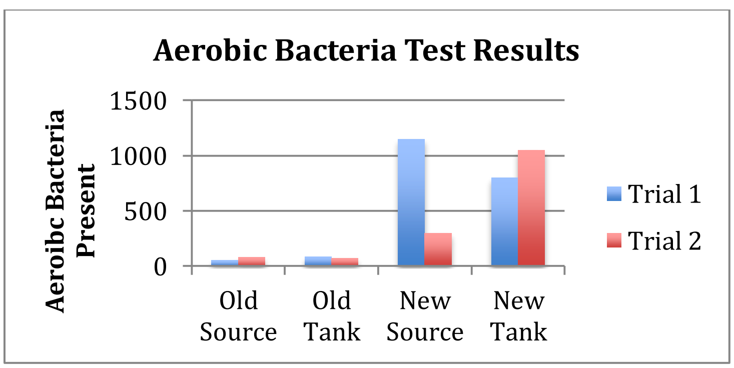

Figure 4: Aerobic Bacteria Test Results

These tests show that the water in both the spring box and the tank of the old system have a relatively low number of coliform bacteria. Coliform bacteria are commonly used as an indicator organism for drinking water supplies. Absence of coliform bacteria indicates that there are no disease-producing organisms in the water. The presence of coliform bacteria does not necessarily mean that the water is contaminated, because some coliform bacteria are found naturally in soils, but it is still used as an indicator of poor water quality [Metcalf & Eddy, p. 117-118]. Additionally, the test results show that the old system has a low count of aerobic bacteria, which can also be used as an indicator of water quality. The new system, on the other hand, had a much higher count in both coliform bacteria and aerobic bacteria. This indicates that the water quality is not as good here, which is also evident by the source. This is typical for surface water sources such as rivers.

3.4 Water Usage

Water usage data was not collected while the team was in country, due to time constraints. An activity suggested in *The Handbook for Gravity Flow Water Systems* by Jordan (1984) was used by Christopher Kingsley to gather this information for the team. The activity calls for giving each family a 5 gallon bucket and then having them keep track of how much water they use, what time of day they use it, and what they are using it for. This data is useful since it not only indicates the total amount of water used, but also the time of day with the highest demand.

The activity was performed in a neighboring community and only 5 families participated in the activity. The water use estimated from this activity was lower than the guidelines prescribed by the Ministry of Health, which recommends a total of 30 gallons per person per day. Therefore, the team decided to use the Ministry of Health's estimate for total water usage. The information from the activity was then used to generate a water use schedule for the community based on 30 gallons per person per day and eight people living in each house. The team also calculated an average use per house based on this data. Table 2 shows the water usage in gallons per day for all the 64 taps in the community based on the community survey and the Ministry of Health's recommendations. It also shows the demand for one tap based on the higher estimate. The team assumed that no water was used during the night hours.

Table 1: Water Usage in the Community in gallons

Time	Community Survey	Ministry of Health's recommendations	Per Tap
6:00am-11:00am	5890	9888	154
11:00am-3:00pm	930	1561	24
3:00pm-8:00pm	2170	3643	57
Daily Total:	8990	15091	236

3.5 Gully Crossing Data

Gulley crossing data was collected by Peace Corps Volunteers after the team left Panama. Chet Hopp and Christopher Kingsley surveyed seven points where gully crossing supports would be needed and sent the data to the team. This data included distance of the gully crossing; change in elevation between the two points, and if there were any further constraints at each site.

3.6 Material Cost Info

The cost of materials is important in developing of a total cost estimate for the project. The project is located in Panama, where the material prices are different than those found in the United States. During the assessment trip in August 2012, there was not sufficient time to gather data on the cost of materials near Cerro Miel. Due to this, Uno Más had to find other means of gathering this data. Christopher Kingsley, who aided Uno Más on their assessment trip, has designed aqueduct systems for communities in the same region as Cerro Miel. Kingsley gave Uno Más the estimate sheets from a previous project that he completed in Bajo Salitre. Many of the materials that are required for the construction of the Cerro Miel aqueduct were found on this material list, along with material prices. Uno Más assumed these material prices to be valid. For prices that were not on the Bajo Salitre material list, Uno Más used online quotes. Although these quotes are prices from the United States, Uno Más assumed these prices to be valid because the cost of these items compared to the total cost was insignificant.

3.7 Scheduling Data

A construction schedule is useful in determining how long the Cerro Miel aqueduct will take to construct. Uno Más received scheduling data from Christopher Kingsley on construction tasks such as pipeline construction and material delivery. The specific information that Uno Más received from Kingsley include:

- A typical crew for laying pipe will include 17 people.
    - This crew can lay 0.5 km of 4” pipe in a working day.
    - This crew can lay 0.8 km of 1.5” or smaller pipe in a working day.
- A typical crew for unloading delivered material includes 5 people. Two deliveries can be made per day.
- A typical crew for the construction of gully crossing supports includes 5 people. Each gully crossing support will require 3 days to construct.

Aside from the information that was received from Kingsley, Uno Más assumed that performance data from RS Means (RS Means) would be applicable. The data from RS Means was used to quantify the amount of time required to paint exposed pipeline and to construct the pressure release tanks required for the project.

4.0 Data Analysis/Modeling

The data collected was analyzed using software such as Excel, Google Earth and EPANET.

4.1 Data Validation

Data validation and interpretation was essential to make sure that there was no missing data and that the team had all of the data correctly paired with the notes taken while in Panama. The original data collected from the GPS was compiled into an Excel spreadsheet. Some data from a previous project that had not been deleted appeared. This data was saved, but removed from the data obtained in Cerro Miel. There were a few locations that where entered into the GPS twice. These duplicate points have been deleted. The descriptions of points, such as which were taps, names of each home owner to be connected to the system, tee intersections, and other pertinent information was typed into the spreadsheet. A separate spreadsheet was created to show just the GPS data for tap locations.

To check for inaccuracies in the GPS data, it was compared to the survey data that was also collected while in Cerro Miel. It was determined that the GPS data was consistent with the survey data and suitable for use to design the system.

4.2 Elevation Profiles

During the assessment trip, it was evident that the pipeline would travel over a very large elevation drop for each of the proposed lines. Elevation drops will cause increased pressure buildup to occur within the pipes. In order to quantify the elevation drop that each pipeline would need to travel, an elevation profile was made using data from the Abney level survey. The elevation plot can be found in Figure 5.

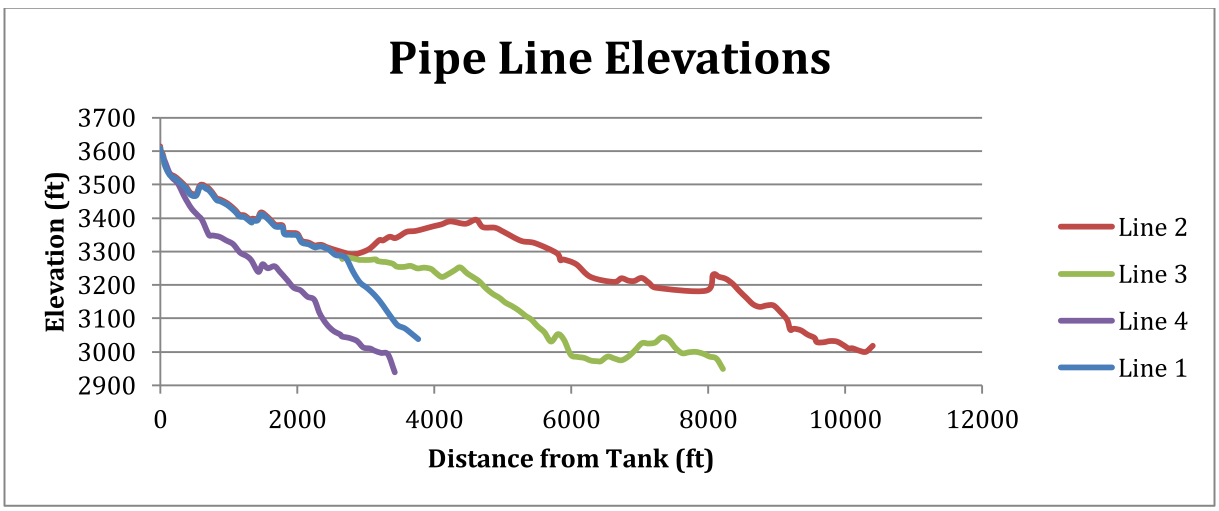

Figure 5: Pipe Line Elevation Profiles

From the elevation profiles shown, it can be seen that Line 4 is the line that will experience the greatest elevation difference, and therefore experience the highest pressure within the pipes. The elevation plots for each line aided in determining where pressure and air release would be required for the project.

4.3 Google Maps

After all of the data was sorted, Google Earth was used to compile the GPS survey data to make a map of the entire system (Figure 6). In order to get the survey data into Google Earth in an easy to edit format, the system lines and locations of taps were created as kml files and edited using Text Edit. This allowed the team to make changes to their system quickly and easily. An example of the code used to draw the lines and place the taps is included in Appendix D and an actual copy of all of the code is included on the supplemental CD. Examples of maps of the system are included in Appendix E for reference.

Some of the edits made to the system were straightening lines, removing faulty data points and moving a number of homes to the old system to avoid pressure issues. There are several advantages to compiling the GPS data using Google Earth. The map generated is overlaid on satellite imagery, which includes obstacles such as roads. Distances between any points in the system can be found relatively easily. Also, Google Earth can make quick elevation profiles and the map can be viewed in 3D. In addition, creating the system lines in code allows the information to be emailed, and easily uploaded on any computer with internet unlike many program that require expensive software.

The Google Earth maps were used to find lengths of piping for the entire system. The total length of pipe in the system is 16.2 miles. The longest section is the 9 mile supply line from the water source above Tugri to the tank in Cerro Miel. Seven miles of pipe are located within the community.

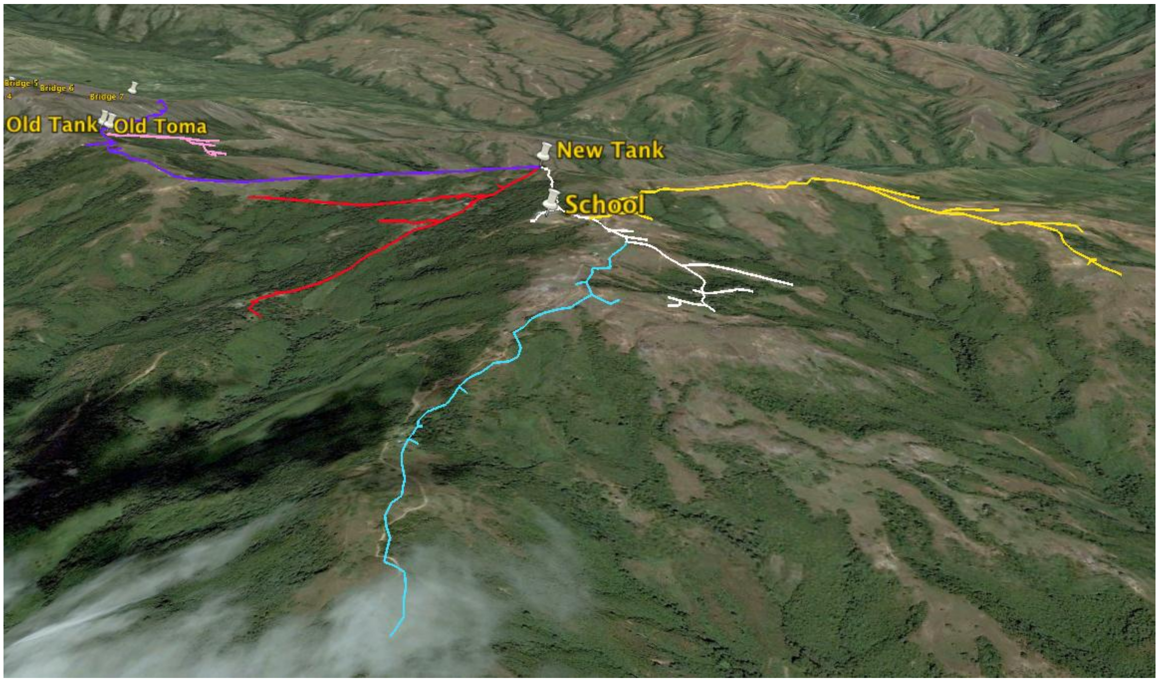

Figure 6: 3D Layout of Pipeline in the Community

Figure 6 shows the main lines in the community. They are organized by distinct colors. The purple line is the supply line for the New Tank, which is located at the high point in the community and is the main water supply. The Old Tank is located to the northwest of the community and only supplies Line 6, which includes 8 homes.

4.4 Flow Rate Calculation

A concern for the design of the aqueduct is the amount of water that can flow from the tank in Tugri. There is currently a pipe connecting the tank in Tugri with the tank in Cerro Miel. Replacing this pipe with a larger one would be too expensive for the community. To determine the discharge from the tank in Tugri, the Darcy-Weisbach equation was used:

$$h_L = f \frac{L}{D} \frac{V^2}{2g}$$

The friction factor (f), obtained from the Moody Diagram, is 0.014. The length of the pipe (L) is 33,394 ft and the pipe diameter (D) is 3 inches. Head loss (HL) was determined as the difference in the elevations of the two tanks, which is 737 ft. Solving for V gives a velocity of 4.998 ft/s. By multiplying the velocity by the area of the pipe (3 inch diameter) the discharge could be solved for. The discharge came out to be 0.245 cfs (158,348 gal per day), which is more than adequate, which means that the community's supply needs are met.

4.5 EPANET Model

The water distribution system was modeled using the EPANET 2.0 software and the data collected. The elevation of each tap and tee was manually entered into the program along with pipe characteristics. A summary of the different values and properties used in the model is found in Table 1. The demand was modeled based on the demand analysis described in section 3.4 Water Usage.

Table 1: EPANET Properties

Properties	**Values**
Friction headloss formula	Hazen-Williams
Roughness coefficient for pipes	150
Storage tank volume, new system	1920 ft^3
Storage tank volume, old system	606 ft^3
Daily demand per tap	0.05934 gal/min [240 gal/day]

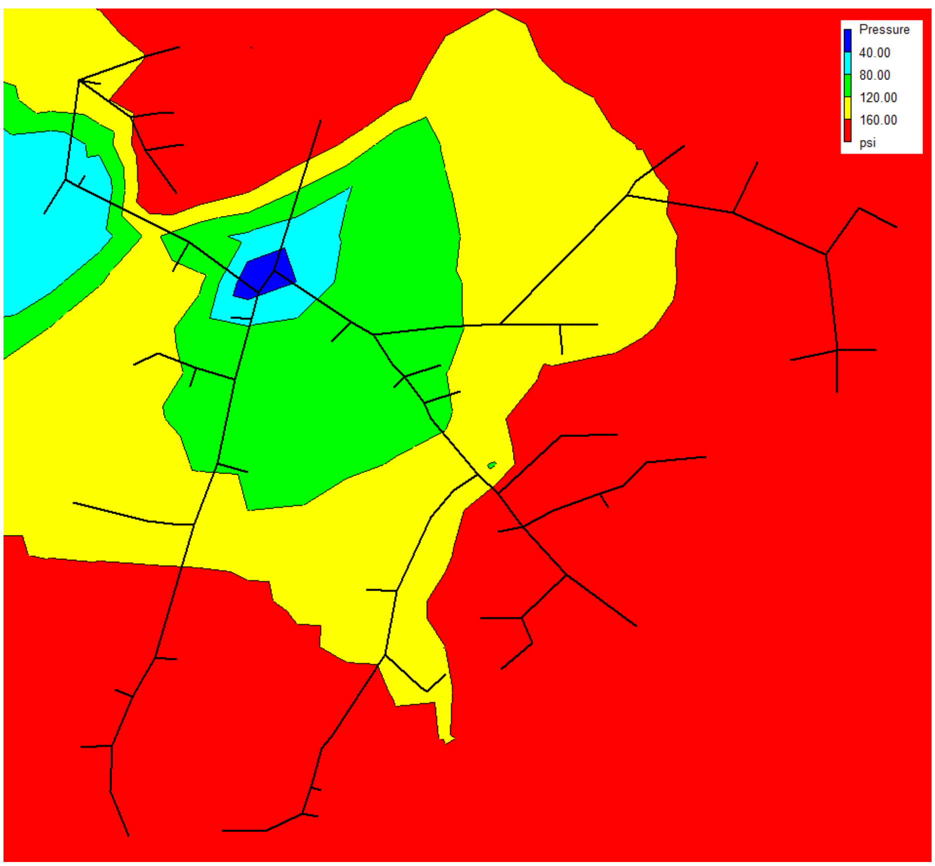

Figure 7: Pressure Levels Across System.

Figure 7 shows the pressure gradient across the system. The red areas are where the pressure exceeds 160 psi and would likely damage the pipe. Figure 7 is a snapshot of the model, taken at a time when the worst case scenario occurs, with the maximum number of nodes that have pressures exceeding 160 psi. This pressure analysis was used to determine the location of pressure break tanks.

An analysis of the EPANET model shows that three pressure break tanks are needed. These were modeled as small tanks. The location was determined in such a way that the pressure was reduced sufficiently, while maintaining a pressure head of 14ft at all the taps. This is the recommended value to ensure that the hydraulic gradient line never dips below the ground surface and that there is sufficient pressure at the tap. This can be seen in Figure 8.

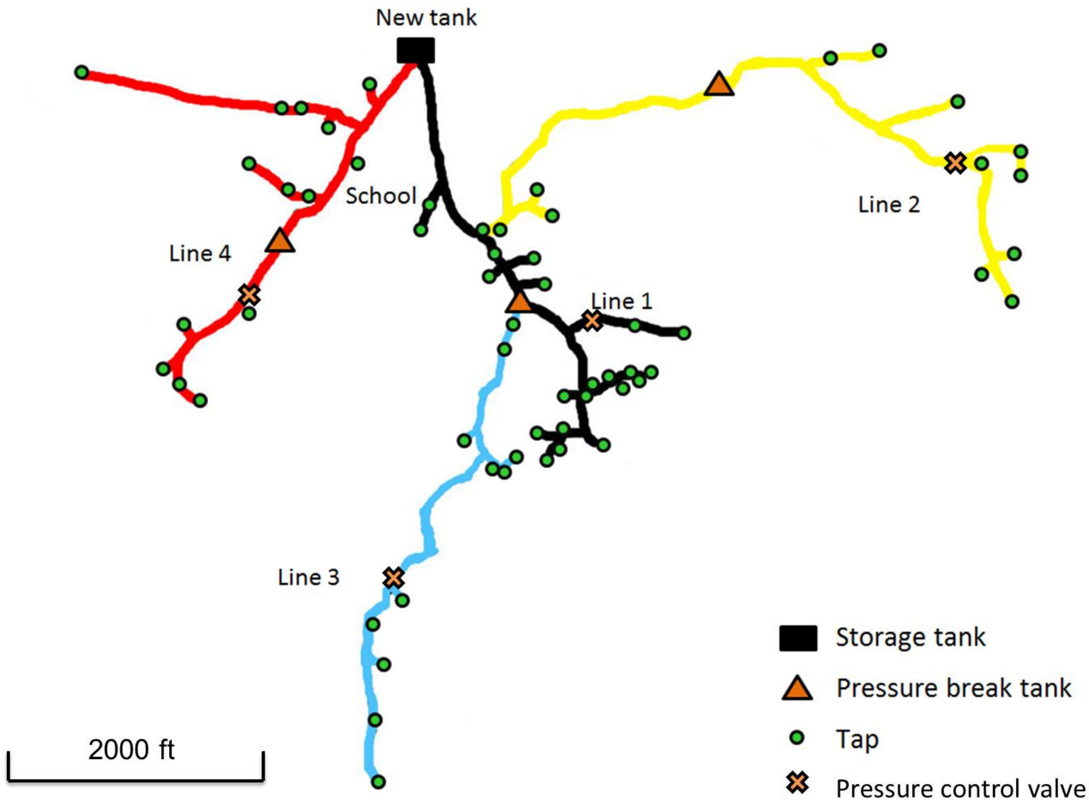

Figure 8: EPANET Model of New System with Pressure Break Tanks

The team found that it would not be feasible to install a pressure break tank at line 5. The reason for that is that there was no location where it could be placed that would at the same time provide enough pressure for the water to run over a hill and provide adequate relief at the end of the line. This section, consisting of 8 houses, was therefore taken off the new system and attached to the old. The school is now attached to the new system.

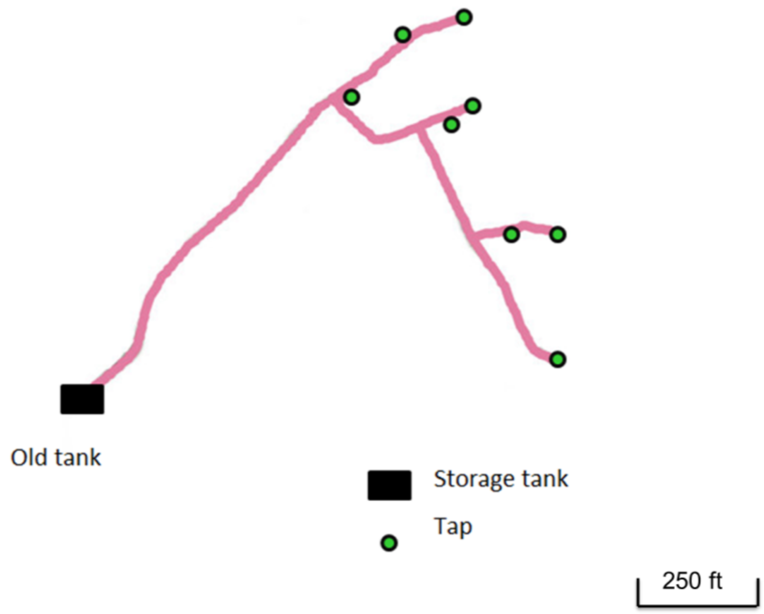

Figure 9: EPANET Model of Expansion of Old System

After installing the pressure break tanks in the model, there are still a few pipelines that have excessive pressure. Reducing the pipe size alleviated some of the problem, but the pressure was still well over 100 psi. Pressure control valves are therefore recommended for locations shown in Figure 8. There are a few places in the system where one can expect pressures below 15psi at certain times during the day, but the pressure is never lower than 6 psi. The final pressures in the system can be found in Appendix F.

5.0 Design

Based on these analyses, the aqueduct system was designed with features such as pressure and air release systems, solar UV protection, water hammer reduction, gully crossing supports, and water treatment.

5.1 Pressure Release

In water distribution systems where the pipeline undergoes large elevation drops, pressure builds up within the pipe. If the pressure rises to a level greater than the pressure rating of the pipe, the pipe may break. This can cause many problems including no water being delivered to homes further down the pipeline andallowing contamination to enter the system. To prevent large pressure buildups from occurring, a means of pressure release can be installed along the pipeline. Traditional means of pressure release incorporate the use of an open-air tank along the pipeline. This tank is open to the atmosphere, reducing the hydrostatic gage pressure within the tank to atmospheric pressure. When pressure tanks are placed properly, less expensive pipe can be used further down the pipeline because the required pressure rating of the pipe would be lower. Uno Más considered two types of pressure release for the Cerro Miel aqueduct: the mason-break pressure tank and the high density plastic (HDP) pressure tank.

The mason-break pressure release tank resembles a small water storage tank. An example of the mason-break tanks can be found in Figure 11. A schematic of the mason-break pressure tank the has been designed for Cerro Miel can be found in Figure 12.

Figure 10: Example of Mason-Break Pressure Tank [Barefooteconomics.com]

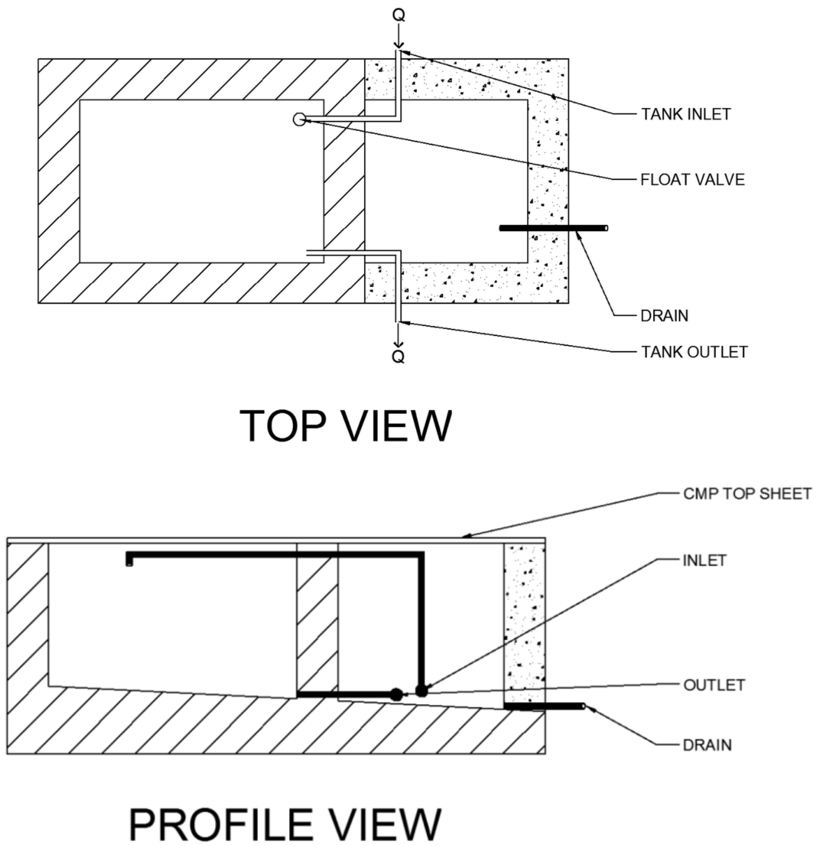

Figure 11 : Mason-Break Pressure Release Tank Diagram

The tank itself is made of concrete. A float valve is located inside the tank to prevent overflows. The design volume of the pressure tank is $8.27 ft^3$, with a wall thickness of 8 in and a base thickness of 12 in. There are a few advantages to using a mason-break pressure tank, the main one being durability. Since the tank is made of concrete, the tank will be much less likely to break than other pressure release options. Another advantage is the float valve incorporated in the design, which serves as a water saving device.

An HDP tank operates in the same manner as the mason-break pressure tank. The tank itself is made up of HDP pipe. A schematic of the HDP tank designed for Cerro Miel can be found in Figure 13.

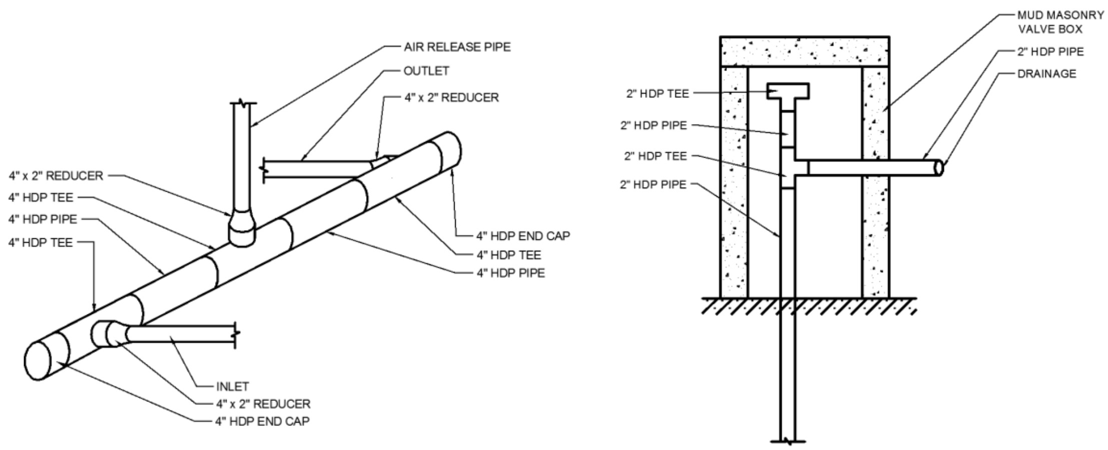

Figure 12: HDP Tank Schematic

The HDP tank is buried beneath the ground. When operating at steady state, water from the pipeline enters through the inlet. Pressure is released via a drainage pipe at the surface. HDP pressure tanks are an ideal option for the Cerro Miel aqueduct because they are inexpensive and easy to construct. A disadvantage to the HDP tank design is that there is no valve incorporated into the design; therefore, water may continually discharge from the pipe when the flow is disrupted. Although water supply is not an issue, the discharge can cause erosion if a properly designed discharge channel is not included in the system.

There will be four pressure tanks required for the Cerro Miel aqueduct system. Three of the tanks will be located within the community of Cerro Miel. Figure 13 shows the location of these pressure release tanks.

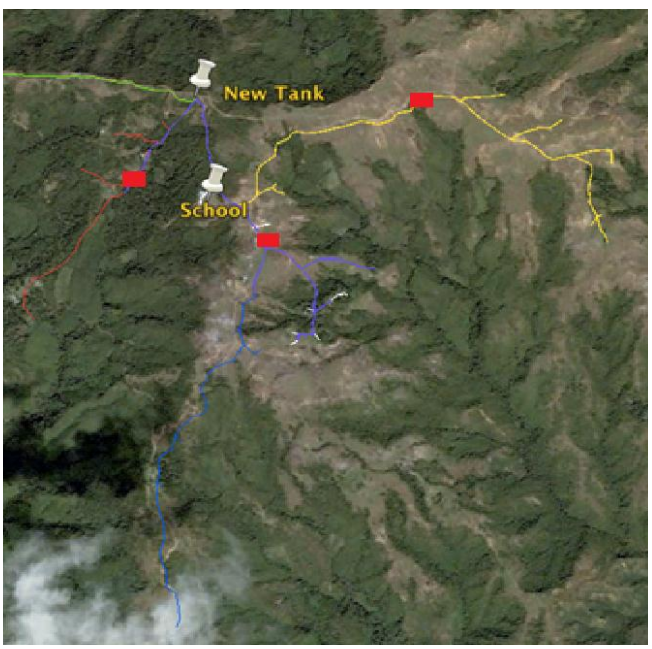

Figure 13: Location of Pressure Break Tanks

Uno Más recommends that these three tanks located within the community be the mason-break pressure design. These tanks will be much more durable than the HDP tanks. The float valve will also help prevent water from being wasted in the community. The mason-break pressure tanks will provide for a long-term solution to the pressure release requirements in Cerro Miel. A fourth pressure tank will be required near the tank in Tugri. High pressure for the slow sand filter and in-line chlorinator located there has made maintenance dangerous. To release the pressure at this location, Uno Más recommends an HDP tank be installed. Although an HDP tank is less durable than the mason-break pressure tank, at this location it is more feasible to install the HDP tank. In the future, the option may arise to locate the sand filter and chlorination tank at the storage tank in Cerro Miel. If this is done, the pressure tank in Tugri will not be needed. Since the pressure release tank in Tugri is not meant to be a long-term solution, the HDP tank is recommended at that location. The drawings for the two tanks can be found in Appendix G.

It is also recommended that pressure control valves be used to ensure that the pressure at the taps will not exceed 120 psi. These valves controls that the water flowing through does not exceed a preset value. Our design calls for valves set at 50 psi, which are some of the most common types.

5.2 Water Hammer

Water hammer results when a tap is closed suddenly, quickly disrupting flow. This disruption in flow can cause pressures large enough to damage the pipeline. The equation to calculate the maximum pressure due to water pressure (Lindeburg 2002) is:

$$\Delta P = pa\Delta V$$

Where:

ρ = 1000kg/m^3

a = 1000kg/m^3= $\left(\frac{E_{total}}{\rho}\right)^{\frac{1}{2}}$

E_{total} is the total energy in the pipe

$$= \frac{E_{water} * t_{pipe} * E_{pipe}}{t_{pipe} * E_{pipe} + D_{pipe} * E_{water}}$$

ΔV = the velocity of the pipe

$E_{water} = 2 * 10^9\ Pa$

t_{pipe} = the thickness of the pipe

$E_{pipe=}2.8 * 10^9\ Pa$

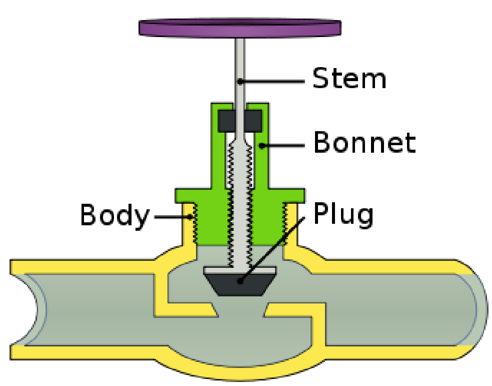

Figure 14: Globe Valve [Aimonen]

At the location of the highest velocity shown in the EPANET model, the pressure increase due to water hammer is 54,949 psi. If the valve is closed quickly, this could damage the system. To counter the increase in pressure from water hammer, alternative valves can be used. Slow turning valves will reduce water hammer. A globe valve is recommended to be used to accomplish this. An example of a globe valve can be found in Figure 15.

Adding a few seconds to the time that it takes to close the valves will increase pressure. The equation to calculate water hammer caused a specified time to close the tap is:

$$P = \frac{0.070 * V * L}{t} + P_i$$

Where: V = flow velocity in the system

L = upstream pipe length

t = time it took for the valve to close

P_i = initial pressure of the system

This will reduce pressure by 50% bringing it down to about 275 psi at a closing speed of 5 seconds. Adding flow reducers will also help reduce the water hammer. These will reduce the velocity of the water which is a major component of the water hammer calculation.

When the tanks are cleaned the intake to them needs to be turned off. This will also increase pressure from water hammer. For this situation, a water hammer arrestor should be installed.

5.3 Air Relief

Pipelines in gravity-fed projects are susceptible to air blockage problems. Air blocks are pockets of air that form in high points of pipes and restrict or entirely prevent flow. Once the air pocket forms, some of the system's head is used in compressing the air because air is highly compressible. If there is not enough head at that point in the system to both compress the air and overcome the high point in the pipe, flow may stop. Air can enter the pipe in a variety of ways, such as inconsistent flow or turbulent conditions at the source. For simple gravity-fed systems like this, it is usually safe to assume there will be some air in the pipes.

Air block should not be a major issue in our community due to the large amount of head the system has. Also the community has not reported any previous issues with air block problems. Notches in the pipes have been created throughout the system and especially on the supply line to check for water flow. These notches may also be acting as air relief for the system as a small amount of water and air is always escaping when there is pressure in the pipes. Notching the pipe however, is not the best solution to air blockage problems because it weakens the pipe and creates a greater risk for contamination of the water if the pipeline loses pressure. Based on these reasons, Uno Más recommends the installation of air release valves in all of the new lines placed in the community. Replacing the currently notched pipeline from Tugri would be too expensive for this project, so it is recommended that that pipeline is left with notches.

To design for air release in the community air release locations were first identified. Locations chosen were those with a high point that was at least 20 higher than the pipe nearby on either side. To find these locations, elevation profiles from each line were used to find high point. Eleven points were found on the lines that come from the main tank and one additional location was found on Line 6 off the Old tank. There are also eleven locations where air release valves are recommended when the supply line to Tugri needs to be replaced. Figure 15 below shows the locations on the lines from the new tank.

Several options for the actual air release valves were explored, including automatic air release valves, homemade automatic air release valves, globe valves, three way valves, ball valves, and comp stop valves. The option chosen was a PVC ball valve with a locking handle due to its added security, ease of installation and moderate price. The secondary selection in case the community is opposed to locking handles is a simple comp stop valve. A downside to these valves is that if air block is ever encountered, someone will have to walk the pipes and manually open the air release valves. In a large system such as this, this could be very time consuming. The locations for air release can be found in Appendix H and design in Appendix I.

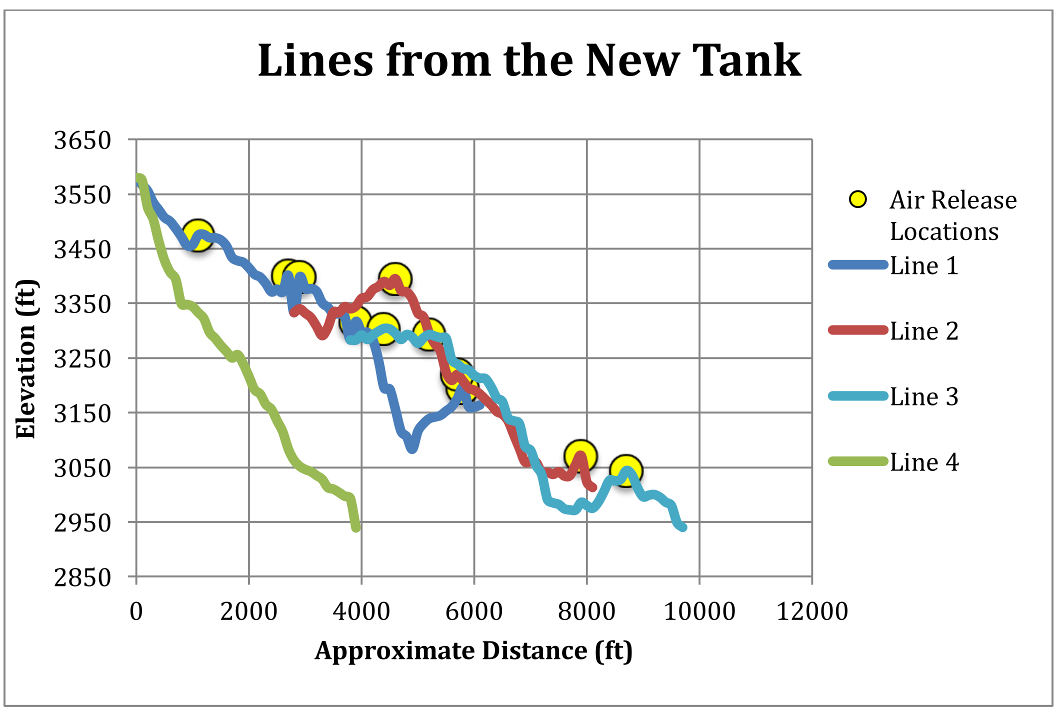

Figure 15: Air Release for Lines 2 and 5

In this figure the yellow circles indicate points where air release is recommended.

5.4 Gully Crossing Supports

When pipeline has to cross a gully, the pipe will bow from the weight of itself and the water that it is carrying. This is not good for the pipe, and it creates a weak spot in the system. To address this problem, a cable bridge can be installed to support the pipe. This involves a strong cable that is fastened to the pipe and anchored by a metal rod at each end of the gully. At each end of the gully, a concrete footing is used to secure the cable bridge. A cable bridge is the preferred solution for this problem because it is the most durable. However, this option is also the most expensive. Alternatives include: installing a wood bridge under the pipe or using a v- notched stick to support it. These options were not selected because they were not as reliable.

There are seven gullies on the supply line from Tugri to Cerro Miel that were require support. Constructing cable bridges at these points will make the system more reliable. For these cable bridges, an initial sketch of the design was made, as shown in Figure 16. This design is recommended because the pipe is supported equally along the length of the pipe.

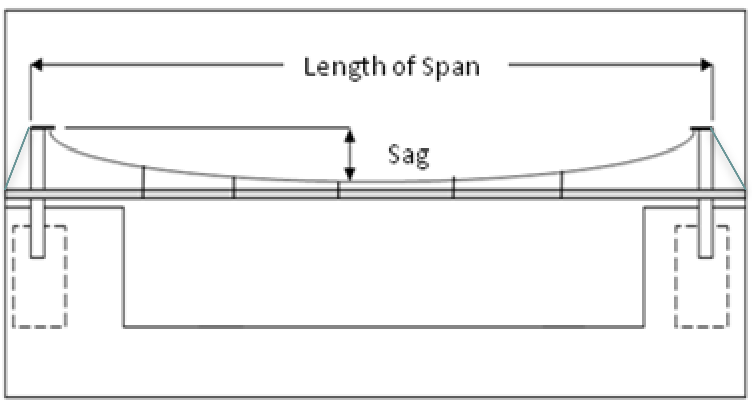

Figure 16: Gully Suspension Bridge

When designing this system, there were a few constraints that had to be considered. First, the size of pipe that the bridge would support was known. From that data, the weight of the pipe could be determined as well as the weight of the water that would be flowing in the pipe. Also, the spans of the each bridge were known. Lastly, change in elevation was determined for each of the gullies. A difference in elevation will lead to changes in the shape of the bridge.

Using these constraints, the total tension that the cable would need to withstand was calculated. The strength of cable that would be needed to support each pipe was calculated. The type of cable needed was found using the table in Mihelcic et al. (2009) (Appendix A-2p. 516). For each bridge, the 1 x 19 cable was able to support the weight of the pipe.

This cable is able to support a greater tension than what was calculated. Therefore, the design can be optimized by recalculating the sag for the bridge. The will change the required height of the pipe.

Accounting for the change in elevation between the two ends of the bridge, was done using Appendix A-4 (Mihelcic 526). This table also gave an estimate for the new apex and length of the cable. Finally, the concrete supports were designed for each bridge, noting that some bridges had trees that would be used as supports. The final designs are shown in Appendix J. These designs are all based off of the initial design, but are adjusted to support different conditions.

5.5 Solar UV Protection

The UV radiation produced by the sun can cause PVC pipe to become brittle. To prevent this, the piping needs to be covered. By protecting the pipe, the cost to maintain the system decreases because the pipe will last longer. The best way to protect the pipe is to bury it. This will also protect the pipe from other elements such as animals stepping on it. When possible the pipeline should be buried. In places where the ground is too rocky, it may not be practical to bury it. When this is the case, Uno Más recommends that the pipe be painted with a light colored, water based latex paint.

5.6 Water Treatment

Another major design consideration is water treatment. Since this water is coming from a stream, it is not clean enough to meet the water quality standards that are desired in a drinking water system. This is why in the original project, slow sand filters were installed along with an in-line chlorination system. This system was very expensive and would provide adequate water treatment operating under optimal conditions.

A primary concern is high pressure in the pipeline coming into the filter, which can be dangerous when valves are opened during maintenance. Uno Más suggests two things to alleviate this issue. First, a HDP pressure break tank as discussed previously should be installed. Secondly, posters with pictures detailing which valves to open and shut should be posted inside the small building that houses the filters. This would ensure that whoever is cleaning the filters have a process to follow that is easily understood. These posters should be designed by a Peace Corps volunteer working on the project who understands the system.

Another issue with the current treatment system is its physical location. The current filters and chlorination system are located in Tugri, which is several miles from Cerro Miel. This is a problem because people who are not depending on water from the system are doing the system maintenance. The tank that supplies water for Tugri can be lined up with the water for Cerro Miel but the Tugri tank is mostly supplied by another source. Therefore the people in Tugri have little motivation to maintain this system. The distance from Cerro Miel is also a downside because there are two tanks and several miles of pipe between the treatment and the taps at people houses, increasing that chance that the water can be contaminated before it reaches the taps. In response to this issue, Uno Más has two design recommendations. In the short term, it is recommended that the tanks and all of the air release and shut-off valves be equipped with padlock, reducing the risk of contamination from people entering tanks or taking water out of the system. In the long term, the treatment system should be moved to Cerro Miel and the line disconnected from the tank in Tugri.

6.0 Cost Estimate and Construction Schedule

Based on this design, Uno Más estimated the total cost of the system, as well as developed a construction schedule.

6.1 Cost Estimate

A major concern in the design of the Cerro Miel aqueduct is that the system should be affordable since much of the project will be funded with grants. Cerro Miel currently has the grant from IPADEHM in the amount of $5,000. Although this grant may be increased, it should not be relied upon to cover the entire cost of the project. Other grants or community funds may be available to fund the remaining portion of the project.

The final costs of the recommended design are summarized in Table 1. A more detailed breakdown of the cost estimate can be found in Appendix K.

Table 2 : Cost Estimate Summary

Item	Cost
Pipeline, Fittings, Valves	4350
Pressure Release	535
Air Release	215
Gully Crossing Supports	1380
UV Protection	440
Transportation	930
Total:	**$7,850**

With the final estimated cost being $7,850, an amount of $2,850 will need to be covered by funding beyond the grant from IPADEHM. The largest cost for the project is the PVC pipe required to expand the system. Although PVC pipe itself is not very expensive, it has the largest quantity of any material required for the project giving it the largest cost. The final cost estimate includes no labor cost, assuming that the community would be able to provide the labor required for the project. Any skilled labor that is required will be provided for by Peace Corps volunteers Christopher Kingsley and Chet Hopp. An overhead of 10 percent has been included in this estimate to account for unforeseen materials costs.

6.2 Schedule

A construction schedule is useful for determining the sequence in which construction tasks should be completed, as well as the total length of time to construct the project. Using the assumptions stated earlier in this report, Uno Más created a detailed construction schedule, which may be found in Appendix L. For the most part, only one construction task will be completed at a time with the pipelines and pressure tanks located within Cerro Miel being completed first. The gully crossing support construction and painting of exposed pipe will take place simultaneously after the piping is in place. The estimated time to construct the project is 105 working days. If work days are shortened due to inclement weather, the total time to construct the project will increase.

7.0 Construction Guidelines

Uno Más has developed guidelines for the construction of the pipeline, pressure break tanks, and gully crossings, as well as painting of the pipeline.

7.1 Pipeline Construction

The pipeline in the community of Cerro Miel should be constructed using the guidelines presented below.

Phase 1: Preparation for Pipeline Installation
Before the pipeline can be constructed, the path that the pipeline will follow must be cleared of any debris, foliage, or large rocks. The path to be cleared can be found in the map below. The path is approximate, but should follow the map in Figure 17 as much as possible.

Figure 17: Map of Pipeline

A trench approximately 2 feet deep and 1 foot wide should be dug to place the pipe in. The trench can be dug by hand with shovels. For ground that is difficult to dig through, a pick axe may be used. Excess material should be placed near the trench so it may be used as backfill material. The purpose of burying the pipe is to prevent damage to the pipe from people, animals, and the environment.

Phase 2: Pipeline Installation
After a sufficient trench is dug, the pipe then needs to be installed. To install the pipe, lower the pipeline into the bottom of the excavated trench. Each pipe segment is only 20 feet long, so segments will need to be connected with PVC joint glue. If a pipe segment need to be shorter that the 20ft pipe segment, a hacksaw may be used to cut the pipe. To

connect two segments of pipe together, the ends of each pipe segment should first be cleaned and have PVC primer applied to them. PVC joint glue should then be applied to the primed end sections of the pipe segments. The pipes may then be inserted into each other to form the connection. As soon as the pipes are connected, the pipes should be given a ¼" turn to ensure that the PVC joint glue is evenly distributed and a tight seal forms. Excess joint glue may then be wiped away.

After the pipeline is installed, workers may then backfill the trench with the excavated material from trench excavation. The air release valve can be added in the same manner that two pipes are connected. PVC joint glue is applied to the end of the pipeline where the air release valve is to be located. It should also be applied to the PVC tee that will be connected to the pipeline. The air release valve should then be connected to the tee.The tee should be aligned so that the air release valve sticks out of the ground after the pipeline is buried.

7.2 Pressure Break Construction

<u>**Mason Break Pressure Tanks**</u>

Phase 1: Site Preparation
The site of the proposed mason-break pressure tank should first be cleared of any debris, large rocks, or foliage. After the site has been cleared, a rectangular pad the size of the tank should be dug 30cm deep. The base of the dug-out pad should be compacted and leveled.

Phase 2: Tank installation
After the site has been prepped, the mason-break pressure tank may be installed. A form for the base of the tank should be made out of wood. The forms should be constructed to fit the base of the tank which can be found in the plans for the mason-break tank (Appendix G). The concrete can then be mixed and poured into the form and allowed to fully cure. After the base is fully cured, forms for the walls of the tank should be constructed allowing holes where the pipe is to enter and leave the tank. Once the forms for the walls are constructed and in place, excess pipe can be placed through the inlet and outlet holes in the forms. Concrete can then be poured into the forms. The concrete should then be allowed to cure before the forms are taken away. The top of the tank can be covered with a piece of metal roof sheeting. Pipes and valves should then be installed. The inlet and outlet of the tank should be sealed with a water-tight seal.

<u>**HDP Tanks**</u>

Phase 1: Site Preparation
The site of the proposed HDP pressure tank should first be cleared of any debris, large rocks, or foliage. A rectangular hole should then be dug at the specific location of the HDP tank. The dimensions of the hole are as follows:

- Length: The length of the HDP tank (found in plans) plus 2 feet on each end of the pipe to allow room to install the pipe
- Width: The width should be the diameter of the HDP pipe plus 2 feet on either side of the pipe to allow room to install the pipe.
- Depth: The depth should be the same as the pipeline.

Phase 2: Tank installation
Once the hole for the HDP tank in dug, the tank can be assembled. HDP pipe and fittings can be connected using PVC joint glue. The tank can then be lowered into the hole and connected to the pipeline inlet. The outlet of the pipeline can then be constructed once the HDP tank is connected to the pipeline inlet. The hole that was dug out previously can then be backfilled with the dug-out material. A box should then be constructed to protect the portion of the HDP tank that is not buried. This can be made out of mud masonry. A mesh screen should be placed over the end of the drainage pipe to prevent bugs or debris from entering the tank.

7.3 Gulley Crossing Construction

Before a suspension bridge can be put in place, all rocks and trees in the way of the pipeline should be cleared. The surrounding area should be examined for signs of erosion to determine the stability of the soil. If the area looks unstable, further measures must be taken to make sure that the supports will not move.

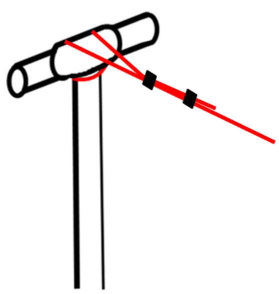

Figure 18: Proper Connection from Pipe to Cable

Once this is done, forms should be constructed and the concrete should be poured to the specifications of Appendix J. This concrete should be allowed to fully cure remembering to install the support piping into the concrete. The cable then needs to be cut and connected to the pipe as shown in Figure 18. The cable should be fastened with three cable clamps. Once this is done, the ties should be installed, connecting the cable to the pipe. Then, the cable should be pulled tight and attached to the other support. The excess cable should be cut.

7.4 Painting for Solar UV Protection

Painting the pipes is required when the pipe is being laid across ground where it would be difficult to, and where it is exposed to sunlight. In dense jungle, this is not a problem because the pipe will not be exposed to sunlight. For the project, a 2 man crew is required, and it is estimated that 14 % of the total pipeline will need to be painted. A total of 19 cans of paint will be required to do this. A light colored, water-based latex paint should be used.

8.0 System Maintenance

The following guide has been developed to ensure proper maintenance and operations of the system.

8.1 Funding

After the aqueduct in Cerro Miel is finished, it will be crucial to maintain the systems so it has a long operating life. To fund these operations a service fee may need to be established. The water committee of Cerro Miel currently has a service charge of $0.50 per month for any home that is connected to the water distribution system. Many of the homes that are currently connected to one of the water distribution systems do not pay the fee because the system is not operable. Once the aqueduct is completed, 70 homes will be connected to the system. Assuming every home pays the service fee, the community would have $35 per month to maintain the system. Uno Más recommends that this service fee be continued in order to properly maintain the system. The money obtained from the fee can be used to pay for labor, materials, or equipment needed to repair the system.

8.2 Materials

With a monthly service fee continually bringing in funds to maintain the system, Uno Más recommends that the water committee have materials in community to be able to service the pipe. Many of the materials needed to make repairs on the system are located in Tolé, which is a 2 hour chiva ride from Cerro Miel. By having the recommended materials in community, repairs to the aqueduct can be made in a timely manner. The materials recommended for the water committee of Cerro Miel to have on hand include:

- Extra pipe fittings including tees, elbows and joints
- Tools necessary to make repairs including a shovel and hacksaw
- Extra 20 ft pipe segments
- PVC Joint Glue
- Air Release and Shut-Off Valves
- Float Valves for Pressure Tanks

Uno Más recommends that these supplies always be on hand. This means that if one of these materials is used up in repairs or maintenance, it should be replaced in a timely manner. All of these materials should be kept in a public location (i.e. not in individual homes). A log book should be kept with the materials so records of repairs or maintenance can be recorded.

8.3 Pipeline Maintenance

Little pipeline maintenance is required on a regular basis. Adding cable suspension to all of the gulley crossings, burying the pipe whenever feasible and painting the exposed pipe to reduce damage from the sun will help to keep the pipeline from breaking. Still, the pipe may occasionally break, so, extra pipe, a shovel, and PVC pipe glue should be kept on hand. Another issue related to the pipeline is air blockage. If a problem with air block occurs, the air will have to be released manually. This is done by opening all the air release valves on the line where the problem is occurring until water flows out. Air release valves should be opened slowly while staying clear of the open end of the valve. If no water comes out when a valve is opened, make sure that any air release valves further uphill are checked and that all shutoff valves are in the open position.

8.4 Tank Maintenance

Both the tanks in this system should be cleaned periodically. Uno Más recommends cleaning them at least once per year. The tank cleanings should be scheduled for the beginning of the dry season since the flow rates to the tanks will be lower then. Materials needed to clean a tank include a small shovel, a five-gallon bucket, a ladder, and the key to the tank padlock. To clean a tank, the inflow and outflow from the tank should be shut off and the tank drained. Someone then has to enter the tank to remove sediments. When finished, the inlet valve should be opened to fill the tank. Then, close the inlet valve to isolate the tank and add 1 large chlorine tablet to each tank. (See Appendix M for calculations). These chlorine tablets will kill any microbial colonies in the tank. The tank should be left isolated for about a half a day before returning it to regular use to avoid decrease residual chlorine. After this, the inlet and outlet valve may be opened and the tank returned to regular use.

8.5 Filtration and Chlorination Maintenance

The sand filters and chlorination system will also require periodic maintenance. The filter is cleaned by first draining it and then removing the top inch of sand. The sand should be cleaned and stored for later. This can be used to replenish the filter when it is left with only a few inches of sand (Mihelic et al, 2009). When the flow coming out of the filters is slow, increasing the cleaning frequency should be considered. On the other hand if the flow is always very good, the frequency may be extended.

To maintain the chlorine system, chlorine pellets will need to be added on a regular basis. These tablets are provided by the Panamanian government free of charge. The ideal residual chlorine level is about 0.35mg/l (Orner). Sodium hypochlorite tablets, like the ones likely to be used, are only about fifty percent active chlorine by mass, which means approximately 0.70mg of tablets should be added per liter passing though the chlorinator. This, however, does not take into consideration the organic matter in the water, which will reduce the amount of residual chlorine. Therefore, a ten percent safety factor was applied to the calculations. If none of the added chlorine reacts, the level is still within the

World Health Organizations recommended residual chlorine concentration (Guidelines 2011). Since there will be about 16,900 gal per day or 63,900 liters per day passing through the chlorinator, a total mass of about 50 grams is needed each day. This amounts to 5 to 6 chlorine tablets each week. Ideally this estimate will be used as a preliminary estimate and the community with the help of Peace Corps volunteers will be able to test the residual chlorine in the downstream system and adjust the chlorine added as necessary.

9.0 Conclusion

Uno Más Engineering's ultimate goal for this project was to provide the community of Cerro Miel with safe and reliable drinking water. Upon traveling to the community, the team discovered that Cerro Miel had two water aqueduct systems in place and that neither system was meeting their needs. Uno Más was, therefore, tasked with expanding these existing aqueduct systems to include 57 additional houses and updating the systems to be more reliable and easy to maintain. To accomplish this, Uno Más mapped where the system would be located using Google Earth Pro and created an expanded EPANET model to show the hydraulics of the system.

Modeling the system was the first and most important step in the design. In the EPANET model, all houses receive an adequate flow of water throughout the day and there is adequate pressure throughout the system. In order to achieve this, Uno Más designed for three mason pressure break tanks in the community along with a number of pressure reducing valves. In order to reduce water hammer concern, Uno Más plans to use globe valves at all of the taps and water hammer arrestors in front of the tanks.

A major component of this project was to improve the sustainability of the system. Uno Más looked for weak points in the current design and worked to alleviate them. These include the potential for air blockage, long stretches of piping exposed to the sun, unused water treatment system, and unsupported pipe crossing gullies. For each of these items the team researched options for removing or mitigating the problem and has specific design recommendations. Air release valves will be installed at high points in the pipe and will mitigate the chances of air block issues. To protect the pipe, the team recommends that the pipe should be buried whenever possible and painted when that is unfeasible. Additionally the team designed cable suspension bridges to support the pipe over every gully crossing. To solve the water treatment system and other issues with system maintenance, the team is supplying the community with a maintenance guide and recommends that the treatment system be moved closer to the community.

This new system will take approximately 105 days to construct by a team of 17 community members led by a Peace Corps volunteer. With a total cost of $7,850, this project exceeds the $5,000 grant the community currently has. The team is therefore encouraging the Peace Corps volunteer to seek additional funding sources.

Special Thanks

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Christopher Kingsley- Peace Corps Volunteer
Chet Hopp- Peace Corps Volunteer
Alfonzo Zurdo- Water Committee Head

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Appendices

Appendix A: Survey Data

Point 1	Point 2	Distance (ft)	Forward Angle	Back Angle	Forward Bearing	Back Bearing	360-Forward	True Back Bearing
1	**2**	**100**	**12**	**-10**	**280**	**87**	**80**	**87**
2	**3**	**100**	**10**	**-9**	**298**	**71**	**62**	**71**
3	**4**	**100**	**10**	**-8**	**290**	**65**	**70**	**65**
4	**5**	**70.7**	**8**	**-6**	**290**	**70**	**70**	**70**
5	**6**	**100**	**9**	**-10**	**276**	**96**	**84**	**96**
6	**7**	**100**	**17**	**-16**	**270**	**90**	**90**	**90**
7	**8**	**100**	**17**	**-15**	**275**	**84**	**85**	**84**
8	**9**	**100**	**14**	**-12**	**255**	**65**	**105**	**65**
9	**10**	**100**	**11.5**	**-9.5**	**233**	**130**	**127**	**130**
10	**11**	**100**	**9**	**-9**	**240**	**65**	**120**	**65**
11.20	**20**	**100**	**18.5**	**-18**	**320**	**126**	**40**	**126**
20	21	74	31	-32	324	139	**36**	**139**
21	22	100	4.5	-6	331	150	**29**	**150**
22	23	100	1.5	-2	300	1/7/2012	**60**	**40915**
23	24	100	9	-9.5	289	100	**71**	**100**
24	25	61	8	-8	265	87	**95**	**87**
25	26	48	-0.5	-0.5	360	0	**0**	**0**
26	27	85	-0.5	-1	360	175	**0**	**175**
27	28	100	5.5	-4.5	326	44	**34**	**44**
28	31	65	5	-4.5	336	n/a	**24**	**n/a**
29	30	100	12.5	-11.5	255	112	**105**	**112**
30	31	91	2	-1	260	43	**100**	**43**
31	32	28	4	-5	81	255	**279**	**255**
31	34	79	14.5	-15	318	135	**42**	**135**
33	34	39	2	-1.5	322	147	**38**	**147**
34	35	100	2	-1	348	168	**12**	**168**
35	36	100	12	-12.5	310	135	**50**	**135**
36	37	55	15	-15	310	122	**50**	**122**
37	38	79	-14	13.5	305	111	**55**	**111**
38	39	11	0	0	319	n/a	**41**	**n/a**
39	40	100	-3	4	320	125	**40**	**125**
40	41	75	12	-12	315	138	**45**	**138**
41	303	59	3	-1.5	326	135	**34**	**135**
42	43	74	9	-11.5	345	171	**15**	**171**
43	44	68	12	-11	350	170	**10**	**170**
44	45	88	7	-6	345	345	**15**	**345**
45	46	50	11	-10	355	167	**5**	**167**
46	47	69	2	-3.5	7	n/a	**353**	**n/a**
47	48	53	21	-20.5	35	183	**325**	**183**
48	49	35	19	-19	3	150	**357**	**150**
49	50	41	5	-4.5	23	172	**337**	**172**
50	51	40	9	-8.5	345	151	**15**	**151**

51	52	23	2	-2	5	183	**355**	**183**
52	53	46	-7	7	15	174	**345**	**174**
53	54	83	-15	15.5	350	167	**10**	**167**
54	55	61	2.5	-3	355	164	**5**	**164**
55	56	78	13.5	-12	353	163	**7**	**163**
56	57	87	11	-10	350	155	**10**	**155**
57	58	70	13	-12	10	175	**350**	**175**
58	59	46	10.5	-9	355	175	**5**	**175**
59	60	41	20	-19	340	165	**20**	**165**
60	61	33	31.5	-37	341	155	**19**	**155**
61	62	39	40	-40.5	339	137	**21**	**137**
62	63	17	46	-47	316	112	**44**	**112**
63	64	53	15	-15	315	145	**45**	**145**
201	202	63	-8	9	11	349	**349**	**349**
202	203	100	-11.5	13	98	265	**262**	**265**
203	204	100	-13	13.5	95	265	**265**	**265**
204	205	73	-8	9	25	335	**335**	**335**
205	206	81	-6	8	0	360	**360**	**360**
206	207	57	1.5	-2.5	22	338	**338**	**338**
207	208	97	1	-1	17		**343**	**0**
208	209	98	-2.5	3	15		**345**	**0**
209	210	41	-1.5	17	28		**332**	**0**
210	211	67	24	-21	20		**340**	**0**
211	212	60	2	-3			**360**	**0**
214	215	92	26	-21	320	43	**40**	**43**
215	2-Nov	20	18	-14	312	43	**48**	**43**
216	218	100	2.5	-5	245	117	**115**	**117**
218	219	78	4.5	-3.5	257	116	**103**	**116**
301	302	39	3	-2	67	255	**293**	**255**
301	303	20	5	-5	68	255	**292**	**255**
303	42	23	5	-5	355	145	**5**	**145**
338	**346**	**200**	**-3**	**1.5**	**312**	**121**	**48**	**59**
346	**347**	**200**	**3**	**-4**	**305**	**127**	**55**	**53**
347	**348**	**200**	**12.5**	**-15**	**315**	**116**	**45**	**64**
348	**349**	**50**	**13.5**	**-14.5**	**302**	**125**	**58**	**55**
349	**350**	**50**	**1**	**0**	**237**	**66**	**123**	**114**
349	**354**	**100**	**10**	**-11.5**	**292**	**119**	**68**	**61**
351	**352**	**195**	**4.5**	**-5**	**265**	**73**	**95**	**107**
352	**353**	**158**	**24.5**	**-25**	**263**	**85**	**97**	**95**
353	**350**	**188**	**16**	**-18**	**260**	**75**	**100**	**105**
354	**355**	**200**	**6**	**-7.5**	**275**	**90**	**85**	**90**
700	701	90						
701	702	32						
702	703	100						
703	704	100						
704	705	92						

Appendix B: GPS Data

Point	Date	Coordinates	Elev
11.20	18-AUG-12 9:25:10AM	N8 26.147 W81 39.806	3195 ft
12	16-AUG-12 2:43:44PM	N8 26.267 W81 39.977	3420 ft
13	16-AUG-12 2:44:34PM	N8 26.266 W81 39.977	3418 ft
14	16-AUG-12 2:52:18PM	N8 26.264 W81 39.976	3416 ft
15	16-AUG-12 4:04:38PM	N8 26.860 W81 40.852	3456 ft
16	16-AUG-12 4:39:14PM	N8 27.360 W81 41.004	3365 ft
17	16-AUG-12 5:51:13PM	N8 26.544 W81 40.526	3364 ft
18	17-AUG-12 9:09:07AM	N8 26.153 W81 39.661	3018 ft
20	18-AUG-12 10:13:43AM	N8 26.156 W81 39.816	3246 ft
21	18-AUG-12 10:22:57AM	N8 26.165 W81 39.823	3283 ft
22	18-AUG-12 10:28:17AM	N8 26.177 W81 39.834	3297 ft
23	18-AUG-12 10:34:36AM	N8 26.183 W81 39.850	3297 ft
24	18-AUG-12 10:40:23AM	N8 26.186 W81 39.866	3317 ft
25	18-AUG-12 10:45:03AM	N8 26.185 W81 39.875	3326 ft
26	18-AUG-12 10:50:19AM	N8 26.192 W81 39.874	3331 ft
27	18-AUG-12 10:56:17AM	N8 26.208 W81 39.876	3331 ft
28	18-AUG-12 11:00:49AM	N8 26.220 W81 39.888	3343 ft
29	18-AUG-12 11:09:08AM	N8 26.237 W81 39.864	3325 ft
30	18-AUG-12 11:13:57AM	N8 26.233 W81 39.879	3344 ft
31	18-AUG-12 11:21:28AM	N8 26.229 W81 39.894	3351 ft
32	18-AUG-12 11:29:39AM	N8 26.227 W81 39.899	3349 ft
33	18-AUG-12 11:41:08AM	N8 26.238 W81 39.902	3372 ft
34	18-AUG-12 11:45:54AM	N8 26.244 W81 39.905	3377 ft
35	18-AUG-12	N8 26.260 W81	3377 ft

	11:51:03AM	39.911	
36	18-AUG-12 11:58:40AM	N8 26.272 W81 39.922	3398 ft
37	18-AUG-12 1:38:24PM	N8 26.274 W81 39.929	3401 ft
38	18-AUG-12 1:43:16PM	N8 26.278 W81 39.941	3371 ft
39	18-AUG-12 1:47:21PM	N8 26.281 W81 39.941	3376 ft
40	18-AUG-12 1:50:56PM	N8 26.292 W81 39.952	3371 ft
41	18-AUG-12 1:56:43PM	N8 26.300 W81 39.961	3386 ft
42	18-AUG-12 2:19:03PM	N8 26.313 W81 39.967	3398 ft
43	18-AUG-12 2:29:46PM	N8 26.325 W81 39.973	3403 ft
44	18-AUG-12 2:33:38PM	N8 26.336 W81 39.970	3415 ft
45	18-AUG-12 2:40:22PM	N8 26.350 W81 39.975	3425 ft
46	18-AUG-12 2:47:06PM	N8 26.358 W81 39.972	3428 ft
47	18-AUG-12 2:52:43PM	N8 26.368 W81 39.979	3434 ft
48	18-AUG-12 3:00:00PM	N8 26.376 W81 39.975	3455 ft
49	18-AUG-12 3:05:53PM	N8 26.383 W81 39.980	3466 ft
50	18-AUG-12 3:10:41PM	N8 26.384 W81 39.980	3470 ft
51	18-AUG-12 3:15:43PM	N8 26.387 W81 39.981	3470 ft
52	18-AUG-12 3:20:31PM	N8 26.398 W81 39.984	3476 ft
53	18-AUG-12 3:25:19PM	N8 26.407 W81 39.982	3475 ft
54	18-AUG-12 3:30:57PM	N8 26.420 W81 39.984	3457 ft
55	18-AUG-12 3:36:40PM	N8 26.429 W81 39.983	3456 ft
56	18-AUG-12 3:40:54PM	N8 26.445 W81 39.987	3472 ft
57	18-AUG-12 3:46:24PM	N8 26.456 W81 39.991	3487 ft

Appendix C: Flow Data

Table showing flow rate data for old system:

Time (s)	Volume (L)	Rate (l/s)
3.92	1	0.255
3.26	1	0.307
8.62	1	0.116
4.19	1	0.239
1.76	1	0.568
	Average	**0.297**

Table showing flow rate data for new system:

Time (s)	Volume (gal)	Volume (l)	Rate (l/s)
4.47	5	18.927	4.234
5.47	5	18.927	3.460
6.48	5	18.927	2.921
8.13	5	18.927	2.328
7.08	5	18.927	2.673
5.7	5	18.927	3.321
		Average	**3.156**

Appendix D: Google Earth Code

Troy Drabek, a fellow engineering student at Michigan Tech, was consulted to initially help with this programing. He showed the team how to export files from Google Earth as kml files, edit them, and re-upload them into the system. Each pipeline in the system has an individual file that includes all of the branches for that line. Branches were given the line name and then a letter for example Line 1 has branches 1a through 1h. Lines were also color coded for ease of distinguishing the various parts of the system. Included below are the programs for Line 6 and for the Taps Proposed for Unbuilt Houses. Parts of the code that were modified by the team to create unique system lines are highlighted. The rest of the codes for the Google Earth maps are provided on the supplied CD.

Line 6

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Taps Proposed for Unbuilt Houses


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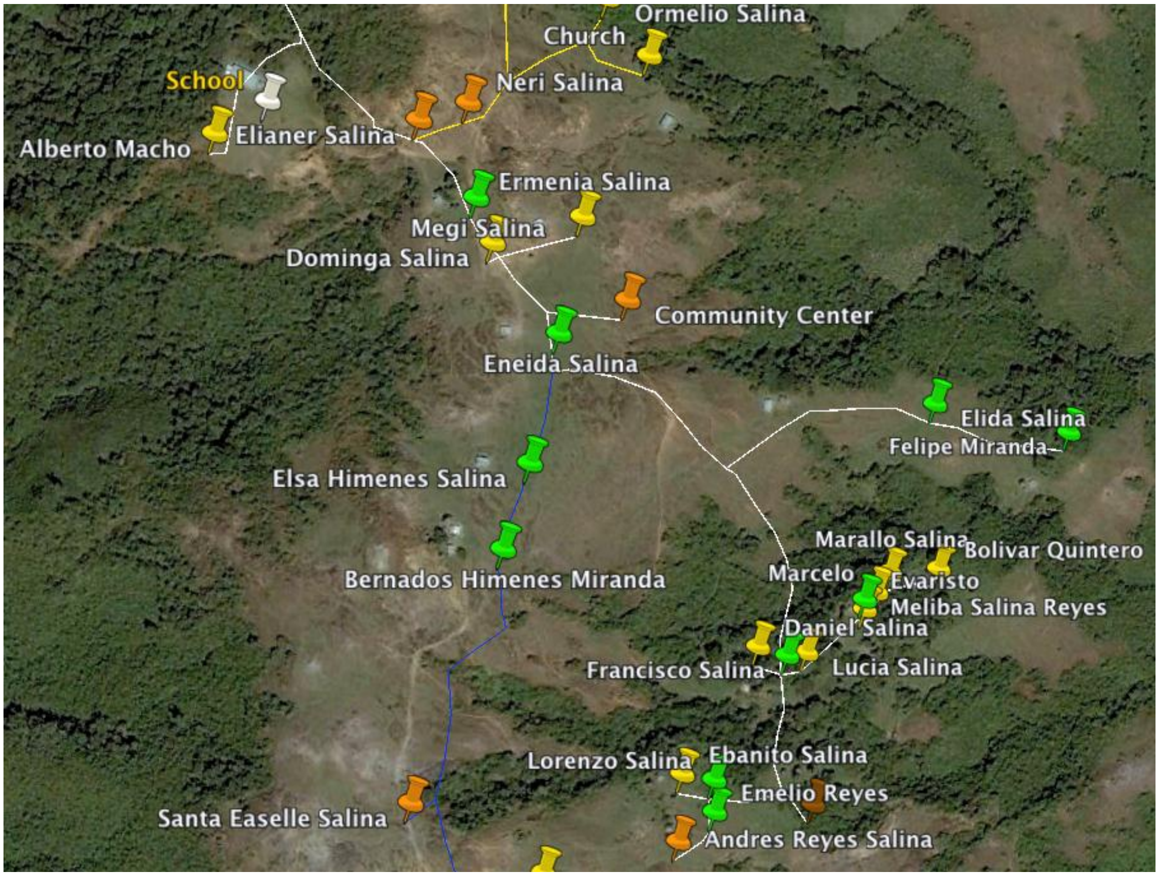
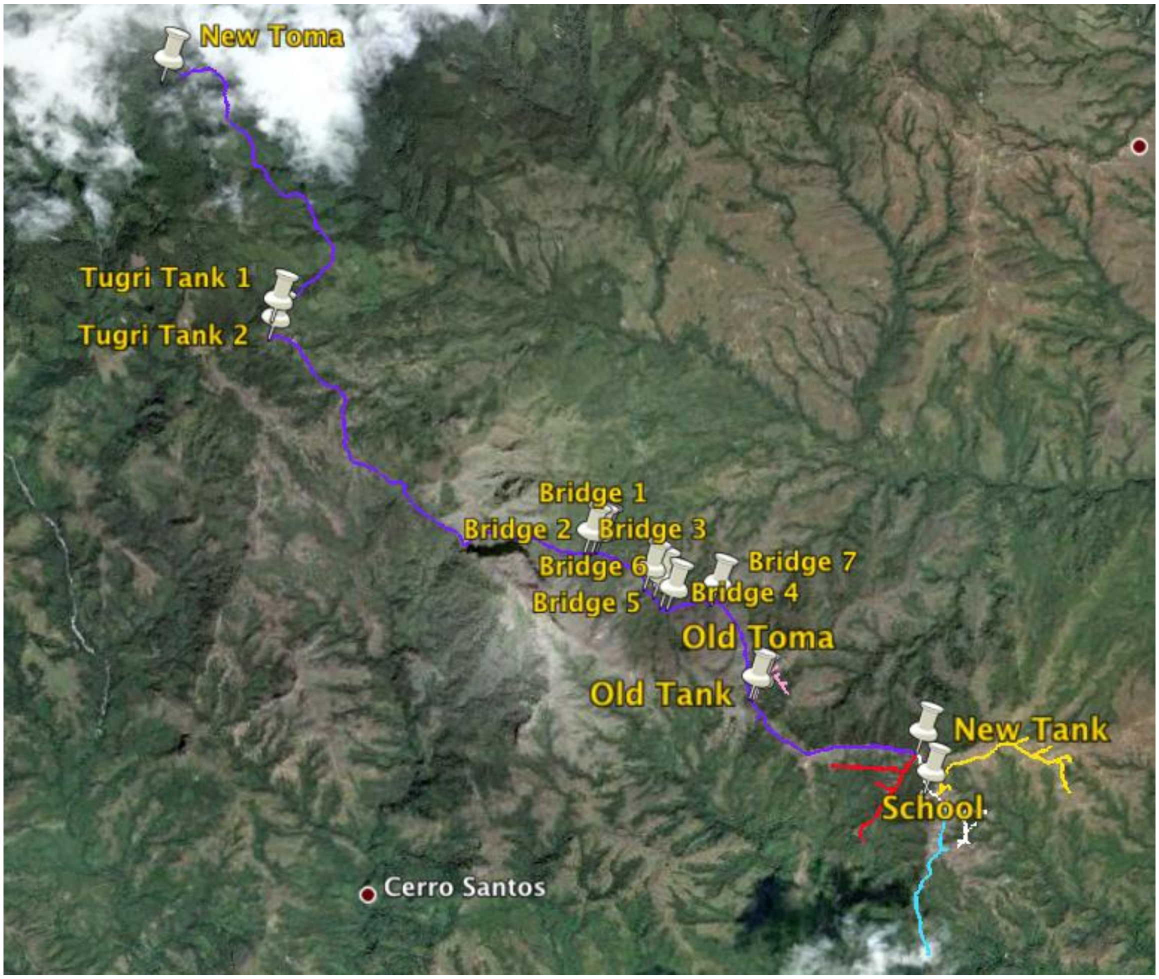
Appendix E: Google Earth Maps

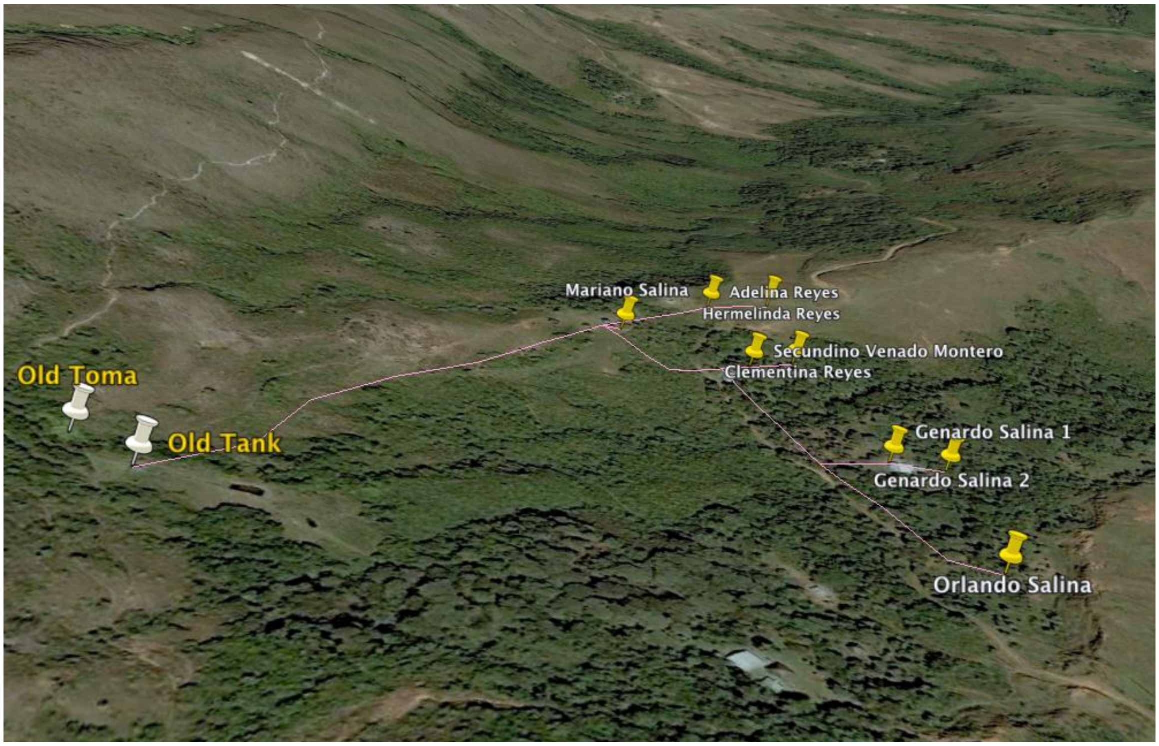
This appendix provides some extra images of the proposed system for clarification.



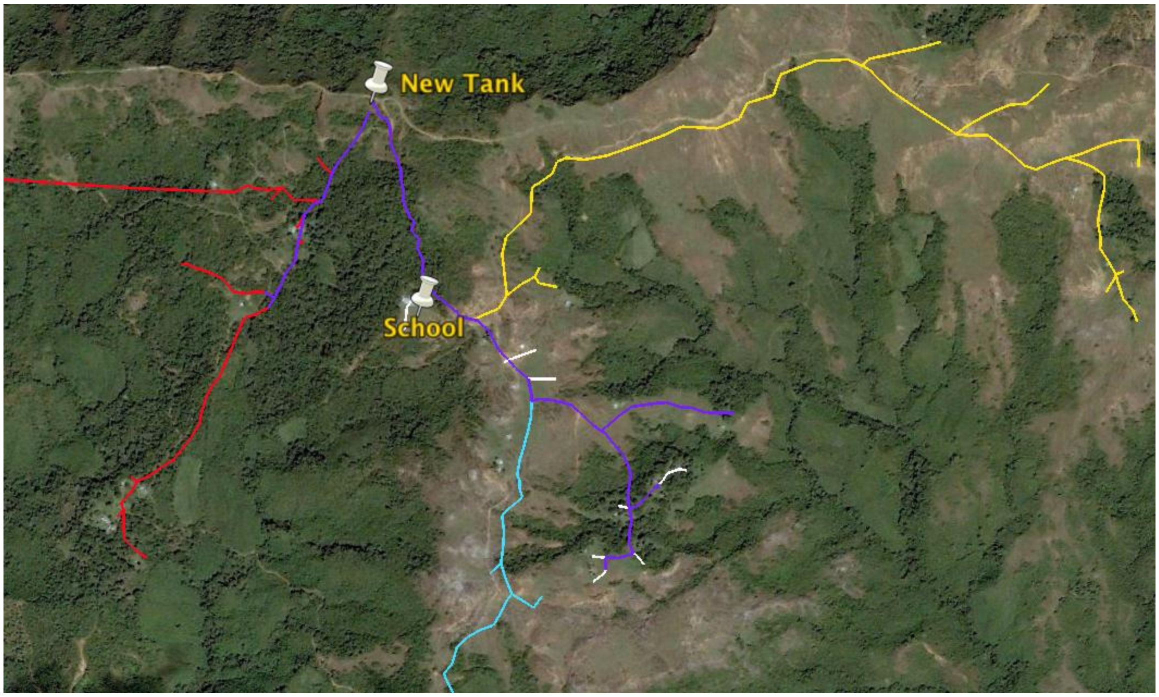
All of the tap locations in the community are marked as existing taps (green), homes that would like a tap (yellow) or locations of proposed homes that requested a tap (orange). Other important locations, such as the school and the tanks, are indicated by a white marker.



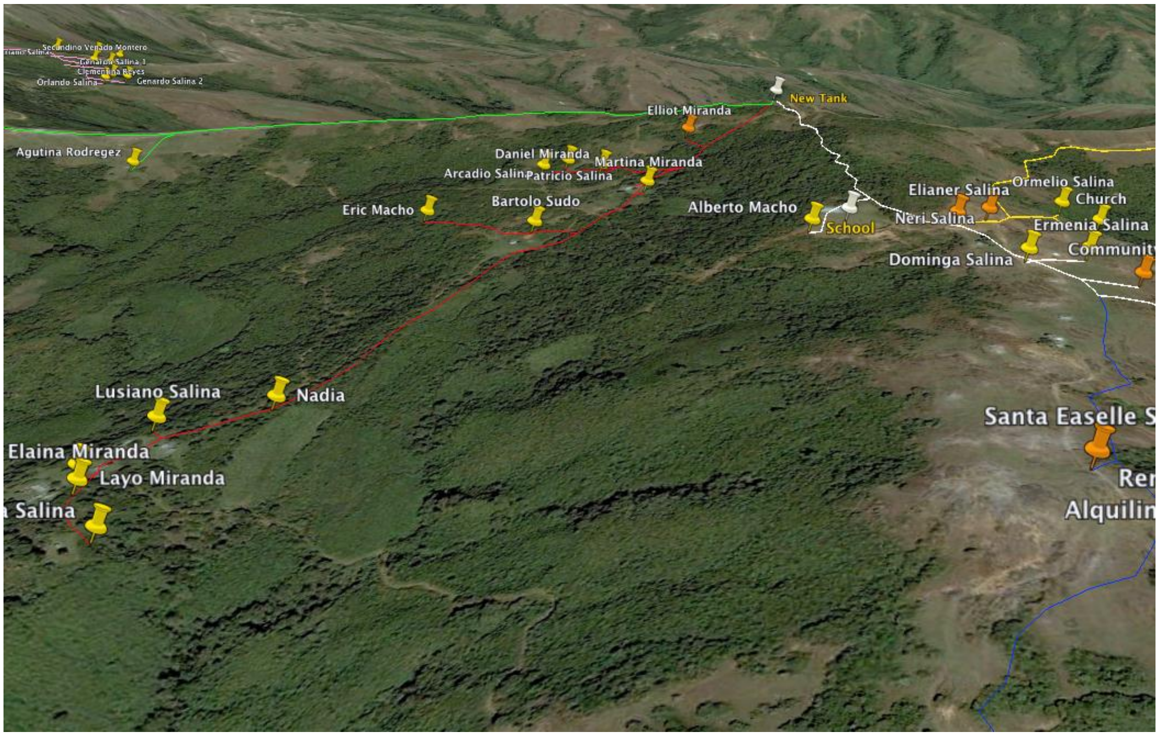
The water for this project comes from a small river in the mountains northwest of the community of Tugri. The line then comes down to Tugri where it is filtered and chlorinated and enters a tank (Tank 1 Tugri). From there the water travels to the New Tank in Cerro Miel and is distributed in the supply lines as shown above. There are several places between Tugri and Cerro Miel where the pipe crosses large gullies and is unsupported these places. These places labeled as bridges above, are the proposed locations of the cable suspension bridges.



The image above shows the houses that were changed from the New System to the Old System to alleviate pressure issues. The pipe from the New System would have to cross the large hill located on the left, which was the cause of the pressure problems.



Here, all the pipeline in Cerro Miel that is currently in existence is highlighted in purple. Much of this pipeline is in poor condition and will need to be replaced anyway.



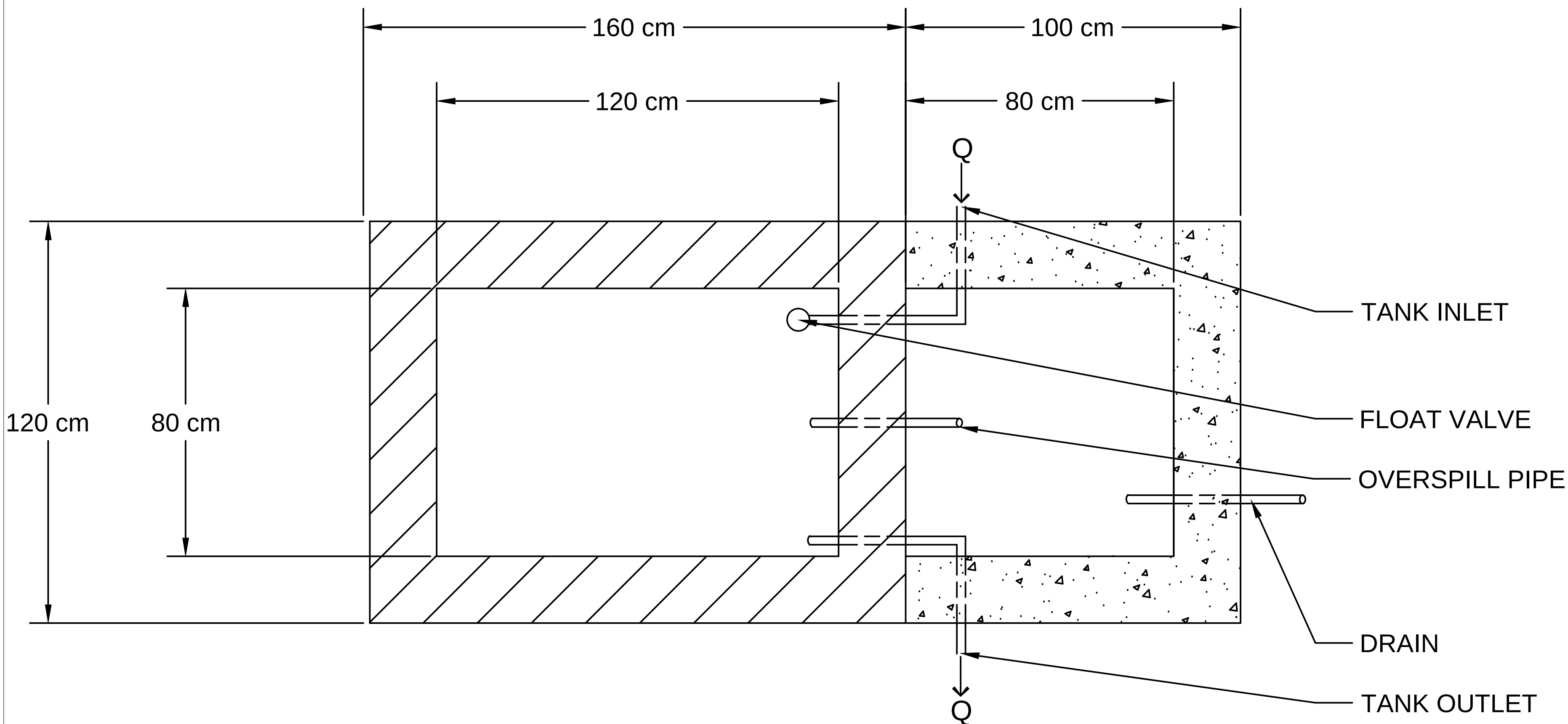
This figure shows the magnitude of elevation changes in the system.

Appendix F: EPANET Model

Table of pressures in system:

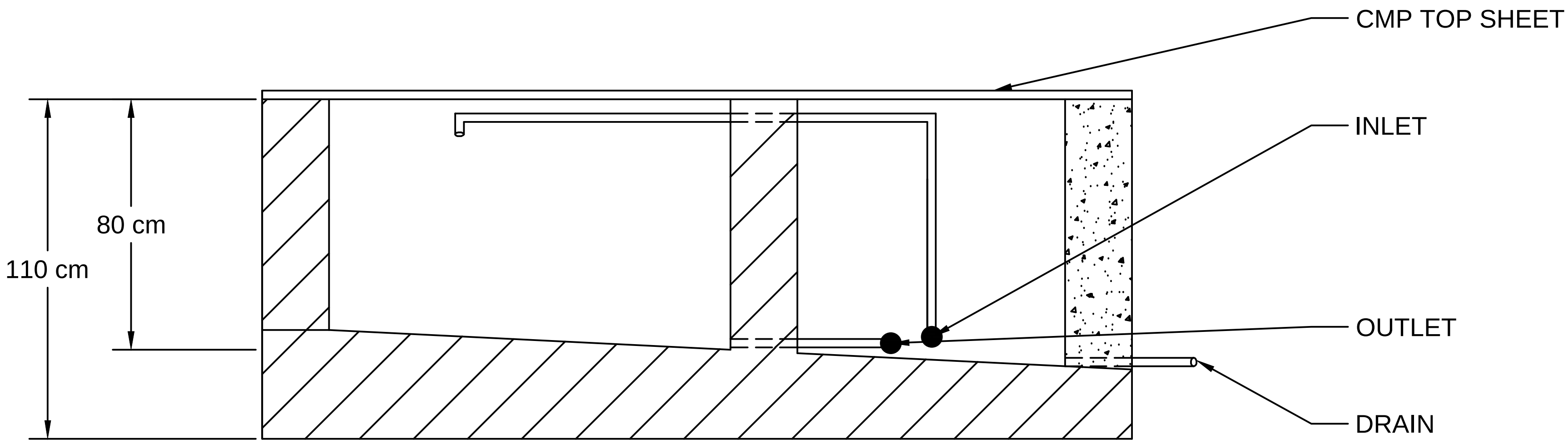
Node ID	Pressure psi
Junc 2	0.01
Junc 5	20.85
Junc 6	26.73
Junc 7	31.41
Junc 8	40.36
Junc 9	62.02
Junc 10	42.46
Junc 11	71.06
Junc 12	102.69
Junc 13	146.02
Junc 14	14.73
Junc 19	109.19
Junc 20	12.57
Junc 24	14.35
Junc 25	24.57
Junc 27	108.32
Junc 29	120.46
Junc 30	84.93
Junc 31	25.99
Junc 32	75.39
Junc 33	60.23
Junc 35	83.63
Junc 36	99.66
Junc 37	59.42
Junc 38	77.19
Junc 40	81.89
Junc 41	132.59
Junc 42	155.55
Junc 43	152.95
Junc 44	124.79
Junc 45	145.59
Junc 46	113.52
Junc 65	24.57
Junc 66	62.00
Junc 67	70.06
Junc 68	8.61
Junc 69	7.31
Junc 70	18.20
Junc 71	14.73
Junc 72	25.56
Junc 73	106.59
Junc 74	115.69
Junc 75	115.26
Junc 76	126.52
Junc 77	126.52
Junc 78	129.12
Junc 79	157.29
Junc 80	27.61
Junc 81	54.39
Junc 82	5.22
Junc 83	15.59
Junc 84	20.65
Junc 85	46.65
Junc 86	16.98
Junc 87	137.36
Junc 89	107.46
Junc 90	109.62
Junc 91	98.79
Junc 92	102.69
Junc 93	103.13
Junc 94	90.56
Junc 95	75.39
Junc 96	74.09
Junc 97	31.03
Junc 98	18.63
Junc 99	13.87
Junc 100	18.20
Junc 101	24.70
Junc 102	18.20
Junc 103	38.56
Junc 104	39.86
Junc 105	41.60
Junc 106	129.56
Junc 107	156.42
Junc 108	158.15
Junc 109	157.29
Junc 110	158.15
Junc 111	134.32
Junc 112	171.15
Junc 113	129.12
Junc 114	42.46
Junc 115	105.73
Junc 16	60.66
Junc 3	21.23
Resvr 15	0.00
Tank 1	4.33
Tank 17	0.87
Tank 18	0.87
Tank 21	0.87

Appendix G: Pressure Release Tank Drawings



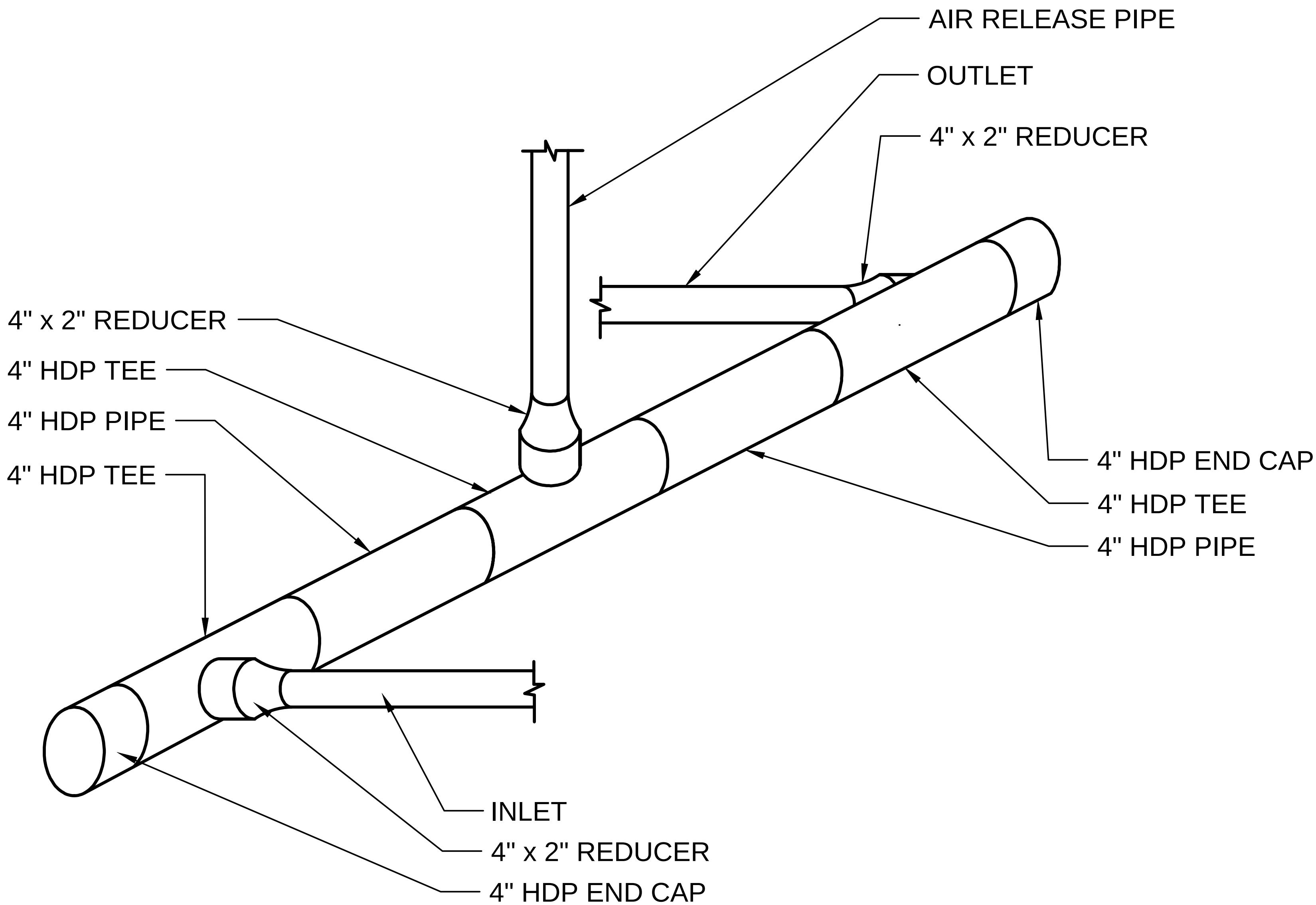
TOP VIEW

UNO MÁS ENGINEERING	A01: MASON-BREAK PRESSURE TANK TOP VIEW	Drawn By: Brittany Allen	Date: 12/9/2012

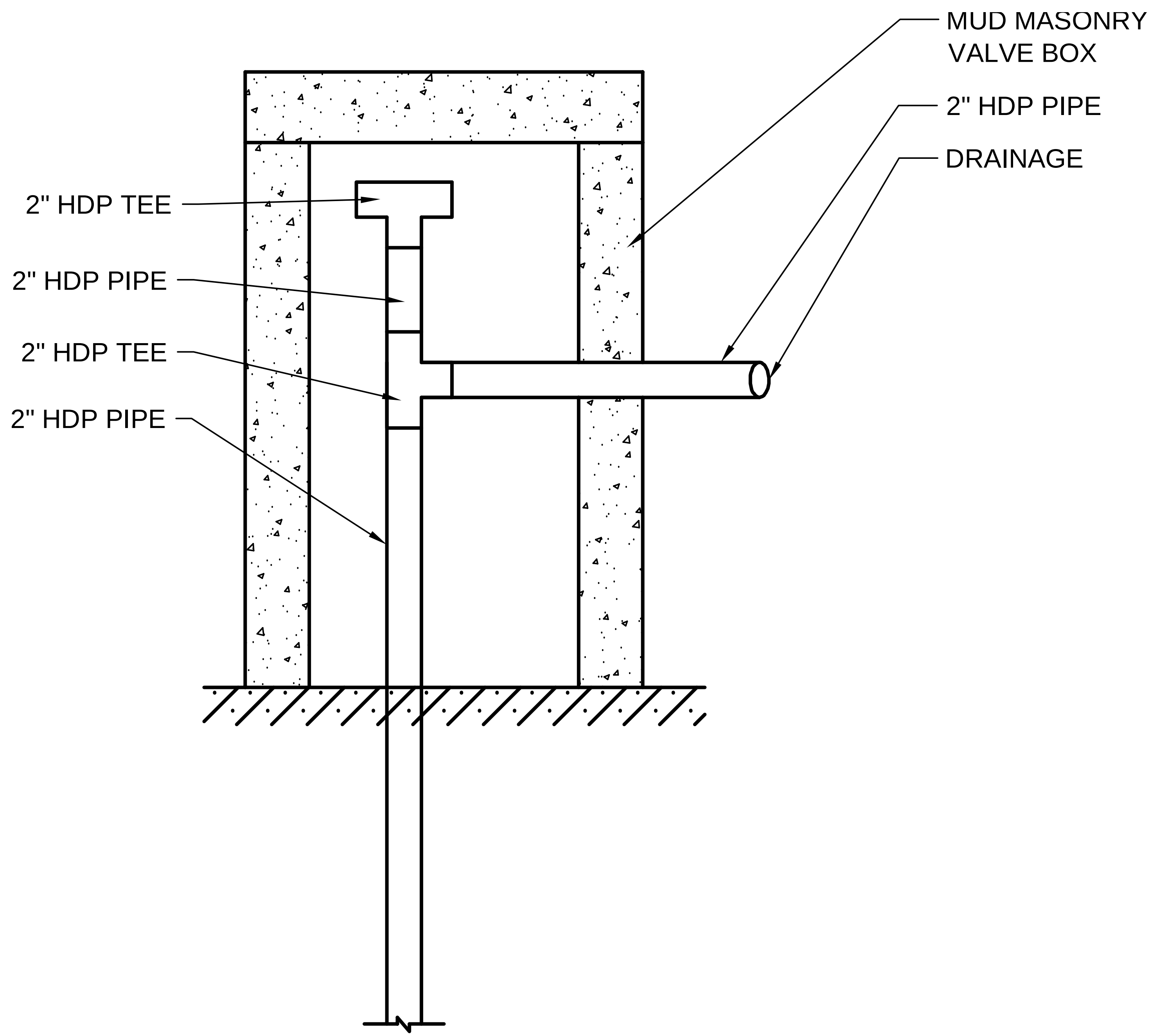


PROFILE VIEW

UNO MÁS ENGINEERING	A02: MASON-BREAK PRESSURE TANK SIDE VIEW	Drawn By: Brittany Allen	Date: 12/9/2012



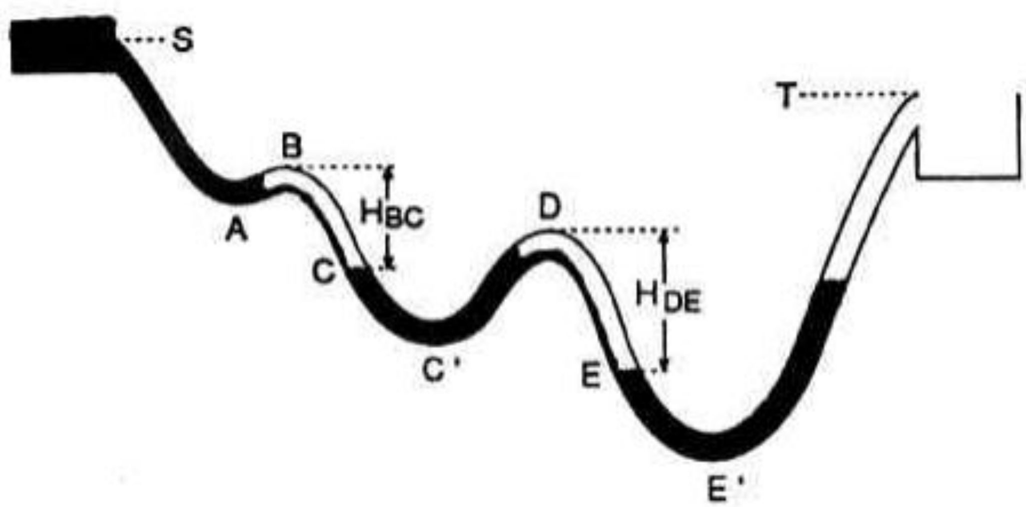
UNO MÁS ENGINEERING	B01: HDP PRESSURE TANK (UNDERGROUND)	Drawn By: Brittany Allen	Date: 12/9/2012
			Michigan Tech



UNO MÁS ENGINEERING	B02: HDP PRESSURE TANK (ABOVE GROUND)	Drawn By: Brittany Allen	Date: 12/9/2012 Michigan Tech

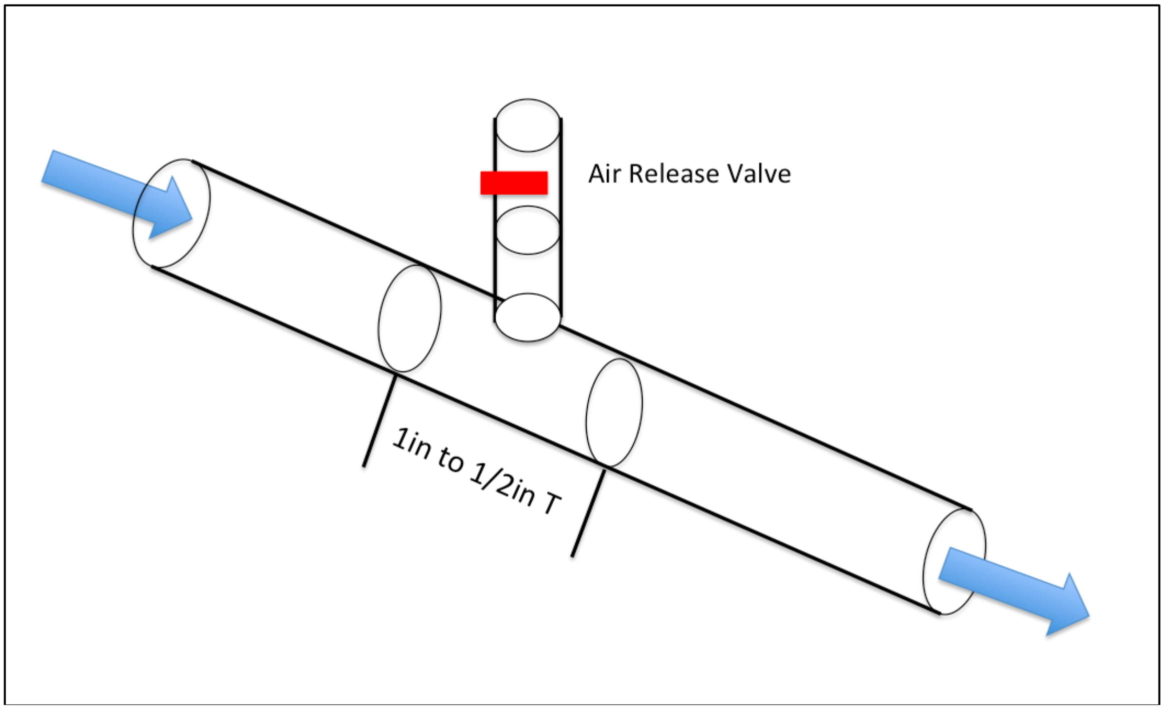
Appendix H: Air Release Locations

This appendix is meant to give the reader a better understanding of air block problems, and air relief in this system. The two graphs in this appendix are the elevation profiles used to determine the locations where air release would be necessary for the supply line and Line 6. Due to the fact that much of the data collected for this system was done using a GPS these elevation profiles were made from the elevations collected by the GPS data assuming 100ft between each reading. .

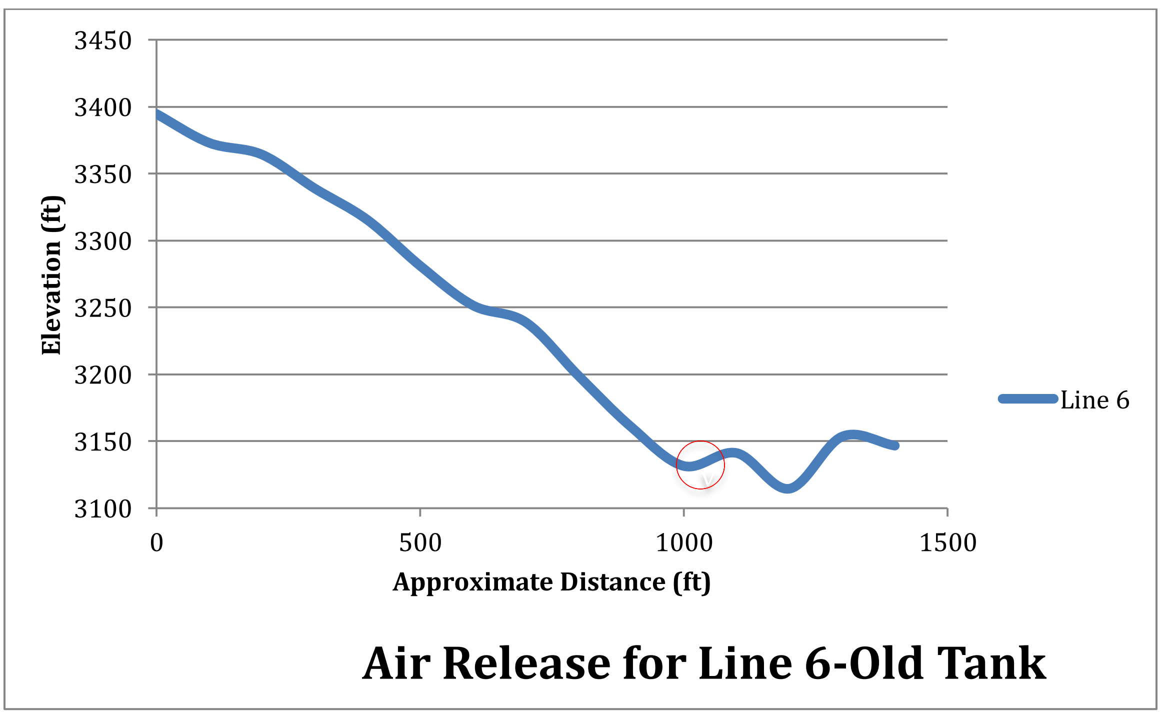


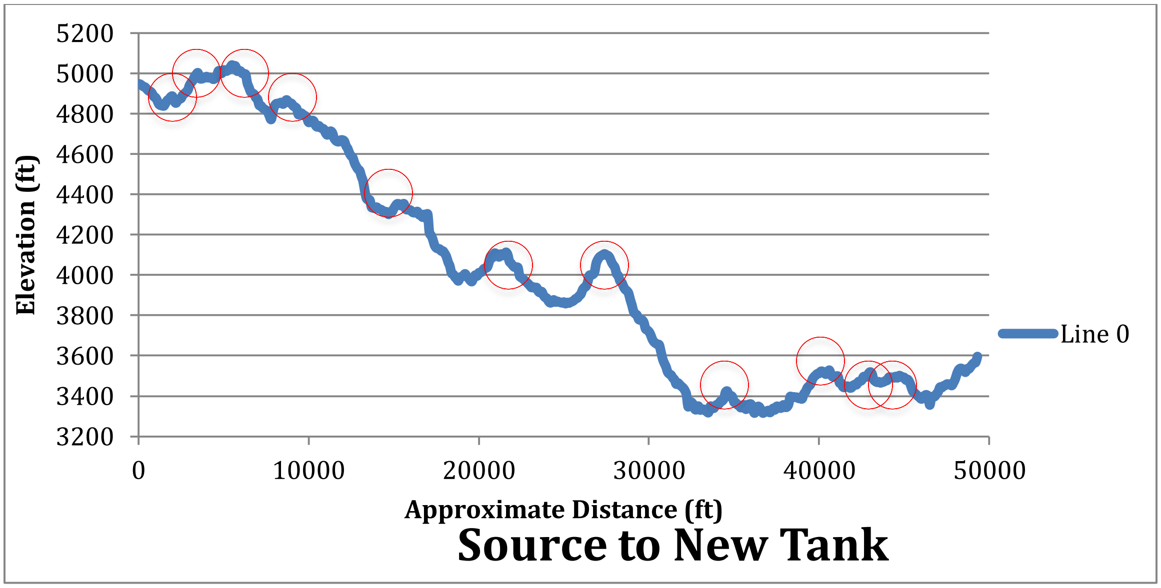
(Corpos)

This diagram is useful for understanding how air collects in water distribution pipes.



This figure shows how the air release valves will be installed in the system.




5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
Elevation (ft)
0
10000
20000
30000
40000
50000
Approximate Distance (ft)
Line 0
Source to New Tank

Appendix I: Valve Options for Air Release

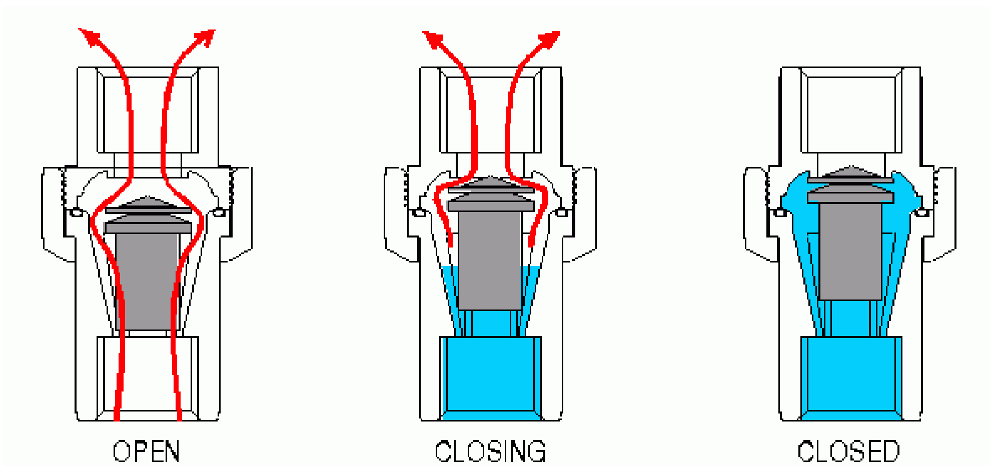
(http://www.asahi-america.com/documents/documents/Asahi-English/T-21%20New%20Product%20Announcement.pdf)

This is the chosen option for air release in the community. The locking handle provides extra security and the valve is relatively easy to install. The cost of each valve is $15 not including the padlock.

(http://kbi-king-brothers-inc.webstorepowered.com/PVC-COMP-STOP-VALVE-SLIP/dp/B000KKVY96)

This is the secondary option recommendation if the community wants to avoid locked valves.

(drillspot.com)



(plastomatic.com)

Appendix J: Gully Crossing Data

In the table below all of the components of the seven bridges that are to be built for the water system are listed. These were calculated using an excel spreadsheet called Gully Crossing Supports. An example of the calculations is shown below.

	Cable		Pipe			Concrete	Clamps	Ties
	Size	Length (ft)	Amount	Height	Size	Amount (ft^3)	Amount	Amount
Bridge 1	1x19	62.49	0	na	na	na	6	6
Bridge 2	1x19	49.83	2	3.00	1 1/4 5S	89.25	6	4
Bridge 3	1x19	46.59	2	3.00	1 1/4 5S	42.07	6	4
Bridge 4	1x19	36.18	2	3.00	1 1/4 5S	52.25	6	3
Bridge 5	1x19	112.42	3	3.00	1 1/4 80-XS-80S	95.50	6	11
Bridge 6	1x19	36.54	1	3.00	1 1/4 5S	20.40	6	3
Bridge 7	1x19	49.33	2	3.00	1 1/4 10S	61.64	6	4
Total	na	393.37	12	na	na	361.11	42	35

Bridge 2:

Known Values:	
Weight of pipe (lb/ft)	1.41
Weight of water (lb/ft)	0.267
Length of Span (ft)	49.21
Estimated Sag (ft)	3
Elevation Drop (ft)	6.56

Calculated Values:	
Horizontal Tension (lbs)	53.10
Angle of Tension (rad)	0.66
Total Tension(lbs)	67.25
Total Tension (lbs)w/SF= 3	201.74

Cable Options				
Construction	Diameter (in)	Wt per ft (lbs)	Minimum Breaking Strength (lbs)	Area of Steel (in^2)
1x19	1/8	0.035	2100	0.0092

Optimized Values:	Calculated:	Use:
Calculated Sag A (ft)	7.29	7.50
Sag Ratio	0.15	0.12
Drop Ratio	0.13	0.11
C/Length Ratio	2.524712	
Apex/Length Ratio	0.775	
Adjusted Length/Length Ratio	1.012542424	
Adjusted Constant	124.25	
Adjusted Apex (ft)	38.14	
Adjusted Length (ft)	49.83	
Angle of Attachment to Support (rad)	0.30	
Vertical Component (lbs)	63.96	
Horizontal Component (lbs)	205.13	
Total Force (lbs)	214.87	

Calculated Pipe and Anchor Size	
Maximum Bending force (lb*in)	1846.14
Maximum Bending force (lb*in) with SF x3	3692.28
Height of pipe (ft)	3.00
Check	0.76
Weight of Mass per ft^3	120.00
Estimated Height of Concrete (ft)	4.25
Estimated Width of Concrete (ft)	3.00
Estimated Length of Concrete (ft)	3.50
Volume (ft^3)	44.63

Steel Pipe Options		
Construction	Diameter (in)	Minimum Breaking Strength (lbs*in)
1 1/4 5S	1.66	4500

Appendix K: Detailed Cost Estimate

Item	Place	Unit Price	Unit	Quantity	Total
Division 1: Piping					
Threaded Elbow PVC 1/2"x90˚	Tolé	0.35	Each	55	19.25
Plain Elbow PVC 1/2"x90˚	Tolé	0.25	Each	55	13.75
Metal Pluma (tap) 1/2"	Supercentro SF	5.9	Each	55	324.5
Shut Off Valve 1/2"	Tolé	1.75	Each	55	96.25
PVC Pipe 1" SDR 26 (20 ft)	Ferreterria Enrique	0.17	L.F.	7978	1356.26
PVC Pipe 1/2" SDR 13.5 (20 ft)	Ferreterria Enrique	0.11	L.F.	18126	1993.86
Tee PVC 1"	Tolé	0.75	Each	40	30
PVC Joint Glue	Tole	8	Can	15	120
				Total	**3953.87**
				Total with 10% Markup	**4350**
Division 2: Pressure Release					
Mason-Break Pressure Tank					
Bag of Cement Panama GU	Tolé	8.95	bag	7	62.65
Sand	Tolé	0.3	5 Gal. Pail	19	5.7
Gravel	Tolé	0.3	5 Gal. Pail	28	8.4
PVC Pipe 1" SDR 26 (20 ft)	Ferreterria Enrique	0.17	L.F.	8	1.36
Plain Elbow PVC 1/2"x90˚	Tolé	0.25	Each	3	0.75
Shut Off Valve 1/2"	Tolé	1.75	Each	2	3.5
Float Valve	Tolé	22.91	Each	1	22.91
Steel Pipe Screen 2"	Tolé	0.16	Each	12	1.92
Hose Clamp 1"	Tolé	0.89	each	12	10.68
				Total (Each Tank)	**117.87**
				Total (3 Tanks)	**353.61**
				Total (3 Tanks) with 10% Markup	**390**
HDP Pressure Tank					
End Cap, 4"	Tolé	7.71	Each	2	15.42
Tee 4"	Tolé	23.35	Each	3	70.05
HDPE Pipe (4")	Tolé	0.1685	L.F.	4	0.674

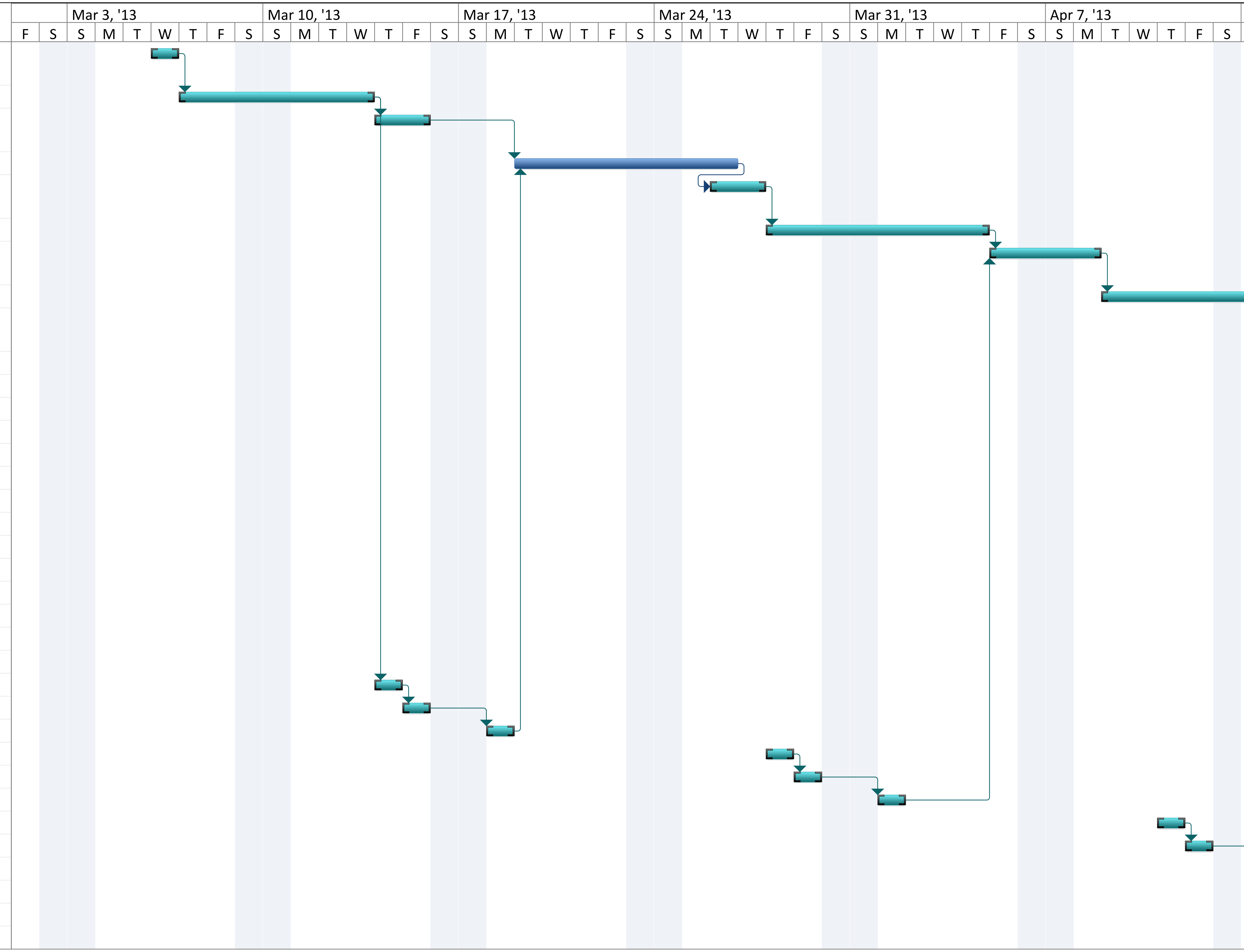
HDPE Pipe (2")	Ferreterria Enrique	0.089	L.F.	8	0.712
4" to 2" Reducer	Tolé	10.67	Each	3	32.01
Steel Pipe Screen 2"	Tolé	0.16	Each	12	1.92
Hose Clamp 1"	Tolé	0.89	each	12	10.68
				Total	**131.466**
				Total with 10% Markup	**145**
Division 3: Gully Crossing Supports					
Bag of Cement Panama GU	Tolé	8.95	bag	62	554.9
Sand	Tolé	0.3	5 Gal. Pail	185	55.5
Gravel	Tolé	0.3	5 Gal. Pail	277	83.1
Steel Pipe 1 1/2"	Ferreterria Enrique	7.95	L.F.	36	286.2
Cable 1/8"	Ferreterria Enrique	0.35	L.F.	395	138.25
Cable Ties	Ferreterria Enrique	1.75	L.F.	35	61.25
Clamps	Tolé	1.75	L.F.	42	73.5
				Total	**1252.7**
				Total with 10% Markup	**1380**
Division 4: UV Pipe Protection					
Paint	Tolé	20	Gallon	19	380
Paint Brushes (4 inch)	Tolé	5	Each	4	20
				Total	**400**
				Total with 10% Markup	**440**
Division 5: Air Release					
Air Release Valves	Tolé	15	Each	12	180
1" to 1/2" Reducer Tee	Tolé	1.15	Each	12	13.8
				Total	**193.8**
				Total with 10% Markup	**215**
Division 6: Transportation					
Pressure Release Supplies	N/A	60	Truck	9	540

			Load		
Pipeline, Air Release, Paint	N/A	60	Truck Load	5	300
Gully Crossing Supports	N/A	60	Truck Load		0
				Total	**840**
				Total with 10% Markup	**930**

Project Total	**7125.446**
Total with 10% Markup	**7850**

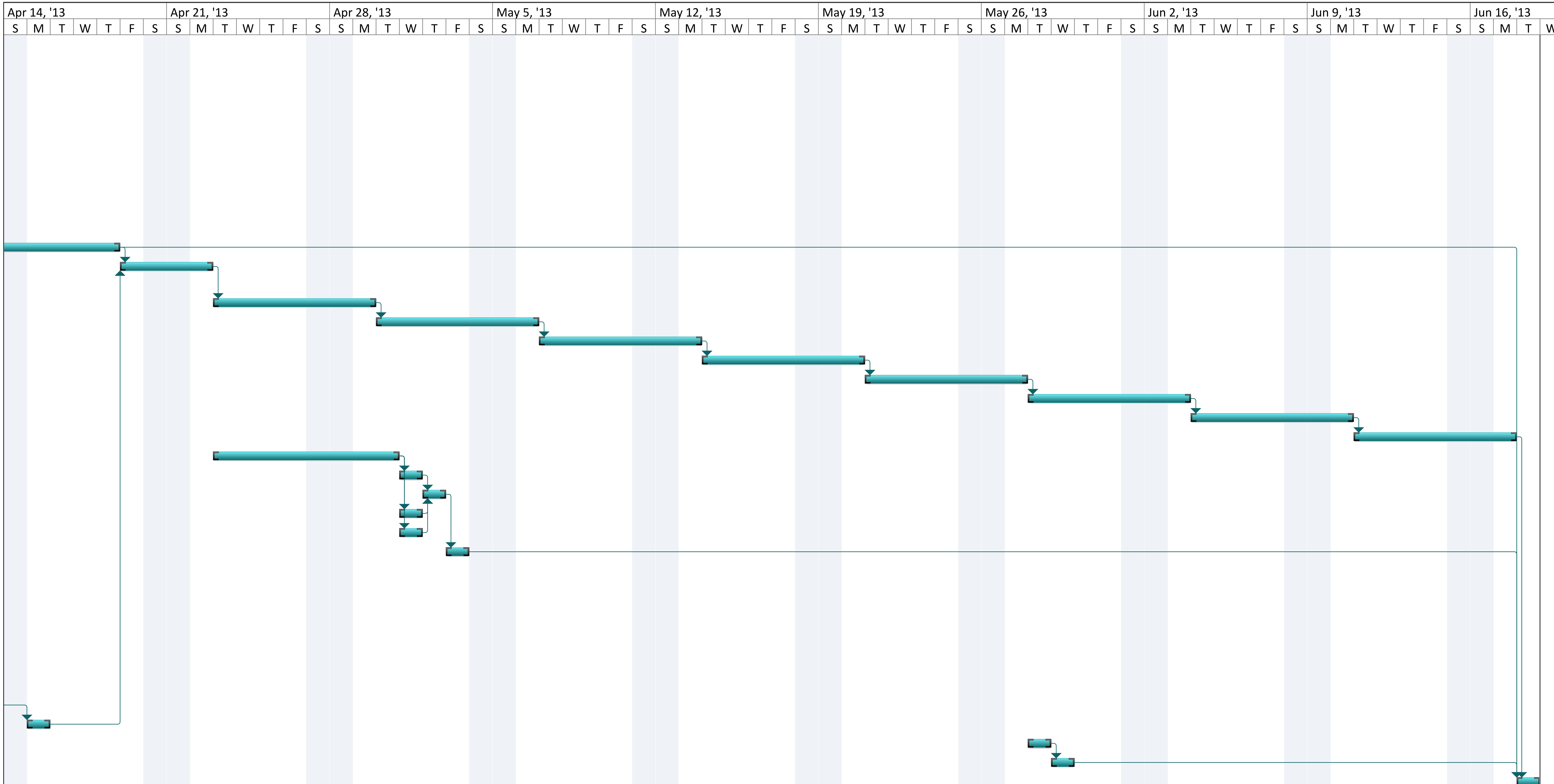
Appendix L: Construction Schedule

ID	Task Name	Duration	Start	Finish	Predecessors
1	Transportation - Pipeline 1 Material	1 day	Wed 3/6/13	Wed 3/6/13	
2	Pipeline 1 Construction	5 days	Thu 3/7/13	Wed 3/13/13	1
3	Transportation - Pipeline 3 Material	2 days	Thu 3/14/13	Fri 3/15/13	2
4	Pipeline 3 Construction	6 days	Tue 3/19/13	Tue 3/26/13	3,26
5	Transportation - Pipeline 4 Material	2 days	Tue 3/26/13	Wed 3/27/13	4
6	Pipeline 4 Construction	6 days	Thu 3/28/13	Thu 4/4/13	5
7	Transportation - Pipeline 2 Materials	2 days	Fri 4/5/13	Mon 4/8/13	6,29
8	Pipeline 2 Construction	8 days	Tue 4/9/13	Thu 4/18/13	7
9	Transportation -Pipeline 6 Material	2 days	Fri 4/19/13	Mon 4/22/13	8,32
10	Pipeline 6 Construction	5 days	Tue 4/23/13	Mon 4/29/13	9
11	Gully Crossing 1 Support	5 days	Tue 4/30/13	Mon 5/6/13	10
12	Gully Crossing 2 Support	5 days	Tue 5/7/13	Mon 5/13/13	11
13	Gully Crossing 3 Support	5 days	Tue 5/14/13	Mon 5/20/13	12
14	Gully Crossing 4 Support	5 days	Tue 5/21/13	Mon 5/27/13	13
15	Gully Crossing 5 Support	5 days	Tue 5/28/13	Mon 6/3/13	14
16	Gully Crossing 6 Support	5 days	Tue 6/4/13	Mon 6/10/13	15
17	Gully Crossing 7 Support	5 days	Tue 6/11/13	Mon 6/17/13	16
18	Paint - Supplyline	6 days	Tue 4/23/13	Tue 4/30/13	
19	Painting - Pipeline 1	1 day	Wed 5/1/13	Wed 5/1/13	18
20	Painting - Pipeline 2	1 day	Thu 5/2/13	Thu 5/2/13	19,21,22
21	Painitng - Pipeline 3	1 day	Wed 5/1/13	Wed 5/1/13	18
22	Painting - Pipeline 4	1 day	Wed 5/1/13	Wed 5/1/13	18
23	Painting - Pipeline 5	1 day	Fri 5/3/13	Fri 5/3/13	20
24	MBPT Forms Line 1	1 day	Thu 3/14/13	Thu 3/14/13	2
25	MBPT Pour Concrete Line1	1 day	Fri 3/15/13	Fri 3/15/13	24
26	MBPT Connections Line 1	1 day	Mon 3/18/13	Mon 3/18/13	25
27	MBPT Forms Line 4	1 day	Thu 3/28/13	Thu 3/28/13	
28	MBPT Pour Concrete Line 4	1 day	Fri 3/29/13	Fri 3/29/13	27
29	MBPT Connection Line 4	1 day	Mon 4/1/13	Mon 4/1/13	28
30	MBPT Forms Line 2	1 day	Thu 4/11/13	Thu 4/11/13	
31	MBPT Pour Concrete Line 2	1 day	Fri 4/12/13	Fri 4/12/13	30
32	MBPT Connection Line 2	1 day	Mon 4/15/13	Mon 4/15/13	31
33	HDP PT Digging	1 day	Tue 5/28/13	Tue 5/28/13	
34	HDP PT Place Tank & Backfi	1 day	Wed 5/29/13	Wed 5/29/13	33
35	System Ready to Use	1 day	Tue 6/18/13	Tue 6/18/13	34,17,8,23



Project: Construction Schedule
Date: Wed 12/12/12

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



Project: Construction Schedule
Date: Wed 12/12/12

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

Appendix M: Chlorine Calculations

The tables included below summarize the calculations used to determine the amount of chlorine tablets necessary for decontamination of the three tanks in this system each time they are cleaned. It is assumed that each tank is full when the chlorine is added and that the chlorine tablets used are the large tablets provided by the Panamanian government. The desired concentration of radical chlorine is 0.35mg/l and the percentage of active chlorine by mass is assumed to be 50 in sodium hypochlorite tablets (Orner).

Chlorination for New Tank		
Item	**Value**	**Unit**
Length	16	ft
Width	20	ft
Height	7	ft
Overspill from top	1	ft
Useful Height	6	ft
Volume	1920	ft^3
with 10% safety	2112	ft^3
	15797.76	gal
	59874	l
Chlorine necessary	0.35	mg/l
Chlorine to add	21.0	g
Weight of Tablets	64	g/tablet
Amount free chlorine	0.5	
# Tablets	0.7	tablets

Chlorination for Old Tank		
Item	**Value**	**Unit**
Length	10.5	ft
Width	10.5	ft
Height	6	ft
Overspill from top	0.5	ft
Useful Height	5.5	ft
Volume	606.375	ft^3
with 10% safety	667	ft^3
	4989	gal
	18909	l
Chlorine necessary	0.35	mg/l
Chlorine to add	6.6	g
Weight of Tablets	64	g/tablet
Amount free chlorine	0.5	

# Tablets	0.2	tablets

Chlorination for Tugri Tank		
Item	**Value**	**Unit**
Length	21	ft
Width	22	ft
Height	8	ft
Overspill from top	1.5	ft
Useful Height	6.5	ft
Volume	3003	ft^3
with 10% safety	3303	ft^3
	24709	gal
	93646	l
Chlorine necessary	0.35	mg/l
Chlorine to add	32.8	g
Weight of Tablets	64	g/tablet
Amount free chlorine	0.5	
# Tablets	1.0	tablets