Gravity-Fed Water System El Hueco, Coclé, Panama Prepared for Peace Corps Volunteer: Shellee Merryman

CYC Environmental Engineering: Louis Bassette, Meredith Brehob, George Meados, Harrison Zost

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Michigan Technological University

iDesign Summer/Fall 2017
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LETTER TO PEACE CORPS VOLUNTEER

Dear Shellee Merryman,

CYC Environmental Engineering has designed a gravity-fed water system to serve the community of El Hueco in Coclé, Panama. The design runs eight kilometers from the Loma Chata storage tank to the community of El Hueco and includes two suspended river crossings, twenty-two stream crossings, one clean out valve, and one pressure break tank. The design also includes a road crossing which is intended to be built in cooperation between the communities of Guayabital and El Hueco.

The following report contains CYC's initial data collection as well as the modeling and analysis that was required to properly design the system. The final design of the system is explained in several sections which outline the design decisions and the reasoning behind them. A detailed construction schedule and cost estimate are also included in the following report.

The water system is intended to be built by the people of El Hueco over a period of four months and paid for with government funds from the *representante* of the Toza area. The total cost for the system is $14,500 and the reduced cost is $7,500. The reduced cost does not include items that CYC deemed unlikely to be built as well as non-material items (such as transportation costs) that the *representante* did not want included in the cost estimate. CYC Environmental Engineering believes that this system will provide the people of El Hueco a reliable source of clean water for years to come.

With regard,
CYC Environmental Engineering
Louis Bassette
Meredith Brehob
George Meados
Harrison Zost

DISCLAIMER:

This report, titled "Gravity-Fed Water System - El Hueco, Coclé, Panama", represents the efforts of undergraduate students in the Civil and Environmental Engineering Department of Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report ***should not*** be considered professional engineering.

Gravity-Fed Water System- El Hueco, Coclé, Panama

SUBMITTED TO:

David Watkins, PhD, PE – Michigan Technological University
Mike Drewyor, PE, PS – Michigan Technological University
Shellee Merryman – Peace Corps Volunteer in Guayabital, Coclé, Panama

SUBMITTED BY:

CYC Environmental Engineering
Louis Bassette
Meredith Brehob
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MISSION STATEMENT:

The mission of CYC Environmental Engineering is to provide the community of El Hueco in Coclé, Panama easy access to clean drinking water.

ACKNOWLEDGEMENTS:

CYC Environmental Engineering would like to thank the following people for their contributions to this project:

Dr. David Watkins, International Senior Design Professor
Mr. Mike Drewyor, International Senior Design Professor
Dr. Melanie Kueber Watkins, Adviser on Panama Trip
Shellee Merryman, Peace Corps Volunteer/Host
The community members of El Hueco, Guayabital Arriba, Guayabital Abajo, and Loma Chata, especially Casi Miro, Inieda, Capitan, and Canela.

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EXECUTIVE SUMMARY

This report analyzes a gravity-fed water system for El Hueco, Coclé, Panama. The CYC Environmental Engineering team visited this community in Panama to survey and gather information in August of 2017. The team took this data back to Michigan Technological University to fully design the gravity-fed water system for the 15 people of El Hueco. CYC was guided by Shellee Merryman, a Peace Corps Volunteer stationed in the neighboring village of Guayabital Abajo. The water system goes through three neighboring villages, starting in Loma Chata, then continuing through Guayabital Abajo and Guayabital Arriba, and ending in El Hueco. This community of subsistence farmers will benefit greatly from the gravity-fed water system, as currently their only source of water is from rain catchment or from a river a few hundred meters away. Giving these community members access to clean water is something that CYC Engineering team holds true to the core beliefs of the company. The El Hueco community is currently the last of the four villages in this area to be without a gravity-fed water system. Construction of the new system will follow similar techniques to the existing systems. The system runs 8 km and includes a pressure break tank, a sediment clean out, shut off valves, and pipe bridges. The total cost of the project is estimated to be $7,500. This is below the price of $8,000 that the *representante* recommends as a budget. The project is scheduled to be built in 4 months, from February 8, 2018 to May 9, 2018.

1.0 INTRODUCTION

CYC Environmental Engineering travelled to Cocle, Panama through the International Senior Design (iDesign) program at Michigan Technological University in August of 2017 to identify and assess the need for a water system for the community of El Hueco. The team was assisted by and stayed with Shellee Merryman, a Peace Corps Volunteer who has been stationed in the nearby community of Guayabital Abajo since November 2016. She is a sanitation volunteer and is very well informed on the water needs and politics of the area. The team also worked briefly with Shellee's counterpart, Casi Miro, a local who helps with upkeep of the water systems.

The proposed system takes clean water from a nearby community's storage tank and delivers it in a gravity-fed water system to El Hueco for drinking, bathing, and cooking. CYC learned a lot about the rural communities in which they stayed while in Panama. This knowledge is shared in the following report and was used to develop objectives for the proposed water system. CYC also collected technical data; the techniques used to collect the data are presented below, and some of the data was used for modeling of the water system as described in this report. The final design of the water system includes the water pipeline; its fittings and maintenance features; a pressure break tank; and road, river, and stream crossings. The materials required in the construction of this system, as well as the suggested timeline for this project, have also been outlined.

2.0 BACKGROUND

2.1 SITE LOCATION

The village of El Hueco, Coclé, Panama is located at the point identified in Figure 1. This village is located close to three other communities (Guayabital Arriba, Guayabital Abajo, and Loma Chata), and they have a shared school. These communities are located a half hour from the nearest city, Nata, which is located on the Pan American Highway.

Figure 1. Location of El Hueco in Panama

2.2 COMMUNITY BACKGROUND

El Hueco means "the hole". This name was given to the community as it is located in a depression on top of a hill. The people of El Hueco are subsistence farmers of both crops and livestock. They occasionally make outside money for other necessities by selling the surplus food that they have grown. Other common jobs for men in the nearby communities are working on larger farms for a wage or working for a company in the city. These companies provide transportation from the community to the city in a large truck every morning.

The people of El Hueco are Latino and speak Spanish. They are also Catholic but they do not go to church regularly as it is located too far away to attend weekly services. Occasionally, the community members will attend larger all-day events at the church.

The elementary school for the communities of Loma Chata, Guayabital Abajo, Guayabital Arriba, and El Hueco is for children up to 6th grade. The school is located in Guayabital Abajo and serves 14 children who must walk from 10 to 45 minutes to attend school. Older students attend *Colegial* (high school) which is located in Nata and requires a *chiva* (rural public transport). Most students finish elementary school, but many drop out of or do not attend *Colegial*.

Some community members will work in cities and move away from the area, especially after finishing *Colegial,* which is equivalent to an associate's degree in the United States. Although people move away, they often keep their land, as they would not profit from selling it and can return to live on the land and be with family in their older age.

The village of El Hueco consists of 15 people who are all relatives. There are five residences in the community, one of which is a collection of houses that nine people live in as seen in Figure 2. El Hueco is the only of the four communities in the area that does not have access to a clean gravity-fed drinking water system. The communities of Guayabital have a single water committee in charge of their shared water system, and the community of Loma Chata also has a water committee. Each home accessing the water system pays the Loma Chata water committee president, Inieda, 50 cents a month to maintain their water system. Inieda also owns the land where the Loma Chata *tomas* (water catchments) and tank are located.

Figure 2. Collection of houses in El Hueco

2.3 PROBLEM DESCRIPTION

The community of El Hueco currently gets its water from the Rio Chico, a nearby river. The small, low-income community of 15 people must carry water up a hill from the river to be used in the village. During the wet season, some rainwater collection in 55-gallon drums takes place to supplement their water usage, as seen in Figure 3. However, in the dry season from December to March, this source of water dwindles and the people must rely solely on the river. The community members use the river for all of their water needs, including cleaning, bathing, and drinking. This usage produces obvious health concerns for those living in El Hueco, as an unfiltered source of water that is open to the environment can contain pathogens that cause a host of diseases and other sicknesses.

Figure 3. Rainwater collection in El Hueco

The *representante* of the Toza area, a government employee who has funding from the Panamanian government, has pledged to pay for the El Hueco water system. Originally, the people of El Hueco wanted a gas-powered pump to draw water up from a well. However, the *representante* prefers the gravity-fed system because he has funded well and pump projects in the past and has run into a variety of issues. Wells are expensive and can run dry, and the *representante* even noted that he has had parts stolen from them. Therefore, the gravity-fed design would be preferred if it cost less than the estimated $8,000 that it would take to build a well and pump.

The proposed system will run from the Loma Chata water tank to El Hueco. The pipeline must run alongside roads due to the property rights of landowners in the areas. The route is shown in Figure 4. Since the pipeline cannot run on the most direct route, which is 5.6 kilometers long, it covers a distance of 8 kilometers. The cost for such a length of pipe is a major constraint on the available budget.

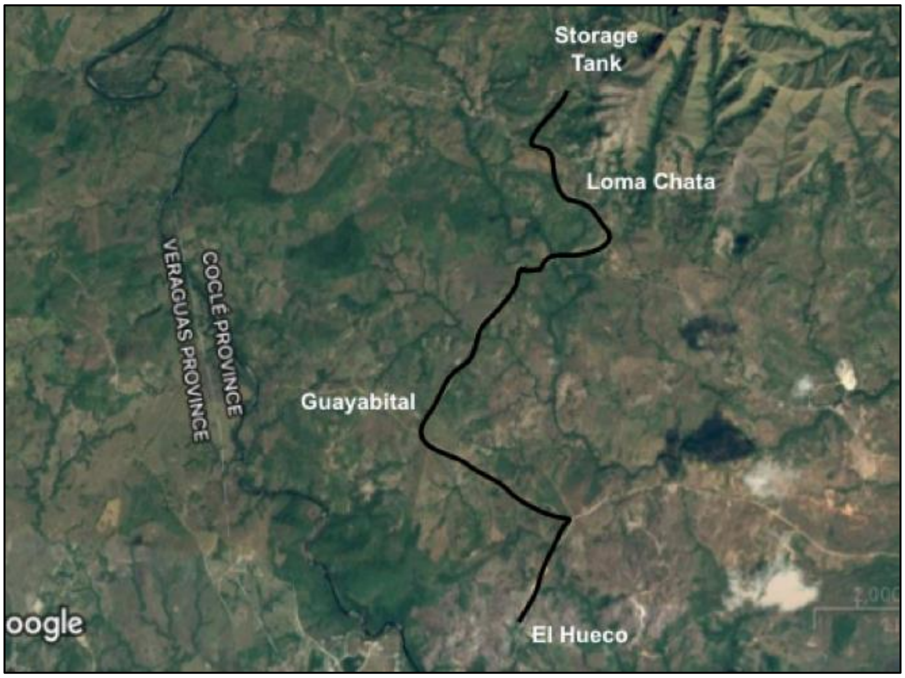

Figure 4. Map or Proposed System Path

The predetermined pipe route also means that the system elevation profile, shown in Figure 5, cannot be changed. The system must allow adequate head (increased with pipe diameter) to bring the water to its final destination. This must be done without exceeding the budget which is challenging due to the increased price of the pipe with increased size. The pipe walls also need to be thick enough to hold high water pressure caused by large elevation changes with an appropriate factor of safety. This thicker wall pipe also adds to the cost of the system.

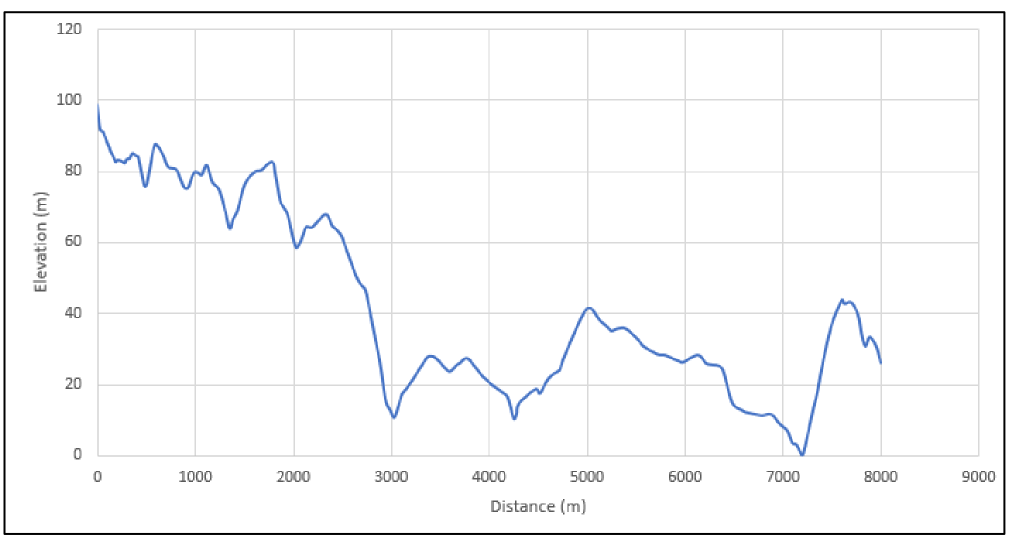

Figure 5. Elevation Profile of El Hueco Water System

The pipeline will be buried approximately 3 feet deep, which will be labor-intensive despite having a trench digger supplied by the *representante*. Fuel for this trench digger needs to be considered in the overall cost of construction. To reduce costs, the project will require volunteer community labor. Individuals will need to make time during their week for the construction of the water line.

The amount of water available for distribution is usually a constraint. However, for this water system, there should not be any shortage of water. The system is expected to provide 105 gallons per day per person, or 1,570 gallons per day for the entire community, easily achieving the minimum World Health Organizations (WHO) guidelines of 5.3 gallons per person per day for basic access [1]. These numbers are based on the current water supply from the tank and the number of people from both Loma Chata and El Hueco, a total of 215, that will be connected to it. The total water supply flow rate data is in Appendix A.

The route of the water system must cross a paved road, and therefore a road crossing must be included in the design that allows trucks and other vehicles to pass underneath. This suspended pipe bridge must be 5 meters above the road to allow for all semi-trucks to pass safely underneath [2].

2.4 PROJECT OBJECTIVES

Safety - The water system must provide consistently clean and safe water. Specifically, there should be no detection of E. coli (less than 1 E. coli colony per 100 mL) [3]. The main water line and distribution lines must be able to transport the water with a low risk of infiltration so as to not contaminate the water inside. The system should be buried at least 3 feet deep to ensure that the water lines will not be disturbed and casings must be installed around the pipe at road crossings. The stream crossings must also be properly secured with anchors to avoid disruption of the water lines.

Serviceability - The water system should provide water during all seasons and at all times of the day, taking into account the dry season and peak times of use. Based on WHO guidelines for the amount of water needed for basic hygiene and food needs, the system should provide at least 5.5 gallons of water per person per day, totaling to 80 gallons per day for the entire community of 15 people [1]. The system should not be easily disrupted by breaks in the line or other inconveniences and should require only limited and simple maintenance through the use of clean out and shut off valves. Maintenance must be performed by El Hueco community members or members of the Loma Chata water committee.

Economical - The project should be assigned to a trusted member of the community that will assure that the money for this project is used efficiently. The other communities in the area have water committees; however, El Hueco does not have a large enough population to warrant the creation of a committee. El Hueco community members should instead meet with the Loma Chata water committee to ensure proper education and training for the maintenance of their system. The system must be as inexpensive as possible and should require limited labor to construct and maintain. Materials should be bought from a local source and transported efficiently with the largest loads possible, as each trip taken is a flat cost. The system should be made with the least amount of material possible to limit cost. The material for the system has already been determined to be PVC pipe, as the established water systems of the area are constructed using PVC pipe. This means that it has the advantages of being locally available and being familiar to the community members. The project will ideally have no construction cost due to being made with volunteer labor. The operation and maintenance costs should be minimal because, with a well-designed system, the only required maintenance will be cleaning the various tanks, *tomas*, and clean out of the system. The total cost for all facets of the project should cost less than $8,000. The project should also cost less than a well with a gas-powered pump, as that is another proposed solution to the water shortage.

The proposed system will use two existing *tomas* owned by the community of Loma Chata that keep the spring closed from the atmosphere, not allowing animal feces or other debris to contaminate the source. Water flows in PVC pipes out of the existing spring boxes and comes together at a junction, which then leads to a 10,000-gallon storage tank. Images of *toma* 1, *toma* 2, and the tank are pictured in Figure 6.

Figure 6a. Toma 1

Figure 6b. Toma 2

Figure 6c. Loma Chata Storage Tank

The two spring boxes and storage tank currently serve the community of Loma Chata, providing water to 200 people living in 24 households. The El Hueco system will be designed with separate pipes emitting from the tank and then following the route of the Loma Chata water system. The El Hueco system continues and runs alongside the Guayabital system soon after the Loma Chata system ends. The Guayabital system receives its water from a different spring and storage tank. The system will be designed to follow the Guayabital system to its end and then continue by itself to the community of El Hueco. Figure 4 shows the path the water system will take from the tank in Loma Chata, past Guayabital and into El Hueco.

The El Hueco system will be designed with five tap locations, with individual taps for four houses and one tap to be shared amongst nine people in a group of five houses. In the future, they can add additional taps with the stipulation of each house only being allowed to turn on one tap at a time. Households will also need to use their own funds if they would like to add showers, sinks or additional tap stands.

The success of this gravity-fed system relies on the support of many individuals and groups, each with a stake in the project. The people of El Hueco obviously have the largest stake in this system, as they will rely on the system for all of their water needs. It was very important to take note of what they wanted and how their needs could be best met. Shellee has spent a year in her community getting to know the people and learning what they need to improve their lives. She provided the team with a host of information relating to what design choices would most benefit the people using it. The Loma Chata Water Committee President, Inieda, also plays a large role in this project. She is in charge of the *tomas* and tank that the El Hueco system will take water from, and she owns the land on which they are located. She is very progressive for her community and has been very helpful in taking this project on.

3.0 DATA COLLECTION

3.1 SURVEYING

The team surveyed from the storage tank in Loma Chata to the community of El Hueco to ensure that the gravity-fed system would have enough head to reach its destination. There are a lot of changes in topography between these two places. CYC surveyed from the *chiva* stop between Loma Chata and Guayabital to the El Hueco community on the first day. This was roughly five kilometers in length. CYC was able to do this because the water pipe will be running alongside the road and the surveying path was very clear. On the second day, CYC surveyed three kilometers from the tank to the *chiva* stop, completing the eight kilometers of surveying for the main water line path. The complete surveying data can be found in Appendix B. The area between the *tomas* and the storage tank was not surveyed because the existing pipes are sufficient for the new system. The water storage tank is considered the starting point of the El Hueco system design.

The last surveying task was done on the third day: mapping a bridge that will go over the main road for the water system to cross. The existing water pipe for the Guayabital system runs under the road through a culvert. Their water committee is planning a new road crossing in the form of a bridge that the El Hueco system will also be able to use. The bridge location can be seen in Figure 7. The bridge will run from the camera location to the top of the other side of the road.

Figure 7. Future Water Pipe Bridge Location

A laser rangefinder, abney level, tape measure, compass, and GPS were used for surveying. The laser rangefinder was balanced on top of a stick while another stick with a target at the same height was used to ensure that the measurements were parallel to the ground. Each team member kept the same surveying task each day so that there would be no change in recordings due to inconsistency from people doing different tasks.

3.2 FLOW DATA

Flow rates were measured at the *tomas*. This was done by emptying out the *toma* and taking the flow measurement from the clean out pipe using a one-liter bottle. When the *toma* is empty, the clean out pipe has identical flow as the water coming into the *toma*. The clean out is the bottom pipe in Figure 6a. Multiple tests were taken, and the average of these tests was used in the calculations. The flow rate available at the tank, calculated by adding the flow rates from the individual *tomas,* is 23,000 gallons per day. The full results from the flow rate measurements can be seen in Appendix A.

3.3 WATER QUALITY

Coliform bacteria tests were taken at the *tomas*, the water storage tank, and at a Loma Chata community member's water tap. Figure 8 shows example results from a 3M petrifilm coliform test kit. Both *tomas* had no indication of E. coli. *Toma* 1 had an average of 70 CFUs (colony forming units) per mL, with an average of 1.3 having bubbles near them. *Toma* 2 had an average of 28.8 CFUs per mL, with 1.8 having bubbles around them. Bubbles indicate that there are active coliform bacteria colonies. The water storage tank is chlorinated with tablets, but the water treatment system is on the wrong side of the tank. Chlorination should occur before the water enters the tank to provide residual time for chlorination to take place; however, on the Loma Chata tank, the chlorination occurs on the distribution side. There were many fewer coliforms in the water storage tank than the *tomas*. The water storage tank had an average of 13.6 CFUs per mL with 0.6 having bubbles around them. This is low, but does not meet the stringent standards for potable water. The test results from the Loma Chata community member's house were the most alarming, with an average of 142 CFUs per mL and 26.3 CFUs per mL having bubbles around them. There was also E. Coli in their water, with an average of 6.3 E. Coli CFUs per mL and 4.3 CFUs per mL having bubbles around them. There are a few possible ways E. Coli may have gotten into these tests: the water was pipetted out of a household cup which may not have been washed properly, or the water pipes that run through cow pastures may have introduced contamination. The coliform bacteria tests (Figure 8) were provided by the advisors of iDesign. The tests were performed by taking 1 mL of water and placing it under the plastic film of the test kits. They were then stored in a safe, dry location for 24 hours to allow the bacteria to grow. CYC counted the number of E. Coli and coliforms present. The complete bacteria test results can be seen in Appendix C.

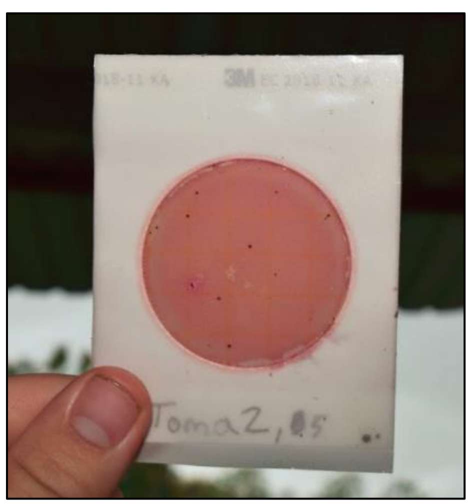

Figure 8. Example Coliform Test Kit Results

4.0 SYSTEM MODELING

The gravity-fed water system that will carry water from the Loma Chata tank to five taps in the community of El Hueco was modelled using EPANET, which is a public domain water distribution system modeling software. Two different models were created in the software, one featuring just the El Hueco system and one featuring both the design system and the existing Loma Chata system, which are shown in Figures 9 and 10, respectively. A zoomed in image of the distribution lines and tap locations that are represented in both models is shown in Figure 11. Since the flow rate is high enough that water shortages should not be an issue, the model containing only the El Hueco system was developed using a reservoir in place of the tank, to simplify the model. This model was intended to show instantaneous pressures and velocities in the system when taps were turned on, and to ensure that there would be enough head for water to reach the community. The model features five taps, just as the real system will, and was designed to allow two taps to be open at once with a design flow of 1.5 gpm each, while maintaining a pressure of greater than 10 psi throughout the system. A pressure break tank was added to the system atop the hill leading into the community in order to reduce the pressure at the taps. With the addition of the pressure break tank, the taps will produce a pressure ranging from 20 to 50 psi for any combination of one or two taps open at once.

The model featuring the El Hueco system and the existing Loma Chata system was intended to ensure that community members in both El Hueco and Loma Chata would have enough water throughout the course of a day based on changing demands. This model had a tank added to model the storage tank, and a reservoir fed this tank to model spring flow into the tank. Another branch was added off the tank to model the water demand of the 200 people in Loma Chata who are already on the system. The five taps and pressure break tank remained a part of the El Hueco branch. A demand pattern was added to the system to model changing demands through the course of a day. A 24-hour period was divided into six four-hour segments, beginning at 12am and ending at 12am the next day. In this demand pattern, the morning saw the largest use of water and the middle of the night the least, as shown in Appendix D. This model shows what was already suspected by the flow rate, that all community members shall have ample access to water at all times of the day, with little fluctuation in storage tank levels.

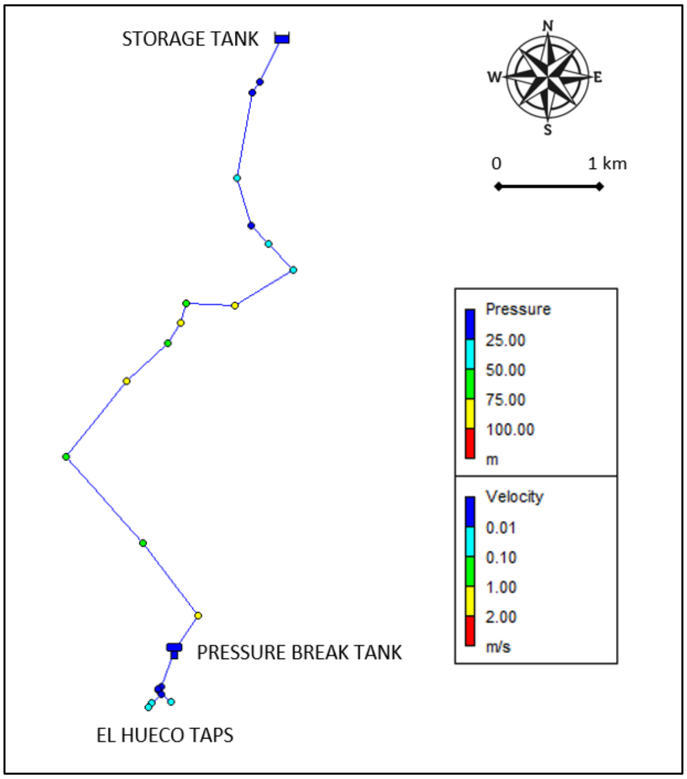

Figure 9. El Hueco System

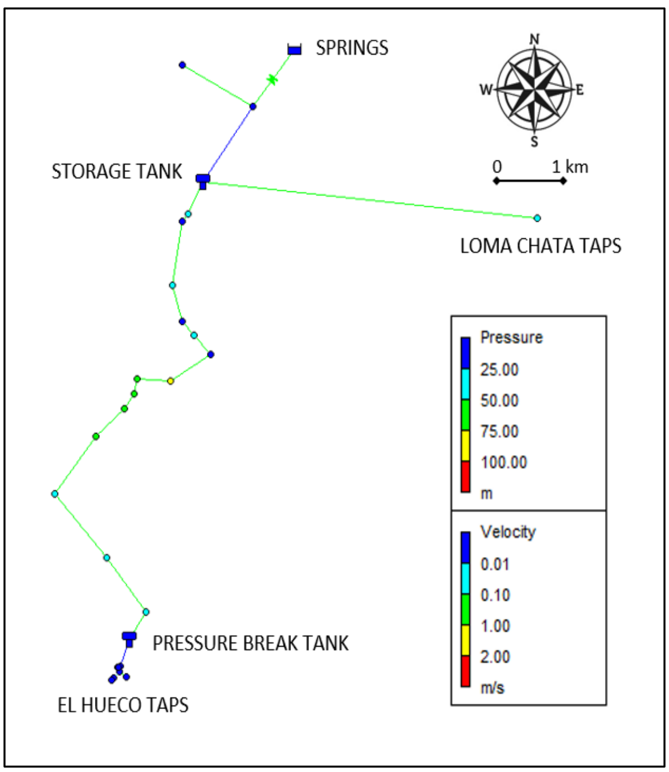

Figure 10. El Hueco System with line to Loma Chata

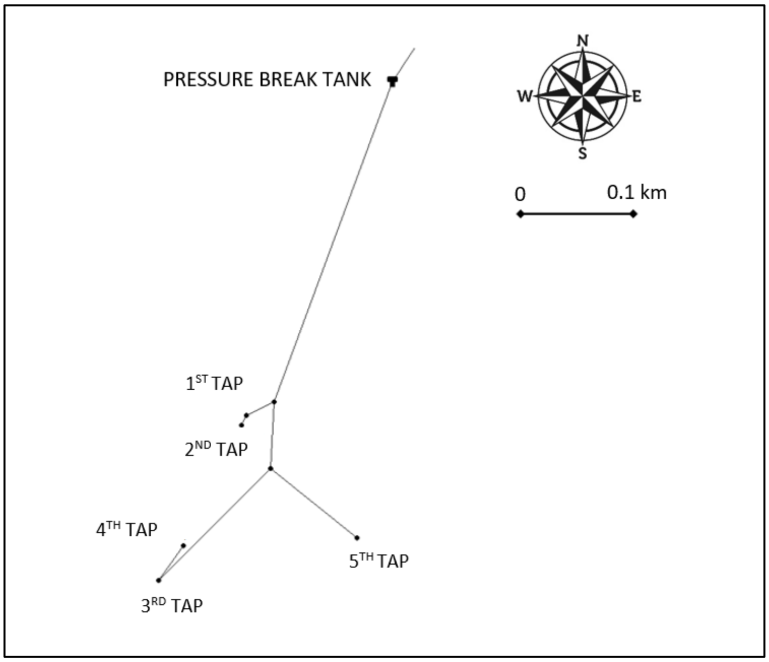

Figure 11. Distribution Lines in El Hueco

5.0 FINAL DESIGN AND RECOMMENDATIONS

5.1 SPRING BOXES/STORAGE TANK

Spring boxes and storage tanks are not part of this design project. The El Hueco water system will use water from the existing Loma Chata water tank. This 10,000-gallon tank receives water from two existing *tomas* nearby. The current tank and *tomas* are in excellent condition and will not need any further work done to them. Currently, there is excess water in the tank during all seasons of the year. The Loma Chata water tank supplies more than enough water for the proposed project and the water supply is also chlorinated, albeit on the wrong side of the tank. Coliform tests from the unchlorinated tank water find an average of 13.6 Coliforms/mL and 0.6 Coliforms with bubbles/mL (active coliforms), but the tests find no evidence of E.Coli.

5.2 WATER TREATMENT

Although the results of coliform tests on the Loma Chata water tank show evidence of coliforms, there is chlorine treatment as the water passes out of the tank. The detention time of the water from the chlorine treatment location to the first El Hueco tap location is estimated to be 536 minutes. The detention time is calculated by dividing the volume of the main pipe by the flow rate. The minimum required contact time is 40 minutes assuming a reasonable concentration of chlorine, a pH of 7.0, and a minimum water temperature of greater than 50°F (see calculations in Appendix E) [4]. The detention time of 536 minutes is sufficient for treatment as it is greater than the minimum required contact time and is not too long. Too long of a chlorine detention time allows the chlorine residuals to completely decay and bacteria to grow. CYC recommends chlorine testing at the taps in El Hueco to ensure that there is an appropriate amount of chlorine residuals remaining in the system.

5.3 PIPE NETWORK

The pipe network has been designed to run from the Loma Chata tank to the community of El Hueco, a distance of 7,960 meters(m) from the tank to the first branch, as shown in Figure 12. The line will have five taps, as shown in Figure 13. The first branch connects two taps, first leading to a home with one occupant and then to a second dwelling with two occupants. The branch connecting the third and fourth taps leads to a home with two occupants where one tap will be located, and then to a house with a single occupant where another tap will be located. The branch containing the fifth tap runs to a small collection of homes where there will be a single tap for community use. This tap will service nine people. Community members will be allowed to add additional taps to their homes if they so choose, provided only one tap is opened at a time. Figure 13 shows the routes the distribution lines will follow. All blue lines in the figure correspond to one-inch diameter pipe, while red lines correspond to half-inch pipe. Five one-inch to half-inch diameter reducer fittings will be required to make the transition to half-inch pipes at the taps. It is also recommended that each tap have a reinforced concrete tap stand to improve longevity of the tap.

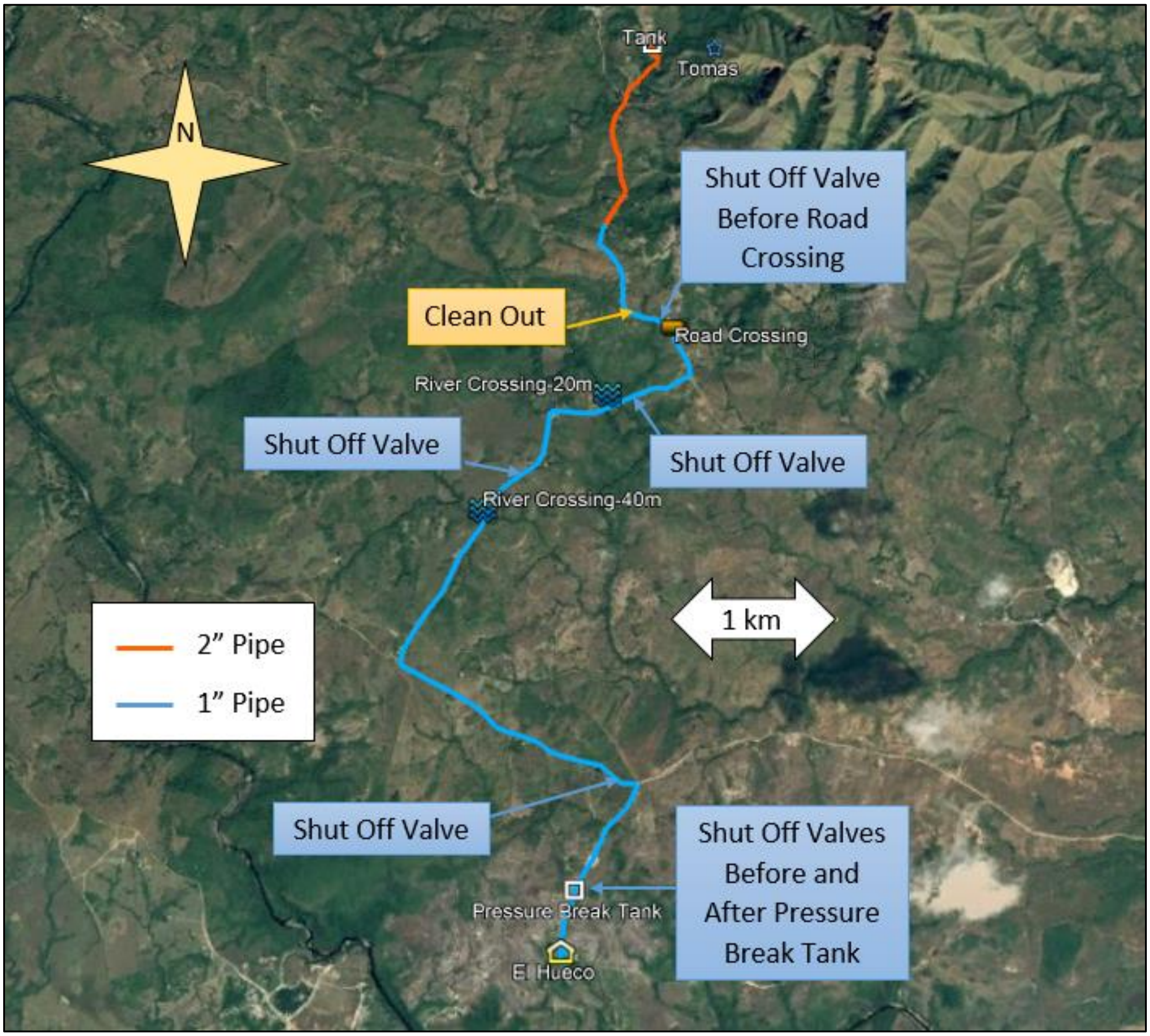

Figure 12. Pipe Network

The pipeline itself will consist of a combination of one-inch and two-inch diameter PVC pipe with a Standard Dimension Ratio (SDR) of 26. A pipe’s SDR is the ratio of the pipe diameter to the wall thickness. Two-inch pipe already runs from the two *tomas* to the storage tank, so the design will only require pipe from the storage tank to the taps. Two-inch pipe will run from the tank for the first 1,360 meters, which is shown in orange in Figure 12. The design then calls for a transition to one-inch pipe, shown in blue in the figure, which will complete the remainder of the system. Tap lines running to houses will be constructed of half-inch diameter pipe, as previously mentioned. There will be one clean out valve in the system, located 2,030 meters from the storage tank. There will also be shut-off valves for maintenance and repair purposes at the road crossing, the pressure break tank, and upstream of high pressure areas, such as near river crossings.

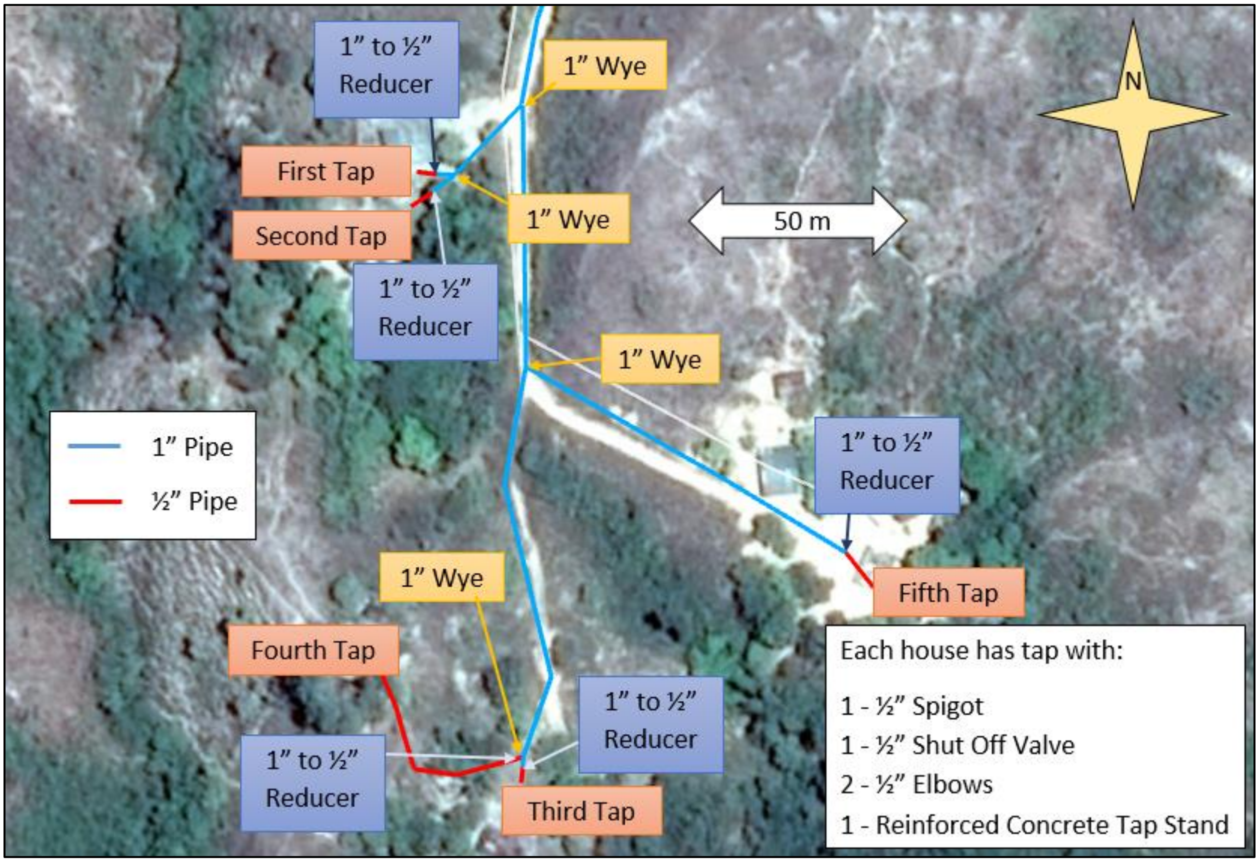

Figure 13. Distribution Lines

The maximum head in the system will occur 7,217 meters from the tank, with 98.65 meters of head, which corresponds to a pressure of 140.3 psi. This is suitable, as SDR 26 pipe is rated for 160 psi at 73.4 °C, as shown in Appendix F [5]. There will be enough head throughout the system to ensure that water will be delivered to El Hueco for any combination of two taps open at once. The hydraulic grade lines for all taps shut and two taps open are shown in Appendix D. The hydraulic grade lines are based on a tap flow rate of 1.5 gpm.

A base demand pattern was also created in EPANET to examine the storage tank level throughout the course of a day. Multipliers were used to determine the change in demand during the day, shown in the figure in Appendix D. Considering the 200 people who already use the Loma Chata system and the additional 15 people in El Hueco who will be added to the system, the tank will contain enough water to satisfy water demands, even for 100 gallons per person per day.

A pressure break tank will be constructed at the top of the hill before entering El Hueco, 7,650 meters from the tank. This tank will reduce pressure at the taps to 20 to 50 psi for any combination of one or two of the five taps being open at a given time. This was calculated based on a design tap flow of 1.5 gallons per minute.

5.4 PRESSURE REDUCING SYSTEM

Flow reducing disks were considered for reducing the pressure at the taps in order to achieve a suitable pressure. The calculation for determining the minor head loss coefficient of the flow disks is shown in Appendix G. Calculations of the loss coefficient for 5/32”, 7/32”, and 5/16” diameter restrictions in 1” and ½” diameter pipes were calculated. These coefficients were put into the EPANET model system at various points along the system to determine head loss when one or two taps were receiving 1.5 gallons per minute. It was found that very small changes in orifice diameters had a large effect on the head loss of the system. It was difficult to accurately model the effect of these flow reducers in EPANET and as a result, the team preferred to look at other methods of reducing pressure at the taps that presented more confident data.

As a result, the team turned to designing a pressure break tank, which will be located on top of the hill before entering El Hueco at a distance of 7,650 meters from the storage tank. The pressure break tank will be at a height ranging from 18.6 m to 35.2 m above the taps according to individual tap elevation. There will be a float valve inside the tank at the inlet pipe, which will keep the volume of water in the tank limited to approximately 0.07 m^3. The pressure break tank will be built with concrete blocks held together with mortar at the joints. The outside dimensions of the tank will be 0.82 m long, 0.84 m wide, and 0.4 m in height. There are three reinforced concrete slabs that must be made. The top slab will be a 0.22 m long, 0.22 m wide, and 0.08 m thick rectangle with a rectangle cut out of the middle that is 0.61 m long and 0.63 m wide; the lid will be 0.62 m long, 0.64 m wide, and 0.08 m thick; and the floor slab will be 0.83 m long, 0.85 m wide, and 0.1 m thick. The concrete blocks will be set on top of the floor slab. The top slab will be set on top of the concrete blocks after it has been poured and set. The removable lid will provide easy access if problems occur in the pressure break tank. To pour the bottom slab, an area 0.83 m long and 0.85 m wide will be cleared, leveled, and compacted. This will allow for forms to be placed on level ground for a level concrete pour. All slabs will be made from a mixture of cement, sand, gravel, and water, and will be reinforced with rebar. The ratio being used will be 1 cement: 2 sand: 3 gravel. This ratio of cement, gravel, sand, and water will hold up to the 15 psi that will be exerted on the bottom of the tank. Water will be added in the mixture while the mixture is being made before it is poured into the forms. Table 1 shows the amount of cement, sand, gravel, and water to make the floor slab, top slab, and removable lid of the pressure break tank.

Table 1: Pressure Break Tank Design

	Volume (m^3)	Cement (m^3)	Sand (m^3)	Gravel (m^3)	Water (L)
Floor Slab	0.07	0.012 (3.1 gal)	0.023 (6.1 gal)	0.035 (9.2 gal)	7.2
Top Slab	0.026	0.0043 (1.1 gal)	0.0086 (2.3 gal)	0.013 (3.4 gal)	2.7
Lid	0.035	0.0058 (1.5 gal)	0.012 (3.2 gal)	0.017 (4.5 gal)	3.4
Horizontal Joints	0.0052	0.0017 (0.5 gal)	0.0035 (0.9 gal)		0.77
Vertical Joints	0.000785	0.00026 (0.07 gal)	0.00052 (0.2 gal)		0.12
Outside Mortar	0.066	0.022 (0.6 gal)	0.044 (11.6 gal)		9.9
Inside Mortar	0.034	0.011 (2.9 gal)	0.023 (6.1 gal)		5

The height of this pressure break tank will be 0.4 m or 2 concrete blocks high from the top of the floor slab to the bottom of the top slab. A mortar mixture of Sika® will be used as a sealant for the cinder blocks. This sealant will be 0.038 m thick at the bottom slab of the tank and 0.025 m around the inside of the tank. A total of 0.5 liter of sealant will be needed for the entire interior of the tank. This sealant will ensure that the water does not permeate through the walls or floor [7]. To protect the pressure break tank from the elements, the outside walls of the tank will have mortar applied to them. The mortar will be 0.05 m thick on each of the four walls. The amount of cement, sand, and water for the horizontal joints, vertical joints, outside mortar, and inside mortar can be seen in Table 1. This mixture requires sand, cement, and water added until the consistency of the mix is right for application. A detailed design of this pressure break tank can be seen in Figure 14.

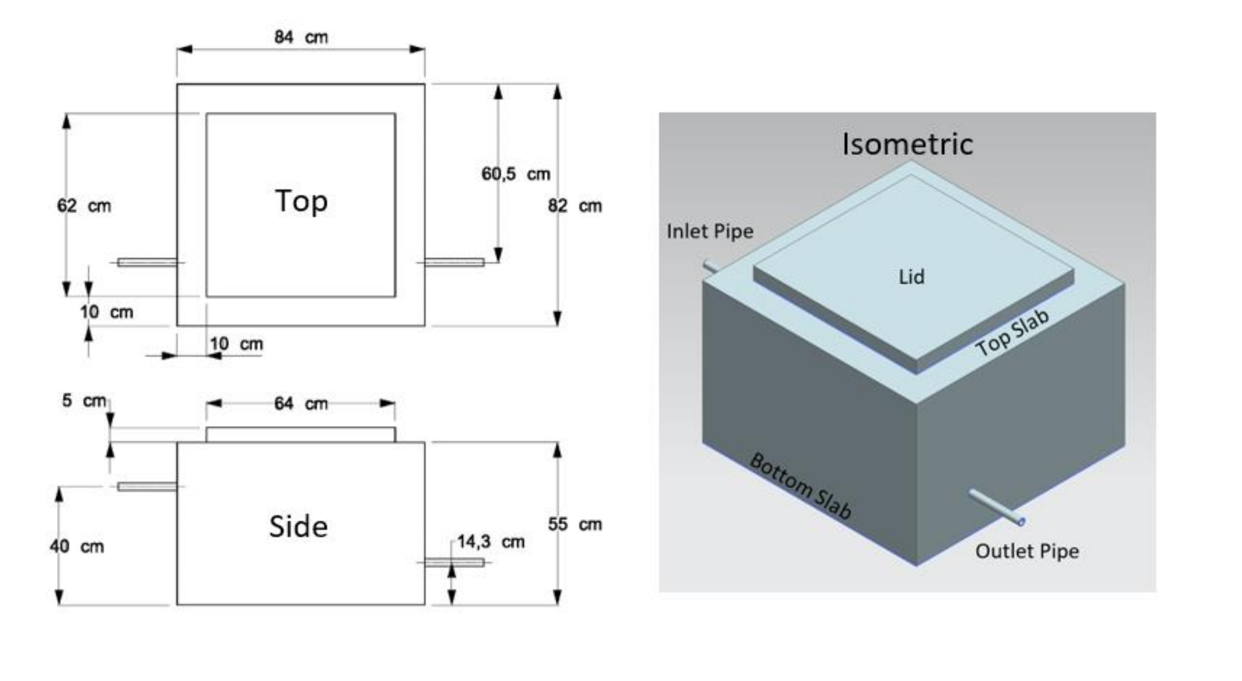

Figure 14. Pressure Break Tank Design and Dimensions

5.5 SHUT-OFF VALVES

The shut-off valves are going to be placed upstream of locations of the highest pressure in the main water line. High-pressure areas have the highest probability of failure, making them good locations for emergency shut-off valves. The points of highest pressure are at three kilometers and four kilometers down the main line, which are river crossings, as well as at seven kilometers. One shut-off valve will be located before the pipe bridge over the paved road, approximately two kilometers down the main line. Two shut-off valves will be placed directly before and after the pressure break tank for maintenance purposes. There will also be one shut-off valve on each of the five distribution lines before the tap stands in case they break. The total number of shut-off valves will be 11 in this system.

5.6 WATER TAP STANDS

A reinforced concrete tap stand is recommended at each of the five tap locations. The tap stands will consist of a 50 cm by 50 cm supporting column buried 30 cm underground and extending 145 cm above the ground, for a total height of 175 cm. The column will be reinforced with #3 rebar, with four 165 cm lengths running vertical in each corner, spaced 20 cm apart. Four hoops of #3 rebar will be constructed, bent to a square with dimensions of 20 cm by 20 cm. These will be evenly spaced 55 cm apart along the length of the column and tied to the four vertical lengths to construct a cage. The tap itself will protrude 25 cm from the column at a height of 130 cm above the ground. The tap will consist of half-inch PVC pipe, two elbows, and a half-inch brass spigot. Wood forms can be built around the cage and pipes to pour concrete. At the base of the spigot, rocks or gravel shall be placed to ease erosion. A sketch of the water tap stand can be seen in Figure 15.

To reduce the cost of the concrete tap stand, it can be substituted with a simple metal stake, which is not as durable but is far less expensive. The PVC pipe dimensions remain the same, with the vertical length of the pipe tied with wire to a stake driven into the ground.

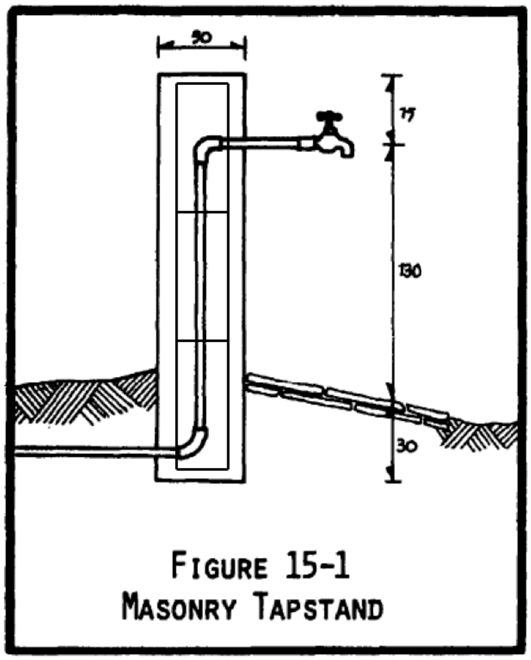

Figure 15. Water Tap Stand Configuration [11]

5.7 AIR RELEASE VALVES

Calculations were done to see if air blocks would develop in the line, potentially not allowing water to reach the taps in El Hueco (Appendix H). These calculations determined that there is no need to have air release valves because the air blocks are not expected to cause substantial problems in the system [8]. The calculations showed a sufficient amount of head to make it to El Hueco, and the volume of trapped air will not stop the flow of water.

5.8 CLEAN OUTS

Clean out valves are typically located at low points in the system where sediment is most likely to build up. The El Hueco water source, however, is very clean with few particles, and a storage tank is already in place to remove most of the sediment from the system. For this reason, the design recommendation is to include only one clean out, located 2 kilometers down line of the tank at a local low point in the system. Flushing the system at this point will remove any remaining sediment not taken out by the storage tank. If water in the system reaches velocities of 3.6 m/s, sediment can cause scour in the line. However, the average water velocity of the El Hueco system is calculated to be 0.37 m/s in one-inch pipes with two taps open, so scour should not be an issue in this system.

5.9 STREAM CROSSINGS

The El Hueco water line crosses several small streams on its path from Loma Chata to the community. A simple stream crossing design for stream widths less than 1.5 m was created for use on all stream crossings along the way. This design utilizes 15-inch anchors that screw into the ground and which provide more than enough support for the weight of the water line, which only causes 6.8 lbs of force per 1.5 m [9]. A 3/32" cable will be used for these crossings, as the tension in the cable is only about 11.8 lbs per 1.5 m [9]. The calculations used to find the force exerted by the cable and the tension in the cable are given in Appendix I. A sketch is shown in Figure 16 [11].

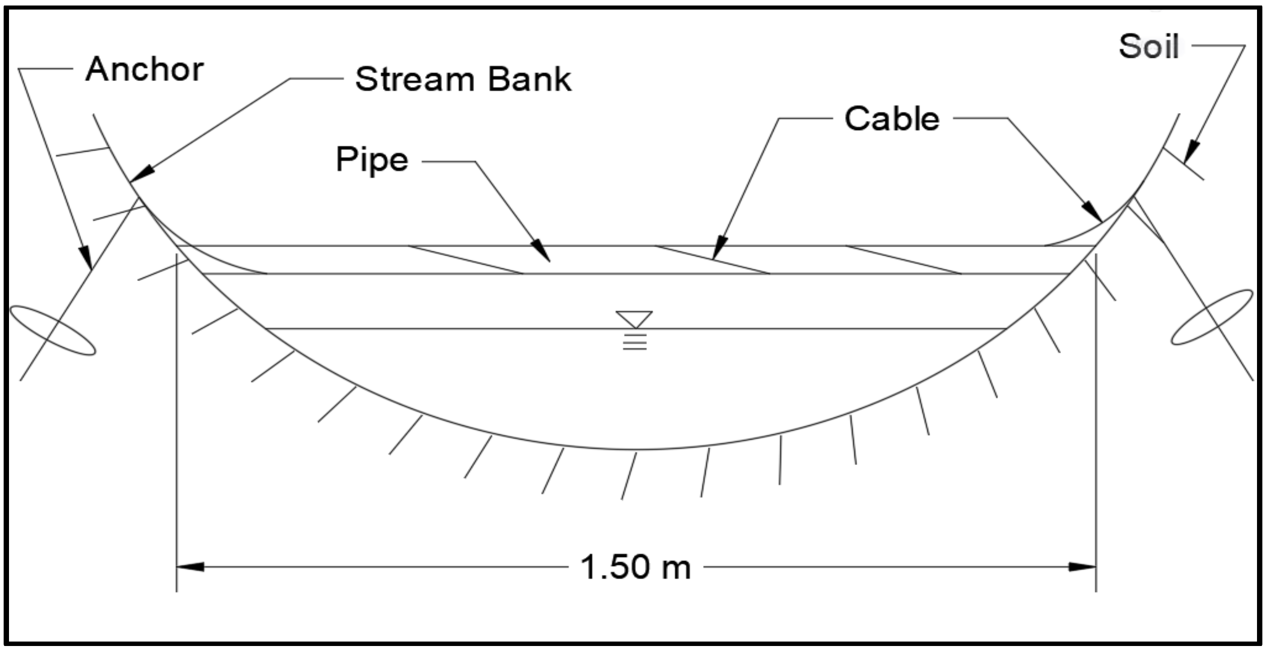

Figure 16. Design of stream crossings with ground anchors (Image to scale, dimension in meters)

5.10 RIVER CROSSINGS

There are two rivers that the water line to El Hueco must cross over. One of the river crossings is 40 meters wide, and the other is 20 meters wide. The existing water system for the people of Guayabital crosses these rivers but uses techniques, such as attaching suspended wires to trees that are not a sustainable solution for supporting the pipes. A design for anchors to suspend wire across the river that could support the load of both the El Hueco and Guayabital water lines was determined. The calculations to determine loading and the anchor weight required are given in Appendix I. These pipe bridges will be made of concrete anchors with reinforcing steel, steel cable, and a carrier pipe. Two 0.07 yd^3 anchors will be used to support the 20-meter-wide river crossing and two 0.18 yd^3 anchors will be used to support the 40-meter wide river crossing. The design for the anchors can be seen in Figures 17 and 18. The same cable will be used for all major crossings, as it will be more economical. This cable should be able to withstand the greatest cable tension from the two river crossings and one road crossing, which is 155 lbs for the 40-meter river crossing. The cable chosen has a working load limit of 840 lbs and has a 3/16-inch diameter [9]. The cable is well above the needed working load limit, but was chosen because there is not a significant increase in cost to increase the size of the cable. Each of the water lines will be inside a 3-inch diameter pipe for protection from the sun and other possible harm.

5.11 SUSPENDED ROAD CROSSING

There will be one major road crossing in the water system. At this crossing, a pipe bridge will be necessary to make sure that the water system does not interfere with the traffic on the road. This pipe bridge will be paid for by the Guayabital water committee and will not affect the budget for the El Hueco water system. Both the Guayabital and El Hueco water systems will use this bridge to go over the road. CYC Environmental Engineering decided to design the bridge crossing for the community of Guayabital to ensure that the bridge will withstand the load of the pipes and that it will be durable. This pipe bridge will be constructed with concrete anchors with reinforcing steel, steel cable and a carrier pipe. The length of the pipe bridge is approximately 35 meters long. The anchors will both be approximately 422 pounds assuming that the density of the concrete is 145 lb/ft^3 [10]. The calculations for these anchors can be found in Appendix I for the dimensions shown in Figure 17. The casing for the pipe bridge crossing will be made of 3-inch PVC pipes, and both of the water systems will be installed in their own casing. This casing will ensure that the PVC water line does not become brittle from the elements and ensures the longevity of the system. The steel cable that will be used is 3/16-inch, 7x9 galvanized cable, with a working load limit of 840 lbs [9].

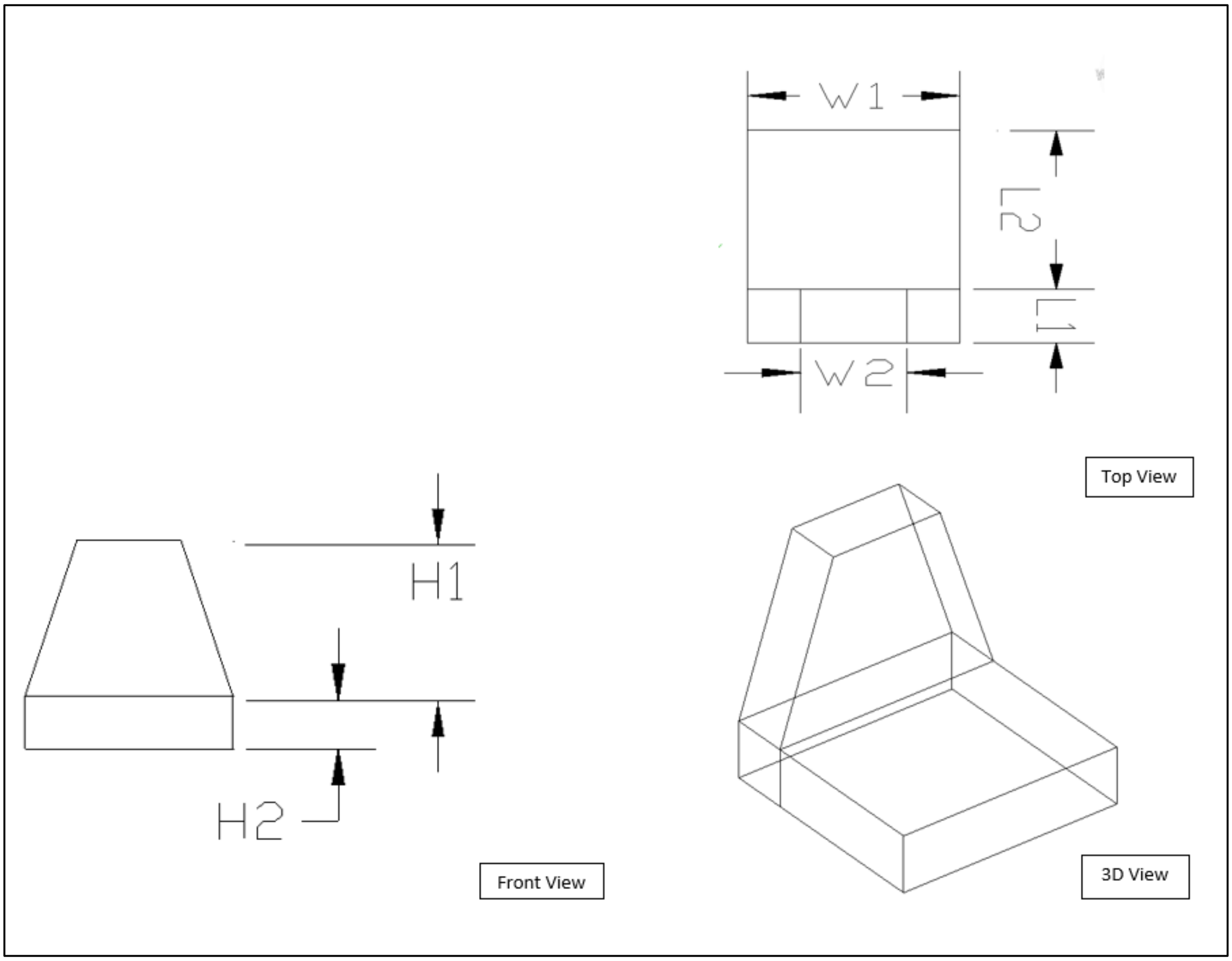

Figure 17. Design Views of Road Crossing Anchor

There will be reinforcing steel in the concrete of the anchor design, and the steel cable will be fastened to it. A sketch of the reinforcing steel can be found in Figure 18. The steel will be made of number 4 bar to ensure that the concrete stays structurally sound.

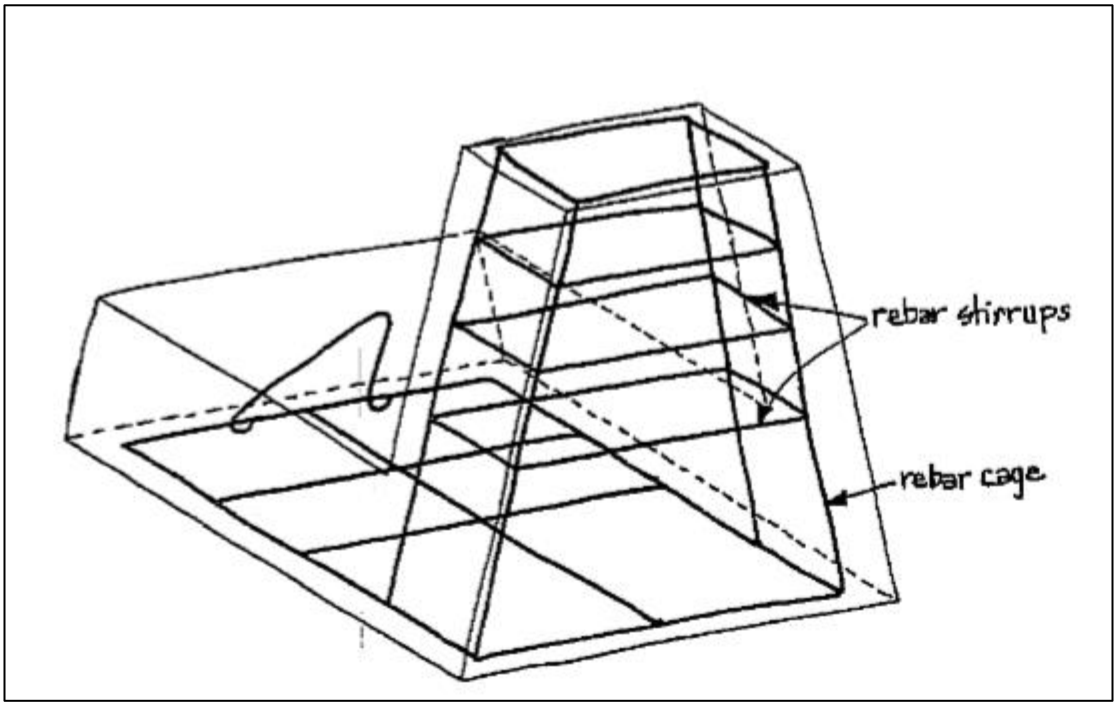

Figure 18. Sketch of the Placement of the Reinforcing Steel in the Bridge Anchor [11]

5.12 CASING PIPE FOR UNDER ROAD

There are three road crossings that require casings. At these locations, the PVC water line will run under the road inside a steel pipe casing. This will ensure the pipe can withstand cars and trucks driving over the road without breaking. The locations of these crossings are before the gravel road where Loma Chata meets the paved road, at the T in the road near Shellee's house, and at the road that leads into El Hueco. The casing will be made from 3-inch schedule 40 steel pipe. The casing comes in 8-foot sections and costs $62.40 per piece [12]. Though the initial cost of the steel casing is expensive, it will save on repair costs by preventing line breaks under the road. The pipe will need to have approximately 20 feet of casing at each road crossing, requiring a total of 8 sections. Each road crossing will require 2.5 sections of casing, which will need to be cut and connected using couplings.

6.0 SCHEDULE AND ESTIMATE

6.1 COST ESTIMATE

Table 2 shows the prices for the different materials that will be purchased for this project. The more detailed cost estimate can be seen in Appendix J. The total cost of the project is $14,500. There are two total costs in this table. One is for the entire system that CYC has designed. The second cost is the reduced cost, which removes expensive items that the community is unlikely to purchase and items that the *representante*, who is funding the system, will pay for separately from the materials. The reduced cost suggests ways that the overall cost could be lowered to be closer to the budget goal. Pipe crossings that are already in place before this system is implemented are unlikely to be changed so pipe crossing designs are not included in the reduced cost. However, not implementing the new design suggestions may result in higher operation and maintenance costs in the future despite the lower construction cost. The reduced cost of $7,500 is the total cost of the project that will most likely be implemented. This is less than the budget of $8,000.

Table 2. Cost Estimate for Materials

Item	Cost ($)	Reduced Cost ($)
Pipe	6793	6793
Fittings	134	134
Misc. Construction Materials	1324	582
Crossings	1941	0
Delivery	2000	0
Fuel	2343	0
Total	14500	7500

6.2 CONSTRUCTION SCHEDULE

Table 3 shows a condensed version of the design schedule. This table shows, in detail, the schedule to design the pressure break tank, water tap stands, and a pipeline section. The sections that have not been shown can be seen in detail in Appendix K. First, it is recommended that the anchors for the road and river crossings be constructed, as they require sufficient time for the concrete to set. The pressure break tank should also be constructed towards the beginning of work because it has several stages of concrete which all require time for setting. The main water line has been divided into eight 1000-meter sections for scheduling purposes. Only one of these eight sections is shown in detail, but they are all very similar. Before the first section of water line construction has begun, a new outlet from the tank must be created. Each 1000-meter water line section includes delivery of materials, marking/clearing the path and laying out piping, setting up trench machine, digging the trench, installation and sealing the pipe, checking that lines hold pressure, and burying and compacting. The sections with features such as clean outs have extra time allotted for the installation of these items. The 1000-meter sections with crossings have time allocated for assembling the cables with cross pieces that wrap around the pipe, suspending the cable, and tensioning the cable after the anchors have been completed. After the main line is constructed, the distribution lines will be created using the same procedure as was used for the main line. The last step in the creation of the water system is the construction of water tap stands. The total time that the project will take to construct is estimated to be 4 months from January to May.

Table 3. Construction Schedule

Task Mode	Task Name	Duration	Start	Finish
	Road Crossing Anchors	**12 days**	**Mon 1/8/18**	**Tue 1/23/18**
	River Crossing 1 Anchors	**13 days**	**Mon 1/8/18**	**Wed 1/24/18**
	River Crossing 2 Anchors	**13 days**	**Mon 1/8/18**	**Wed 1/24/18**
	Pressure Break Tank	**25 days**	**Wed 1/24/18**	**Tue 2/27/18**
	Connect to Water Tank	1 day	Wed 1/24/18	Wed 1/24/18
	Main Line Section 1	**8 days**	**Thu 1/25/18**	**Mon 2/5/18**
	Main Line Section 2	**7 days**	**Tue 2/6/18**	**Wed 2/14/18**
	Main Line Section 3	**8 days**	**Thu 2/15/18**	**Mon 2/26/18**
	Main Line Section 4	**7 days**	**Tue 2/27/18**	**Wed 3/7/18**
	Main Line Section 5	**8 days**	**Thu 3/8/18**	**Mon 3/19/18**
	Main Line Section 6	**7 days**	**Tue 3/20/18**	**Wed 3/28/18**
	Main Line Section 7	**8 days**	**Thu 3/29/18**	**Mon 4/9/18**
	Main Line Section 8	**7 days**	**Tue 4/10/18**	**Wed 4/18/18**
	Distribution Lines	**5 days**	**Thu 4/19/18**	**Wed 4/25/18**
	Water Tap Stands	**11.75 days**	**Tue 4/24/18**	**Wed 5/9/18**

**Trench digger is estimated to dig 1 ft/min.*

7.0 CONCLUSIONS

This design should sustainably provide the community of El Hueco clean drinking water for many years to come. The system will be approximately 8 kilometers long with five taps serving the 15 members of the community. The gravity-fed water system should take the community members a total of four months to build at a cost ranging from $7,500 to $14,500, depending on what design choices are made based on available funding. The *representante* hoped for a budget of around $8,000, which would be equal to the cost of a well and gas-powered pump placed in a centralized area in the community. The total design cost comes in at $14,500 if all design recommendations are put into place. However, to save on cost, certain aspects of the design can be removed, such as the utilization of engineered road, river, and stream crossings, replacing these designs with more rudimentary crossings wired to trees, as is currently done in the area. The masonry tap stands can also be replaced with simpler taps held in place with metal stakes. These design substitutions will greatly reduce the initial cost of the system but may require more repair in the long run. The materials for the construction of the project will be sourced locally to ensure that this water system's economic benefit stays within the area. The system will be constructed by the community members to reduce cost and to give the members a sense of ownership and responsibility for maintenance and care of the system that they built. In order to prolong the life of the system, regular maintenance will have to be performed by the community members. An operation and maintenance manual has been attached as Appendix L as a guide to proper system upkeep.

This water system is a step towards a better life for the people of El Hueco, giving them access to a basic need that they did not have readily available to them. It will provide the community members the opportunity to learn new skills and take on responsibilities, which can give them opportunities in their future endeavors.

8.0 REFERENCES

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9.0 APPENDICES

9.1 APPENDIX A. FLOW RATE DATA [1]

Table A1. Spring Flow Rate Raw Data

	Time Required to Fill 1 Liter (s)							Ave Flow (L/s)	Ave Flow (gal/d)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Avg		
Toma 1	**1.28**	**1.55**	**2.13**	**2.11**	**2.22**	**-**	**1.858**	**0.5382**	**12,284**
Toma 2	**1.23**	**2.41**	**2.25**	**2.41**	**2.53**	**2.06**	**2.148**	**0.4655**	**10,625**

Table A2. Available Water

	Flow Rate (gal/d)
Toma 1	**12284**
Toma 2	**10625**
Total	**22909**
Available Water	**107 gal/person/day**
W.H.O. Guidelines	**5.3 gal/person/day**

9.2 APPENDIX B. SURVEYING DATA

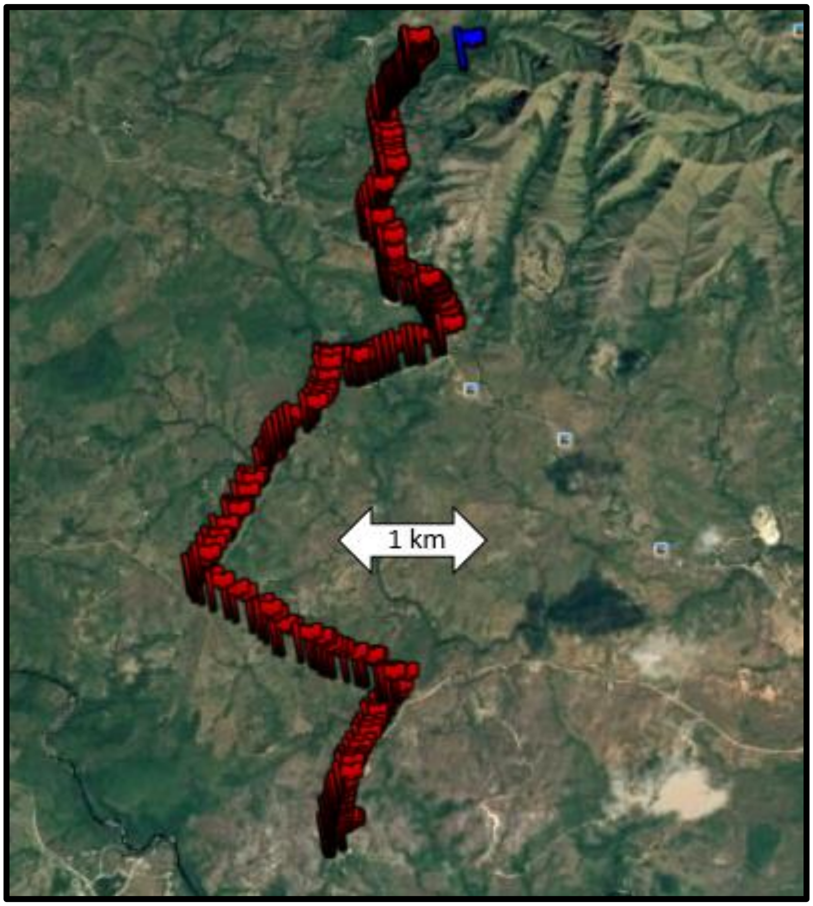


Figure B1. Surveyed Route

Table B1. Surveying Data

GPS Start	GPS End	Elevation Change	Horizontal Distance	Hypotenuse	Angle of Inclination	Degrees from N
110	111	-3.2	12	12.5	-15.2	194
111	112	-3	11.6	12	-14.8	206
112	113	-1	10.8	11	-6	190
113	114	-0.1	8.5	8.5	-3	186
114	115	0.0	5.0	5.0	-1	168
115	116	-0.1	5.1	5.1	-5	140
116	117	-0.1	5.6	5.6	-3	196
117	118	-0.6	10.5	10.5	-11	164
118	119	-0.4	3.9	3.9	-17	172
119	120	-0.6	11.8	11.9	-9	110
120	121	-0.6	6.3	6.3	-17	114
121	122	-0.4	3.7	3.7	-20	114
122	123	-0.6	9.9	10.0	-11	80
123	124	-0.6	8.5	8.5	-12	98
124	125	-0.5	7.6	7.6	-11	194
125	126	-1.0	10.7	10.8	-17	184
126	126	-0.6	11.5	11.5	-10	170
126	127	-0.6	10.0	10.0	-10	170
127	128	-0.4	8.6	8.7	-8	246
128	129	-0.9	13.3	13.3	-12	202
129	130	-0.7	15.0	15.0	-9	250
130	131	0.5	13.3	13.3	7	270
131	132	0.0	15.2	15.2	0	244
132	133	-0.3	26.3	26.3	-2	214
133	134	-0.1	11.4	11.4	-2	214
134	135	-0.4	24.8	24.8	-3	194
135	136	0.8	10.7	10.7	13	258
136	137	0.3	8.1	8.1	6	282
137	138	0.2	13.3	13.3	3	230
138	139	-0.1	14.6	14.6	-1	192
139	140	1.0	20.7	20.8	9	228
140	141	0.5	13.2	13.2	7	248
141	142	-0.4	17.9	17.9	-4	230
142	143	-0.1	7.6	7.6	-3	258
143	144	-0.3	17.1	17.1	-3	206
144	145	-0.2	15.1	15.1	-2	220
145	146	-8	57.8	58.5	-8	200
146	147	-0.4	13.8	14	-2	212
147	148	0.8	16.4	16.5	3.2	190
148	149	10	67.6	68.5	8.4	228
149	150	1.2	23.4	23.5	3.2	202

GPS Start	GPS End	Elevation Change	Horizontal Distance	Hypotenuse	Angle of Inclination	Degrees from N
150	151	-3	71.8	72	-2.4	198
151	152	-3.4	51.2	51.5	-4	178
152	153	-0.8	86.4	86.5	-0.6	170
153	154	-3.4	50.8	51	-4	158
154	155	-1.8	33.4	33.5	-3.2	188
155	156	0.2	38	38	0.6	176
156	157	3.2	39.8	40	4.8	184
157	158	1.2	36.4	36.5	2	166
158	159	-1	53.4	53.5	-1.2	158
159	160	0.4	14.8	15	1.6	188
160	161	2.4	43.4	43.5	3.2	218
161	162	-4.8	58.2	58.5	-4.8	218
162	163	-2	67.4	67.5	-1.7	214
163	164	-6.2	64	64.5	-5.7	210
164	165	-4.8	44.2	44.5	-6.4	212
165	166	2.8	35.8	36	4.5	190
166	167	2.2	42.8	43	3.2	206
167	168	7.6	77.6	78	5.6	135
168	169	3.4	101.4	101.5	2	148
169	170	0.4	60.5	60.5	0.4	150
170	171	2.4	115.4	115.5	1.2	180
171	172	-3.8	34.6	35	-6.4	186
172	173	-7.2	46.4	47	-9	178
173	174	-1.8	35.8	36	-3	136
174	175	-2.4	44.4	44.5	-3.2	114
175	176	-8.8	77.4	78	-6.6	110
176	177	1.4	48.4	48.5	1.8	106
177	178	4.2	58.2	58.5	4.3	118
178	179	0	64	64	0	146
179	180	3.6	135.4	135.5	1.6	150
180	181	-3.2	67.8	68	-2.8	152
181	182	-1.2	47.8	48	-1.6	160
182	183	-1.6	45.4	45.5	-2.2	190
5	6	-3.4	45.2	45.5	-4.4	248
6	7	-8.2	108.6	109	-4.4	248
7	8	-2.4	53.4	53.5	-2.6	280
8	9	-1.6	41.8	42	-2.4	266
9	10	-13.4	96.4	97.5	-8	255
10	11	-7.2	51.4	52	-8	251
11	12	-10.2	56	57	-10.4	250
12	13	-2.8	45.8	46	-3.6	250
13	14	-2	41.8	42	-3	258

GPS Start	GPS End	Elevation Change	Horizontal Distance	Hypotenuse	Angle of Inclination	Degrees from N
14	15	4	50.8	51	4.6	252
15	16	2.6	30.2	30.5	5.2	256
16	18	2.8	76.8	77	2.1	278
18	19	7.6	180.8	181	2.4	278
19	20	0.2	53	53	0.4	278
20	21	0	10	10	-0.8	219
21	22	-1.4	56.8	57	-1.6	195
22	23	-2.8	101.4	101.5	-1.6	194
23	24	1.8	75.4	75.5	1.5	200
24	25	0.4	28.4	28.5	1.2	208
25	26	1.4	55.4	55.5	1.6	220
26	27	-0.2	42	42	-0.4	231
27	28	-4.6	133.8	134	-2	244
28	29	-1.2	47.8	48	-1.6	244
29	30	-1.4	51.4	51.5	-1.6	236
30	31	-1.2	66	66	-1.2	228
31	32	-1	43.4	43.5	-1.4	218
32	33	-1.2	52.8	53	-1.4	204
33	34	-6	58	58.5	-6	204
34	35	-0.2	14.4	14.5	-0.8	216
35	36	1.4	18.8	19	4.3	216
36	37	3	26.2	26.5	6.6	226
37	38	4	169.4	169.5	1.4	222
38	39	-1.2	43.8	44	-1.6	218
39	40	4.2	86.8	87	2.8	212
40	41	2.2	105.4	105.5	1.2	210
41	42	0.6	15.8	16	2.8	212
42	43	2	20.8	21	6	218
43	44	8.8	134	134.5	3.8	222
44	45	5.6	101.2	101.5	3.2	220
45	46	0.4	63	63	0.5	218
46	47	-3	75.4	75.5	-2.4	218
47	48	-1.2	48.8	49	-1.5	206
48	49	-2	75.4	75.5	-1.6	192
49	50	0	12.4	12.5	-0.2	172
50	51	0.6	51	51	0.8	124
51	52	0	87.4	87.5	0	122
52	53	-3	120.4	120.5	-1.5	122
53	54	-2	60.4	60.5	-2	130
54	55	-2.2	142.4	142.5	-0.9	126
55	56	-0.2	71.4	71.5	-0.3	130
56	57	-0.6	51	51	-0.8	136

GPS Start	GPS End	Elevation Change	Horizontal Distance	Hypotenuse	Angle of Inclination	Degrees from N
57	58	-1.2	100	100	-0.7	144
58	59	-0.2	41	41	-0.4	122
59	60	2	145	145	0.8	114
60	61	-2.2	80.8	81	-1.6	114
61	62	-0.4	28.4	28.5	-0.8	126
62	63	-0.2	57.4	57.5	-0.4	136
63	64	-0.2	44	44	-0.4	120
64	65	-1.2	46.5	46.6	-1.6	114
65	66	-9.4	97.4	98	-5.6	112
66	67	-1.8	86.4	86.5	-1.2	110
67	68	-0.6	36.4	36.5	-1	106
68	69	-0.2	24.4	24.5	-0.5	122
69	70	-0.8	139	139	-0.4	140
70	71	0	29	29	0	118
71	72	0.2	85.4	85.5	0.2	96
72	73	-3	94.8	95	-1.9	208
73	74	-1.4	62.8	63	-1.4	212
74	75	-3.6	52.8	53	-4	232
75	76	-0.4	40.4	40.5	-0.8	232
76	77	-3	61.4	61.5	-2.8	224
77	78	2.6	29.8	30	5	218
78	79	10.6	83.8	84.5	7.2	204
79	80	4.6	40.6	41	6.6	21.6
80	81	6.2	41.4	42	8.6	200
81	82	9.2	70.8	71.5	7.4	220
82	83	5	51.2	51.5	5.6	218
83	84	4	59.2	59.5	4	212
84	85	1.6	32.4	32.5	3.1	222
85	86	-1.2	21.8	22	-3.6	206
86	87	0.4	68	68	0.4	194
87	88	-3.6	71.2	71.5	-3	210
88	89	-5.8	37.4	38	-8.9	210
89	90	-3	35.8	36	-4.8	192
90	91	2.6	39.4	39.5	4	186
91	92	-0.8	38.4	38.5	-1.2	206
92	93	-1	19.4	19.5	-3.2	200
93	96	-1.6	24.4	24.5	-4.2	184
96	97	-3.8	35.2	35.5	-6.2	182
Branch to first and second tap						
93	94	-2	27.4	27.5	-4.4	244
94	95	-0.4	9.8	10	-2.4	206
Branch to fifth tap						

GPS Start	GPS End	Elevation Change	Horizontal Distance	Hypotenuse	Angle of Inclination	Degrees from N
97	98	-5.2	51.6	52	-5.9	126
98	99	-4.2	30.2	30.5	-8	122
99	100	-1	18.4	18.5	-3.4	148
Branch to third and fourth tap						
97	101	-2.2	27.4	27.5	-4.7	190
101	102	-3.4	48.8	49	-4	178
102	103	-0.2	26.4	26.5	-0.8	202
103	104	2.2	18.2	18.5	7	294
104	105	0.8	10.4	10.5	4.4	272
105	106	3.2	14.6	15	12.4	4
106	107	3.6	9.2	10	21.6	348
Road crossing						
198	197	1.2	34.8	35	2.2	150
197	196	1.6	13.8	14	7.2	150
196	195	2.4	11.2	11.5	12.8	156
195	194	4.4	31.6	32	8	156
194	192	-2.2	30.8	31	-4.4	238
192	190	-3.4	17.6	18	-11	74

9.3 APPENDIX C. COLIFORM TESTS

Table C1. Coliform and E. Coli Test Results for Toma 1 (CFUs/1mL)

Toma 1	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Avg.
Coliforms	84	96	70	64	67	38	69.8
Coliforms with bubbles	2	3	2	0	0	1	1.3
E. coli	0	0	0	0	0	0	0
E coli with bubbles	0	0	0	0	0	0	0

Table C2. Coliform and E. Coli Test Results for Toma 2 (CFUs/1mL)

Toma 2	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Avg.
Coliforms	30	28	54	18	14	28.8
Coliforms with bubbles	2	3	3	2	1	2.2
E. coli	0	0	0	0	0	0
E. coli with bubbles	0	0	0	0	0	0

Table C3. Coliform and E. Coli Test Results for Storage Tank (CFUs/1mL)

Tank	Trial 1	Trial 2	Trial 3	Avg.
Coliforms	8	11	22	13.7
Coliforms with bubbles	1	1	0	0.7
E. coli	0	0	0	0
E. coli with bubbles	0	0	0	0

Table C4. Coliform and E. Coli Test Results for Host Family Tap (CFUs/1mL)

Host Family	Trial 1	Trial 2	Trial 3	Avg.
Coliforms	206	82	138	142.0
Coliforms with bubbles	29	17	33	26.3
E. coli	13	3	3	6.3
E. coli with bubbles	7	3	3	4.3

Table C5. Average Coliform and E. Coli Test Results (CFUs/1mL)

	Toma 1 (6 samples)	Toma 2 (5 samples)	Storage Tank (3 samples)	Host Family (3 samples)
Coliforms	**69.8**	**28.8**	**13.7**	**142.0**
Coliforms with bubbles	**1.3**	**2.2**	**0.7**	**26.3**
E. coli	**0**	**0**	**0**	**6.3**
E. coli with bubbles	**0**	**0**	**0**	**4.3**

9.4 APPENDIX D. EPANET DATA

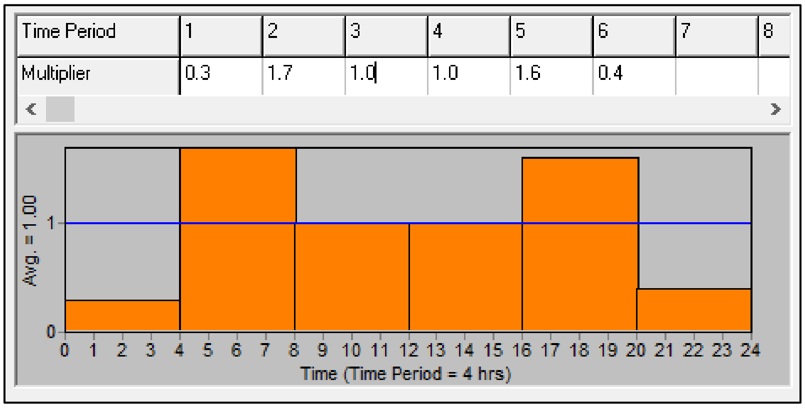


Figure D1. Base Demand Pattern

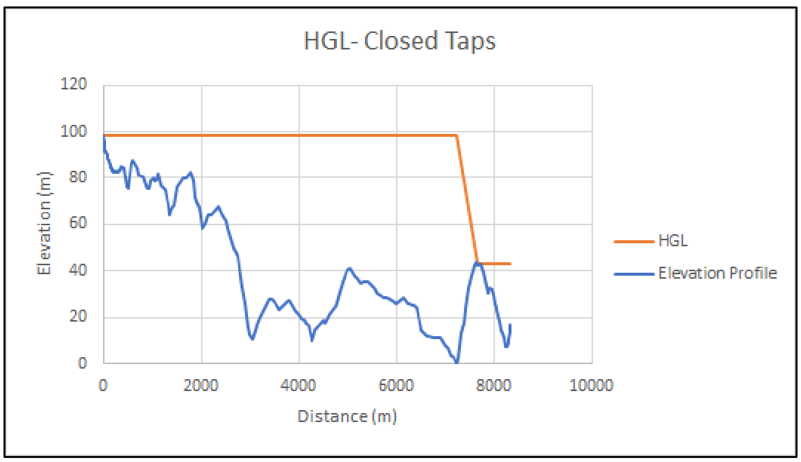


Figure D2. Hydraulic Grade Line: Closed Taps

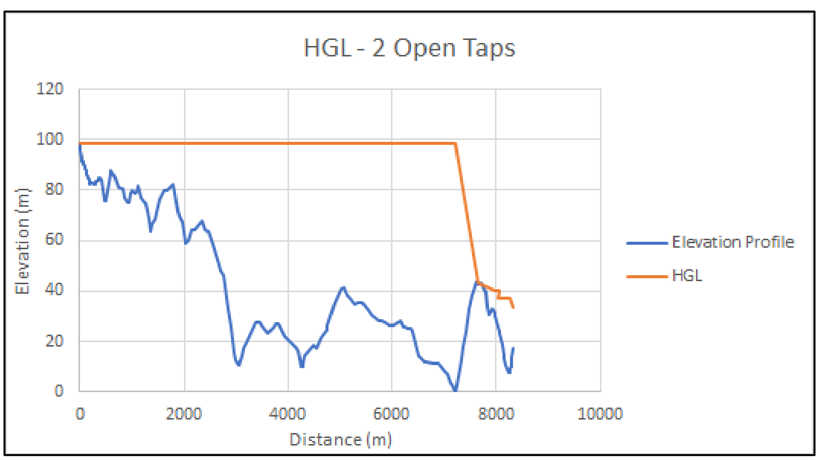


Figure D3. Hydraulic Grade Line: Two Open Taps

9.5 APPENDIX E. WATER TREATMENT CALCULATIONS FOR CHLORINE CONTACT TIME

Flow rate=3 gal/min (for two taps open)

Table E1. Chlorine Contact Time

Diameter of pipe (in)	Cross sectional area of pipe (in^2)	Length (m)	Length (in)	Volume (in^3)	Volume (gallons)	Detention time (min)
2	3.1	1358.0	53463.9	167961.8	727.1	242.4
1	0.8	6576.7	258923.6	203358.1	880.3	293.4
0.5	0.2	27.4	1078.7	211.8	0.9	0.3
					Total=	536.1

Assuming pH=7.0 and lowest water temperature>50°F, K=8 [4]

$$Required\ detention\ time\ (minutes) = \frac{K}{Chlorine\ residual}$$

$$Minimum\ required\ detention\ time = \frac{8}{0.2\ mg/L} = 40\ minutes$$

0.2 mg/L is the concentration of free chlorine residual that should be present for microbiologically clean water. [23]

9.6 APPENDIX F. PRESSURE RATINGS FOR PVC PIPES [5]

Table F1. PVC Pipe Pressure Rating

Pressure Ratings (psi) For Cresline PVC Pipe At 73.4 °F														
SIZE	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"	6"	8"	10"	12"
SDR-26	-	-	-	160	160	160	160	160	160	-	160	160	-	-
SDR-21	-	200	200	200	200	200	200	200	200	200	200	200	200	200
SDR-13.5	315	-	-	-	-	315	315	315	315	-	-	-	-	-

9.7 APPENDIX G. PRESSURE REDUCING SYSTEM CALCULATIONS [14]

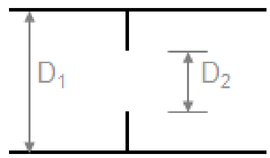


Figure G1. Orifice Diameters

$$\text{Re} = \frac{\rho v D}{\mu}$$

For $\text{Re}_1 < 2500$,

$$K = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{120}{Re_1} - 1\right)\right] \left[1 - \left(\frac{D_2}{D_1}\right)^2\right] \left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$$

For $\text{Re}_1 > 2500$

$$K = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{4000}{Re_1}\right)\right] \left[1 - \left(\frac{D_2}{D_1}\right)^2\right] \left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]$$

Figure G2. Orifice Headloss Equations

Table G1: Orifice Headloss Calculations

Flow (m/s)	D1 (in)	Re	D2 (in)	K
0.19	1	5400.84	0.31	137.07
			0.22	1143.16
			0.16	4478.92
0.75	0.5	10659.55	0.31	9.70
			0.22	59.36
			0.16	258.34

*Pipe flow assumes 1 tap open. Reynold's number calculated at 25 degrees C.

9.8 APPENDIX H. AIR IN PIPES CALCULATIONS

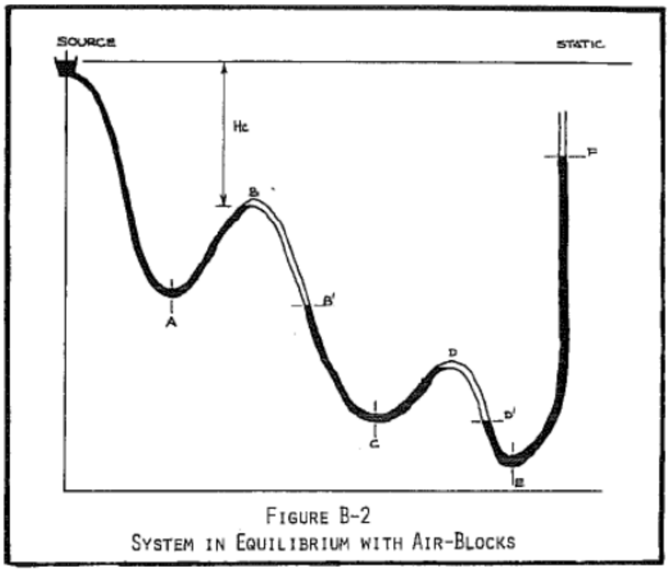


*Figure H1. System in Equilibrium with Air-Blocks**

**Figure H1 shows the possible locations that air blocks can form in a system, and was used to determine locations in Figure H2.*

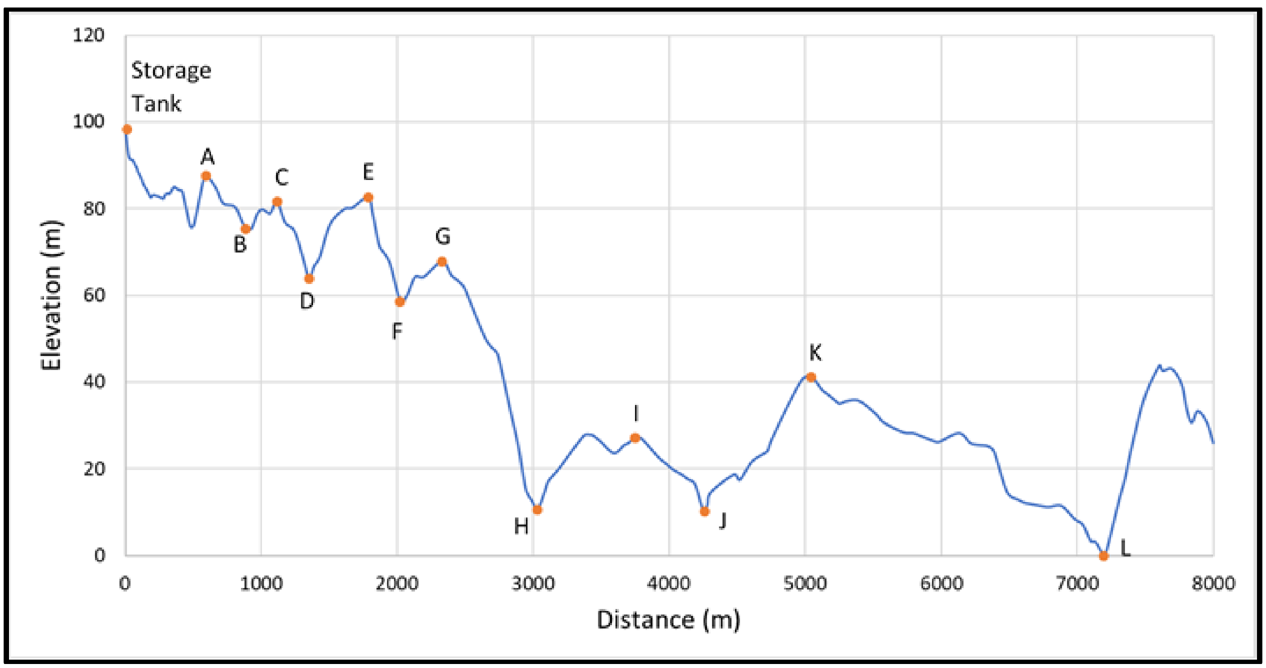


Figure H2. Locations of Possible Air Blocks Along Elevation Profile

Table H1. Compressed Air Calculations

Location in Elevation Profile	Z peak	Z valley	Horizontal Distance from peak to valley (m)	P	Diameter of Pipe	Initial L	Initial V	Compressed V	Compressed L	Height of Compressed Air	Z bottom of compressed air
	m	m	m	m	in	m	m^3	m^3	m	m	m
Storage Tank	98.65			10.3							
A-B	87.6	75.2	293.6	21.35	2	293.862	0.596	0.194	95.633	4.039	83.561
C-D	81.6	63.8	233.8	27.35	2	234.477	0.475	0.208	102.794	7.826	73.774
E-F	82.6	58.6	238.6	26.35	2	239.804	0.486	0.248	122.135	12.285	70.315
G-H	67.8	10.6	701.4	41.15	1	703.728	0.357	0.139	274.715	22.403	45.397
I-J	27.2	10.2	509.6	81.75	1	509.883	0.258	0.087	170.722	5.695	21.505
K-L	41.2	0	2149.3	67.75	1	2149.695	1.089	0.596	1175.502	22.533	18.667

$$Compressed\ V = Initial\ V * \left(\frac{P_i}{P_i + P_{i+1}}\right)$$

$$Compressed\ L = Initial\ L * \left(\frac{Compressed\ V}{Initial\ V}\right)$$

$$Height\ of\ Compressed\ Air = Compressed\ L * \frac{Z\ Peak - Z\ Valley}{Horizontal\ Length\ Peak\ to\ Valley}$$

$$Z\ Bottom\ of\ Compressed\ Air = Z\ Peak - Height\ of\ Compressed\ Air$$

Table H2. Headloss Calculations

Headloss	m	6.6
H_{eq}	m	57.4
H_{final}	m	50.8
H_{final}+Z bottom of compressed air	m	69.5
Z pressure break tank	m	42.0

9.9 APPENDIX I: SUSPENDED CROSSING CALCULATIONS [11, 24]

[1] Volume of Pipe (V) = $\frac{\Pi}{4} * D^2 * L$

[2] Weight of Pipe with water (W) = $\gamma(water) * V$

[3] Force in y at each anchor (Fy) = 0.5*W

[4] Angle of Sag = $tan^{-1}(\frac{0.5*L}{Acceptable\ sag})$

[5] Force in x at each anchor (Fx) = tan(angle of sag) * Fy

[6] Force in Cable (F) = $\sqrt{(Fx)^2 + (Fy)^2}$

[7] Weight of pipe per unit length = W/L

[8] Horizontal tension = $\frac{Weight\ of\ pipe\ per\ unit\ length * L^2}{8 * Acceptable\ sag}$

[9] Angle of Tension = $tan^{-1}(\frac{4*Acceptable\ sag}{L})$

[10] Total Tension = $\frac{Horizontal\ Tension}{cos(angle\ of\ tension)}$

[11] Angle of anchor wire = $tan^{-1}(H/Dist)$

[12] Anchor force in x (Ax) = cos(angle of anchor wire) * F

[13] Anchor force in y (Ay) = sin(angle of anchor wire) * F

[14] Total Volume of Concrete = H2×W1×(L2+L1)+((W1+W2)/2)×H1×L1

[15] Weight of concrete = Total Volume of Concrete × Density of Concrete

[16] Resisting force in x=(Fx+Weight of concrete) × tan(Friction angle)

[17] Safety factor=Resisting force in x/Anchor force in x

*Real safety factor will actually be larger because there is pressure force from soil due to buried anchor

[18] Moment overturn=Anchor force in x × 0.5 × H2+Anchor force in y × (L1+L2)

[19] Top block weight(Wtb)=((W1+W2)/2)×H1×L1 × Density of Concrete

[20] Bottom block weight(Wbb)= H2×W1×(L2+L1) × Density of Concrete

[21] Resisting moment=(Fy+Wtb) × (0.5 × L1)+Wbb × 0.5 × (L1+L2)

[22] Safety factor=Resisting moment/Moment overturn

V = Volume, D = Diameter, L = Length, W = Weight,
γ = *Specific weight* H = Height of tower, Dist = Distance of anchor from tower
Friction angle =20° for silty clay [24]

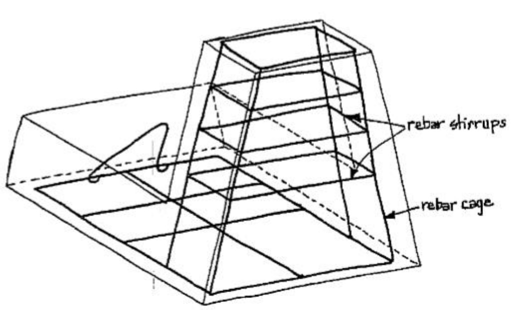


Figure I1. Anchor Block

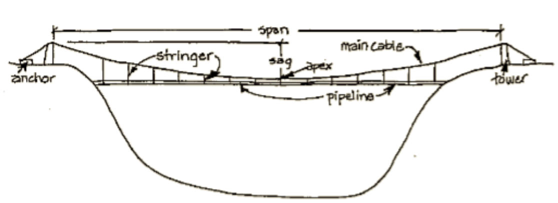


Figure I2. Crossing Design

Table I1. Summary Table of Bridge Calculations

	Road Crossing	River Crossing (20m)	River Crossing (40m)
Length (m)	35	20	40
Diameter (in)	1	1	1
Volume (in^3)	1082.2	618.4	1236.8
Volume (gal)	4.7	2.7	5.4
Weight (lb)	39.1	22.3	44.7
Weight (lb)	78.1	44.7	89.3
Weight (N)	347.6	198.6	397.3
Force in y (N)	173.8	99.3	198.6
Sag in h (m)	2.6	1.5	3.0
Angle of sag (rad)	1.4	1.4	1.4
Force in x (N)	1158.7	662.1	1324.2
Force in cable (N)	1171.7	669.5	1339.0
Weight of pipe per unit length (N/m)	9.9	9.9	9.9
Horizontal tension (N)	579.3	331.1	662.1
Horizontal tension (lb)	130.2	74.4	148.8
Angle of tension (rad)	0.3	0.3	0.3
Total tension (N)	604.9	345.6	691.3
Total tension (lb)	136.0	77.7	155.4
Height of tower (m)	0.3	0.2	0.4
Distance of anchor from tower (m)	0.5	0.5	0.7
Angle of anchor wire (rad)	0.540	0.381	0.519
Anchor force in x (lb)	116.6	72.1	134.9
Anchor force in y (lb)	70.0	28.9	77.1
Density of concrete (kg/m^3)	2400	2400	2400
W1 (m)	0.4	0.3	0.4
W2(m)	0.4	0.3	0.4
H1 (m)	0.3	0.2	0.4
H2 (m)	0.2	0.2	0.25
L1 (m)	0.2	0.2	0.25
L2 (m)	0.5	0.5	0.7
Total volume of concrete (m^3)	0.08	0.054	0.135
Weight of concrete (kg)	192	129.6	324
Weight of concrete (lb)	422.4	285.1	712.8
Friction angle (degrees)	20	20	20
Resisting force in x-direction	168.0	111.9	275.7
Safety Factor	1.4	1.6	2.0

Moment overturn (m lbs)	60.6	27.4	90.1
Moment overturn (ft lbs)	198.9	89.9	295.6
Top block volume (m^3)	0.024	0.012	0.04
Bottom block volume (m^3)	0.056	0.042	0.095
Top block weight (kg)	57.6	28.8	96
Bottom block weight (kg)	134.4	100.8	228
Top block weight (lb)	126.7	63.4	211.2
Bottom block weight (lb)	295.7	221.8	501.6
Resisting moment (ft lbs)	393.9	282.8	886.6
Safety Factor	2.0	3.1	3.0

9.10 APPENDIX J: COST ESTIMATE [9, 12, 15, 16, 17, 20, 21, 22]

Table J1. Complete Cost Estimate

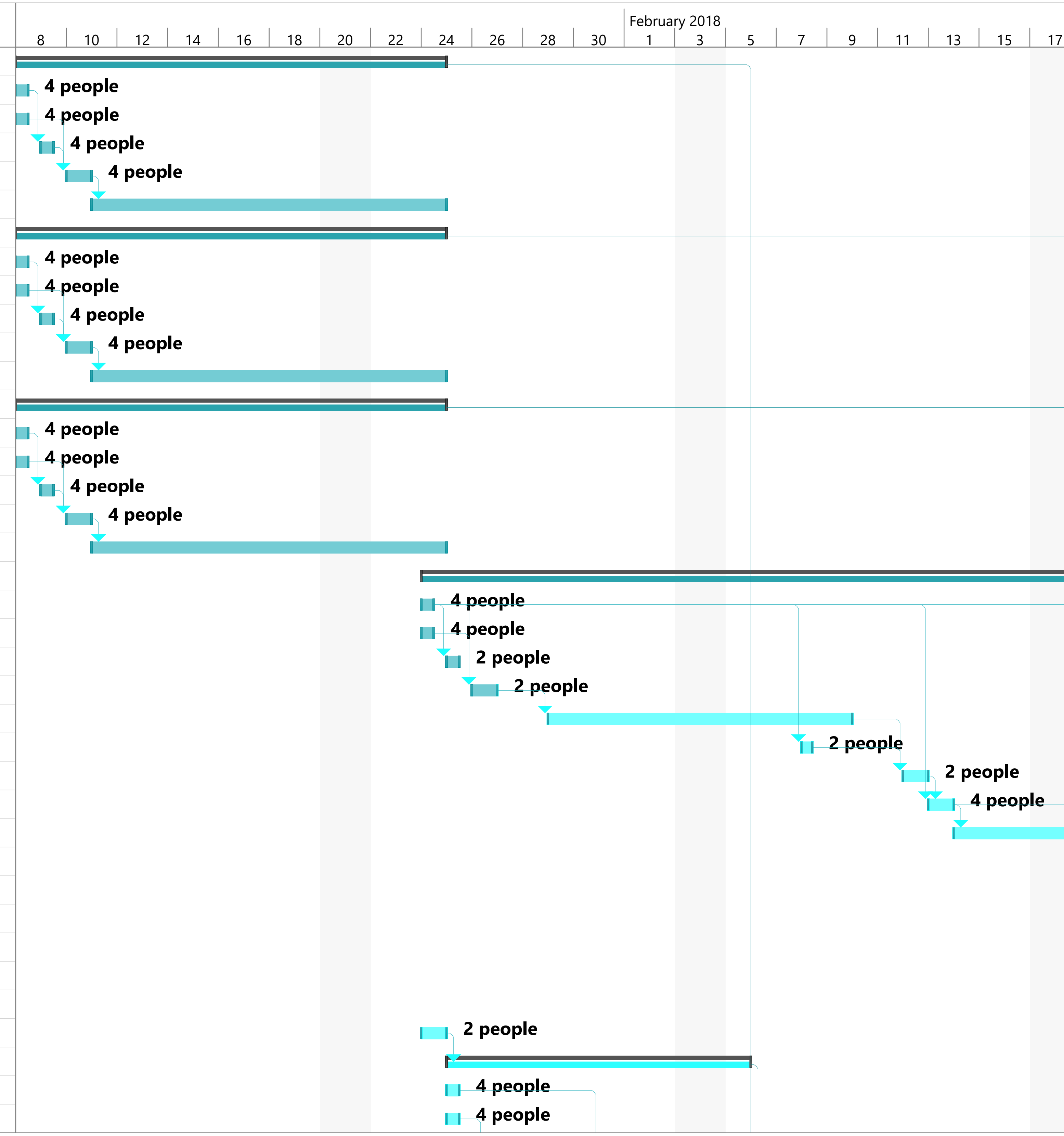
	Item	Unit	Quantity	Unit Cost ($)	Cost ($)	Reduced Cost ($)	Ref.
Pressure Break	Concrete Blocks		12.00	1.25	15.00	15.00	16
	Sika Additive	10 oz	2.00	8.00	16.00	16.00	20
	Cement	100 lbs	1.89	9.75	18.43	18.43	22
	Sand	yd^3	0.15	185.79	27.87	27.87	16
	Gravel	yd^3	0.09	248.48	21.12	21.12	16
	1" to 3/4" Reducer		1.00	0.57	0.57	0.57	15
	3/4" Float Valve		1.00	22.00	22.00	22.00	16
	#3 Rebar	20 ft	1.05	3.50	3.68	3.68	18
Pipe Network	0.5" Shut Off Valve		5.00	1.50	7.50	7.50	22
	1" Shut Off Valve		6.00	3.95	23.70	23.70	22
Clean Out	1" Wye		1.00	3.41	3.41	3.41	15
Clean Out	1" Shut Off Valve		1.00	3.95	3.95	3.95	22
Clean Out	1" Pipe	20 ft	0.25	4.00	1.00	1.00	22
	1" Elbow		7.00	1.00	7.00	7.00	15
	2" Elbow		2.00	4.00	8.00	8.00	15
Valve Access	Brick		20.00	0.40	8.00	34.00	19
Valve Access	Cement	100 lbs	1.33	9.75	12.97	12.97	22
Valve Access	Sand	yd^3	0.16	185.79	29.73	29.73	16
Valve Access	3/16" A36 1' x 1' Steel Plate		1.00	14.19	14.19	14.19	21
Distribution Lines	1/2" Pipe	20 ft	15.00	2.60	39.00	39.00	22
Water Taps Stands	#3 Rebar	20 ft	10.25	3.50	35.88		18
Water Taps Stands	Cement	100 lbs	13.61	9.75	132.70		22
Water Taps Stands	Sand	yd^3	1.07	185.79	198.80		16
Water Taps Stands	Gravel	yd^3	1.61	248.48	400.05		16
Water Taps Stands	1/2" Spigot		5.00	5.25	26.25	26.25	15
Water Taps Stands	1/2" Elbow Joint		11.00	0.25	2.75	2.75	15
	1" Wye		4.00	3.41	13.64	13.64	15
	1" to 1/2" Reducer		5.00	0.80	4.00	4.00	15
Main Line	1" Pipe	20 ft	1140.00	4.00	4560.00	4560.00	22
	2" Pipe	20 ft	230.00	9.50	2185.00	2185.00	22
	Pipe Sealant	16 oz	30.00	8.00	240.00	240.00	16
	Fuel for Trench Digger	liters	3445.00	0.68	2342.60		11
Road Crossing	Cement	100 lbs	0.44	9.75	4.29		22
	Sand	yd^3	0.04	185.79	6.50		16
	Gravel	yd^3	0.05	248.48	12.92		16

	#4 Rebar	20 ft	1.75	5.50	9.63		18
	3/16" Cable	ft	175.00	0.12	21.53		9
	3" Pipe	20 ft	11.50	23.50	270.25		22
	3/16" Zinc Plated Copper Sleeve		62.00	1.09	67.58		9
	1/2" x 8" Stainless Steel Eye x Eye Turnbuckle		8.00	24.16	193.28		9
River Crossing (20m)	Cement	100 lbs	0.30	9.75	2.93		22
	Sand	yd^3	0.02	185.79	4.46		16
	Gravel	yd^3	0.04	248.48	8.70		16
	#4 Rebar	20 ft	1.60	5.50	8.80		18
	3/16" Cable	ft	106.00	0.12	13.04		19
	3" Pipe	20 ft	6.55	23.50	153.93		22
	3/16" Zinc Plated Copper Sleeve		44.00	1.09	47.96		9
	1/2" x 8" Stainless Steel Eye x Eye Turnbuckle		6.00	24.16	144.96		9
River Crossing (40m)	Cement	100 lbs	0.75	9.75	7.31		22
	Sand	yd^3	0.06	185.79	11.15		16
	Gravel	yd^3	0.09	248.48	22.36		16
	#4 Rebar	20 ft	2.60	5.50	14.30		18
	3/16" Cable		200.00	0.12	24.60		9
	3" Pipe	20 ft	13.10	23.50	307.85		22
	3/16" Zinc Plated Copper Sleeve		56.00	1.09	61.04		9
	1/2" x 8" Stainless Steel Eye x Eye Turnbuckle		6.00	24.16	144.96		9
Stream Crossing	Ground Anchor		40.00	5.75	230.00		9
	3/32" Cable	ft	110.00	0.10	11.00		9
	3" Pipe	20 ft	5.50	23.50	129.25		22
	3/32" Zinc Plated Copper Sleeve		44.00	0.15	6.60		9
Casing Under Road	3" Schedule 40 Steel Pipe	8 ft	3.00	2.58	7.74	7.74	12
	Couplings		6.00	2.25	13.50	13.50	15
	Seal End		10.00	9.95	99.50	99.50	15
Miscellaneous	Rebar Tie		5000.00	0.01	30.00	30.00	17
	Delivery	trips	50.00	40.00	2000.00		22
	Bulk Head		1.00	19.95	19.95	19.95	15
Total					14536.62	7511.44	

The estimated total time for this trench digger to complete its work is 455 hours.
*Fuel for the trench digger was found through global petrol prices at $0.68/L. This price came from assuming a diesel engine that consumes 8 L/hr.

APPENDIX K: CONSTRUCTION SCHEDULE GANTT CHART

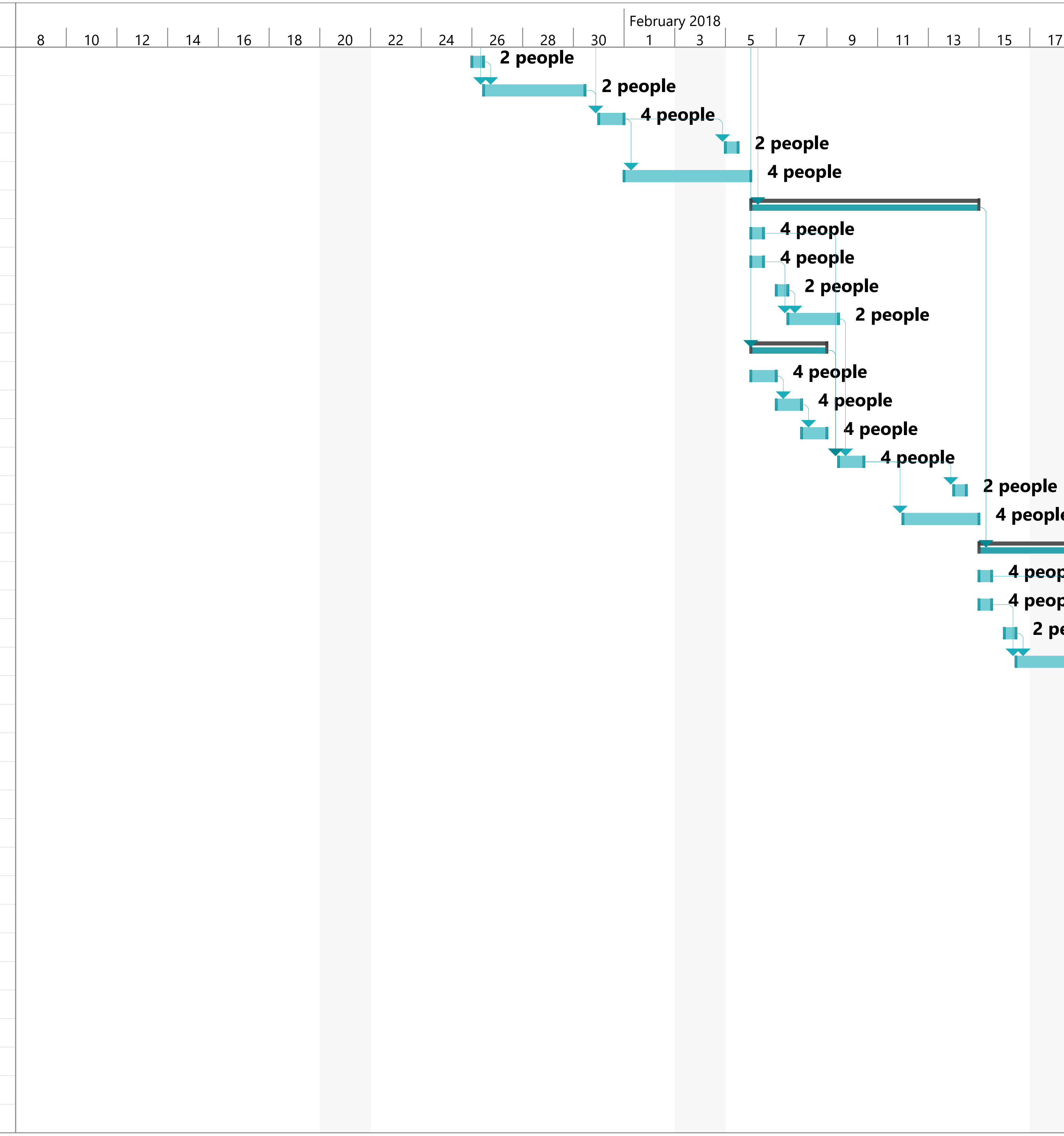
ID	Task Name	Duration	Start	Finish	Predecessors
1	**Road Crossing Anchors**	**13 days**	**Mon 1/8/18**	**Wed 1/24/18**	
2	Delivery of Materials	0.5 days	Mon 1/8/18	Mon 1/8/18	
3	Dig/Level Area	0.5 days	Mon 1/8/18	Mon 1/8/18	
4	Assemble Rebar Frames/Attach Cable	0.5 days	Tue 1/9/18	Tue 1/9/18	2
5	Mix and Pour Concrete	1 day	Wed 1/10/18	Wed 1/10/18	3,4
6	Set Concrete	10 days	Thu 1/11/18	Wed 1/24/18	5
7	**River Crossing 1 Anchors**	**13 days**	**Mon 1/8/18**	**Wed 1/24/18**	
8	Delivery of Materials	0.5 days	Mon 1/8/18	Mon 1/8/18	
9	Dig/Level Area	0.5 days	Mon 1/8/18	Mon 1/8/18	
10	Assemble Rebar Frames/Attach Cable	0.5 days	Tue 1/9/18	Tue 1/9/18	8
11	Mix and Pour Concrete	1 day	Wed 1/10/18	Wed 1/10/18	9,10
12	Set Concrete	10 days	Thu 1/11/18	Wed 1/24/18	11
13	**River Crossing 2 Anchors**	**13 days**	**Mon 1/8/18**	**Wed 1/24/18**	
14	Delivery of Materials	0.5 days	Mon 1/8/18	Mon 1/8/18	
15	Dig/Level Area	0.5 days	Mon 1/8/18	Mon 1/8/18	
16	Assemble Rebar Frames/Attach Cable	0.5 days	Tue 1/9/18	Tue 1/9/18	14
17	Mix and Pour Concrete	1 day	Wed 1/10/18	Wed 1/10/18	15,16
18	Set Concrete	10 days	Thu 1/11/18	Wed 1/24/18	17
19	**Pressure Break Tank**	**25 days**	**Wed 1/24/18**	**Tue 2/27/18**	
20	Delivery of Materials	0.5 days	Wed 1/24/18	Wed 1/24/18	
21	Clear/Level Area	0.5 days	Wed 1/24/18	Wed 1/24/18	
22	Assemble Rebar Frames	0.5 days	Thu 1/25/18	Thu 1/25/18	20
23	Mix and Pour Concrete	1 day	Fri 1/26/18	Fri 1/26/18	20,21
24	Set Concrete	10 days	Mon 1/29/18	Fri 2/9/18	23
25	Mix Concrete for Mortar	2 hrs	Thu 2/8/18	Thu 2/8/18	20
26	Place and Mortar Concrete Blocks on Base	1 day	Mon 2/12/18	Mon 2/12/18	24,25
27	Mix and Pour Concrete for Pipe Inlet and Outlet	1 day	Tue 2/13/18	Tue 2/13/18	20,26
28	Set Concrete	10 days	Wed 2/14/18	Tue 2/27/18	27
29	Mix Concrete with Water Proofing Sika	2 hrs	Thu 2/22/18	Thu 2/22/18	20
30	Mortar Interior with Sika Concrete	1 day	Thu 2/22/18	Fri 2/23/18	27,29
31	Install Piping and Float Valve	0.5 days	Fri 2/23/18	Fri 2/23/18	30
32	Mix Concrete for Mortar	2 hrs	Sat 2/24/18	Sat 2/24/18	20
33	Place and Mortar Top Slab	0.5 days	Mon 2/26/18	Mon 2/26/18	31,32
34	Install Lid	1 hr	Mon 2/26/18	Mon 2/26/18	33
35	Connect to Water Tank	1 day	Wed 1/24/18	Wed 1/24/18	
36	**Main Line Section 1**	**8 days**	**Thu 1/25/18**	**Mon 2/5/18**	**35**
37	Delivery of Materials	0.5 days	Thu 1/25/18	Thu 1/25/18	
38	Mark/Clear Path and Lay Out Piping	0.5 days	Thu 1/25/18	Thu 1/25/18	



Project: Scheduling2
Date: Tue 11/14/17

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

ID	Task Name	Duration	Start	Finish	Predecessors
39	Place Trench Machine	3 hrs	Fri 1/26/18	Fri 1/26/18	
40	*Dig Trench	2 days	Fri 1/26/18	Tue 1/30/18	38,39
41	Installation and Sealing	1 day	Wed 1/31/18	Wed 1/31/18	37,40
42	Check that Lines Hold Pressure	0.5 days	Mon 2/5/18	Mon 2/5/18	41
43	Bury and Compact	3 days	Thu 2/1/18	Mon 2/5/18	41
44	**Main Line Section 2**	**7 days**	**Tue 2/6/18**	**Wed 2/14/18**	**36**
45	Delivery of Materials	0.5 days	Tue 2/6/18	Tue 2/6/18	
46	Mark/Clear Path and Lay Out Piping	0.5 days	Tue 2/6/18	Tue 2/6/18	
47	Place Trench Machine	3 hrs	Wed 2/7/18	Wed 2/7/18	
48	*Dig Trench	2 days	Wed 2/7/18	Fri 2/9/18	46,47
49	**Road Crossing**	**3 days**	**Tue 2/6/18**	**Thu 2/8/18**	**1**
50	Assemble Cable with Cross Pieces	1 day	Tue 2/6/18	Tue 2/6/18	
51	Suspend Cable	1 day	Wed 2/7/18	Wed 2/7/18	50
52	Tension Cable	1 day	Thu 2/8/18	Thu 2/8/18	51
53	Installation and Sealing	1 day	Fri 2/9/18	Sat 2/10/18	45,48,49
54	Check that Lines Hold Pressure	0.5 days	Wed 2/14/18	Wed 2/14/18	53
55	Bury and Compact	3 days	Mon 2/12/18	Wed 2/14/18	53
56	**Main Line Section 3**	**8 days**	**Thu 2/15/18**	**Mon 2/26/18**	**44**
57	Delivery of Materials	0.5 days	Thu 2/15/18	Thu 2/15/18	
58	Mark/Clear Path and Lay Out Piping	0.5 days	Thu 2/15/18	Thu 2/15/18	
59	Place Trench Machine	3 hrs	Fri 2/16/18	Fri 2/16/18	
60	*Dig Trench	2.63 days	Fri 2/16/18	Tue 2/20/18	58,59
61	Installation and Sealing	1 day	Wed 2/21/18	Wed 2/21/18	57,60
62	Installation of Clean Out Valve	0.5 days	Wed 2/21/18	Wed 2/21/18	57,60
63	Check that Lines Hold Pressure	0.5 days	Mon 2/26/18	Mon 2/26/18	61,62
64	Bury and Compact	3 days	Thu 2/22/18	Mon 2/26/18	61,62
65	**Main Line Section 4**	**7 days**	**Tue 2/27/18**	**Wed 3/7/18**	**56**
66	Delivery of Materials	0.5 days	Tue 2/27/18	Tue 2/27/18	
67	Mark/Clear Path and Lay Out Piping	0.5 days	Tue 2/27/18	Tue 2/27/18	
68	Place Trench Machine	3 hrs	Wed 2/28/18	Wed 2/28/18	
69	*Dig Trench	2 days	Wed 2/28/18	Fri 3/2/18	67,68
70	**River Crossing 1**	**3 days**	**Tue 2/27/18**	**Thu 3/1/18**	7
71	Assemble Cable with Cross Pieces	1 day	Tue 2/27/18	Tue 2/27/18	
72	Suspend Cable	1 day	Wed 2/28/18	Wed 2/28/18	71
73	Tension Cable	1 day	Thu 3/1/18	Thu 3/1/18	72
74	Installation and Sealing	1 day	Fri 3/2/18	Sat 3/3/18	66,69,70
75	Check that Lines Hold Pressure	0.5 days	Wed 3/7/18	Wed 3/7/18	74
76	Bury and Compact	3 days	Mon 3/5/18	Wed 3/7/18	74



Project: Scheduling2
Date: Tue 11/14/17

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

ID	Task Name	Duration	Start	Finish	Predecessors
77	**Main Line Section 5**	**8 days**	**Thu 3/8/18**	**Mon 3/19/18**	**65**
78	Delivery of Materials	0.5 days	Thu 3/8/18	Thu 3/8/18	
79	Mark/Clear Path and Lay Out Piping	0.5 days	Thu 3/8/18	Thu 3/8/18	
80	Place Trench Machine	3 hrs	Fri 3/9/18	Fri 3/9/18	
81	*Dig Trench	2 days	Fri 3/9/18	Tue 3/13/18	79,80
82	**River Crossing 2**	**3 days**	**Thu 3/8/18**	**Mon 3/12/18**	13
83	Assemble Cable with Cross Pieces	1 day	Thu 3/8/18	Thu 3/8/18	
84	Suspend Cable	1 day	Fri 3/9/18	Fri 3/9/18	83
85	Tension Cable	1 day	Mon 3/12/18	Mon 3/12/18	84
86	Installation and Sealing	1 day	Wed 3/14/18	Wed 3/14/18	78,81,82
87	Check that Lines Hold Pressure	0.5 days	Mon 3/19/18	Mon 3/19/18	86
88	Bury and Compact	3 days	Thu 3/15/18	Mon 3/19/18	86
89	**Main Line Section 6**	**7 days**	**Tue 3/20/18**	**Wed 3/28/18**	**77**
90	Delivery of Materials	0.5 days	Tue 3/20/18	Tue 3/20/18	
91	Mark/Clear Path and Lay Out Piping	0.5 days	Tue 3/20/18	Tue 3/20/18	
92	Place Trench Machine	3 hrs	Wed 3/21/18	Wed 3/21/18	
93	*Dig Trench	2 days	Wed 3/21/18	Fri 3/23/18	91,92
94	Installation and Sealing	1 day	Fri 3/23/18	Sat 3/24/18	90,93
95	Check that Lines Hold Pressure	0.5 days	Wed 3/28/18	Wed 3/28/18	94
96	Bury and Compact	3 days	Mon 3/26/18	Wed 3/28/18	94
97	**Main Line Section 7**	**8 days**	**Thu 3/29/18**	**Mon 4/9/18**	**89**
98	Delivery of Materials	0.5 days	Thu 3/29/18	Thu 3/29/18	
99	Mark/Clear Path and Lay Out Piping	0.5 days	Thu 3/29/18	Thu 3/29/18	
100	Place Trench Machine	3 hrs	Fri 3/30/18	Fri 3/30/18	
101	*Dig Trench	2 days	Fri 3/30/18	Tue 4/3/18	99,100
102	Installation and Sealing	1 day	Tue 4/3/18	Wed 4/4/18	98,101
103	Check that Lines Hold Pressure	0.5 days	Mon 4/9/18	Mon 4/9/18	102
104	Bury and Compact	3 days	Wed 4/4/18	Mon 4/9/18	102
105	**Main Line Section 8**	**7 days**	**Tue 4/10/18**	**Wed 4/18/18**	**97**
106	Delivery of Materials	0.5 days	Tue 4/10/18	Tue 4/10/18	
107	Mark/Clear Path and Lay Out Piping	0.5 days	Tue 4/10/18	Tue 4/10/18	
108	Place Trench Machine	3 hrs	Wed 4/11/18	Wed 4/11/18	
109	*Dig Trench	2 days	Wed 4/11/18	Fri 4/13/18	107,108
110	Installation and Sealing	1 day	Fri 4/13/18	Sat 4/14/18	106,109
111	Connect to Pressure Break Tank	0.25 days	Fri 4/13/18	Fri 4/13/18	19
112	Check that Lines Hold Pressure	0.5 days	Wed 4/18/18	Wed 4/18/18	110
113	Bury and Compact	3 days	Mon 4/16/18	Wed 4/18/18	110
114	**Distribution Lines**	**5 days**	**Thu 4/19/18**	**Wed 4/25/18**	**105**

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8 10 12 14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15 17

Project: Scheduling2
Date: Tue 11/14/17

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

ID	Task Name	Duration	Start	Finish	Predecessors
115	Delivery of Materials	0.25 days	Thu 4/19/18	Thu 4/19/18	
116	Mark/Clear Path and Lay Out Piping	0.25 days	Thu 4/19/18	Thu 4/19/18	
117	Place Trench Machine	3 hrs	Thu 4/19/18	Thu 4/19/18	
118	*Dig Trench	1 day	Thu 4/19/18	Fri 4/20/18	116,117
119	Installation and Sealing	1 day	Fri 4/20/18	Mon 4/23/18	115,118
120	Check that Lines Hold Pressure	0.5 days	Mon 4/23/18	Mon 4/23/18	119
121	Bury and Compact	2 days	Mon 4/23/18	Wed 4/25/18	119
122	**Water Tap Stands**	**11.75 days**	**Tue 4/24/18**	**Wed 5/9/18**	**114**
123	Delivery of Materials	0.25 days	Tue 4/24/18	Tue 4/24/18	
124	Assemble Piping	2 hrs	Tue 4/24/18	Tue 4/24/18	123
125	Assemble Rebar Frames	0.5 days	Tue 4/24/18	Tue 4/24/18	123
126	Mix and Pour Concrete	1 day	Tue 4/24/18	Wed 4/25/18	124,125
127	Set Concrete	10 days	Wed 4/25/18	Wed 5/9/18	126
128	Place Erosion Control	2 hrs	Wed 5/9/18	Wed 5/9/18	

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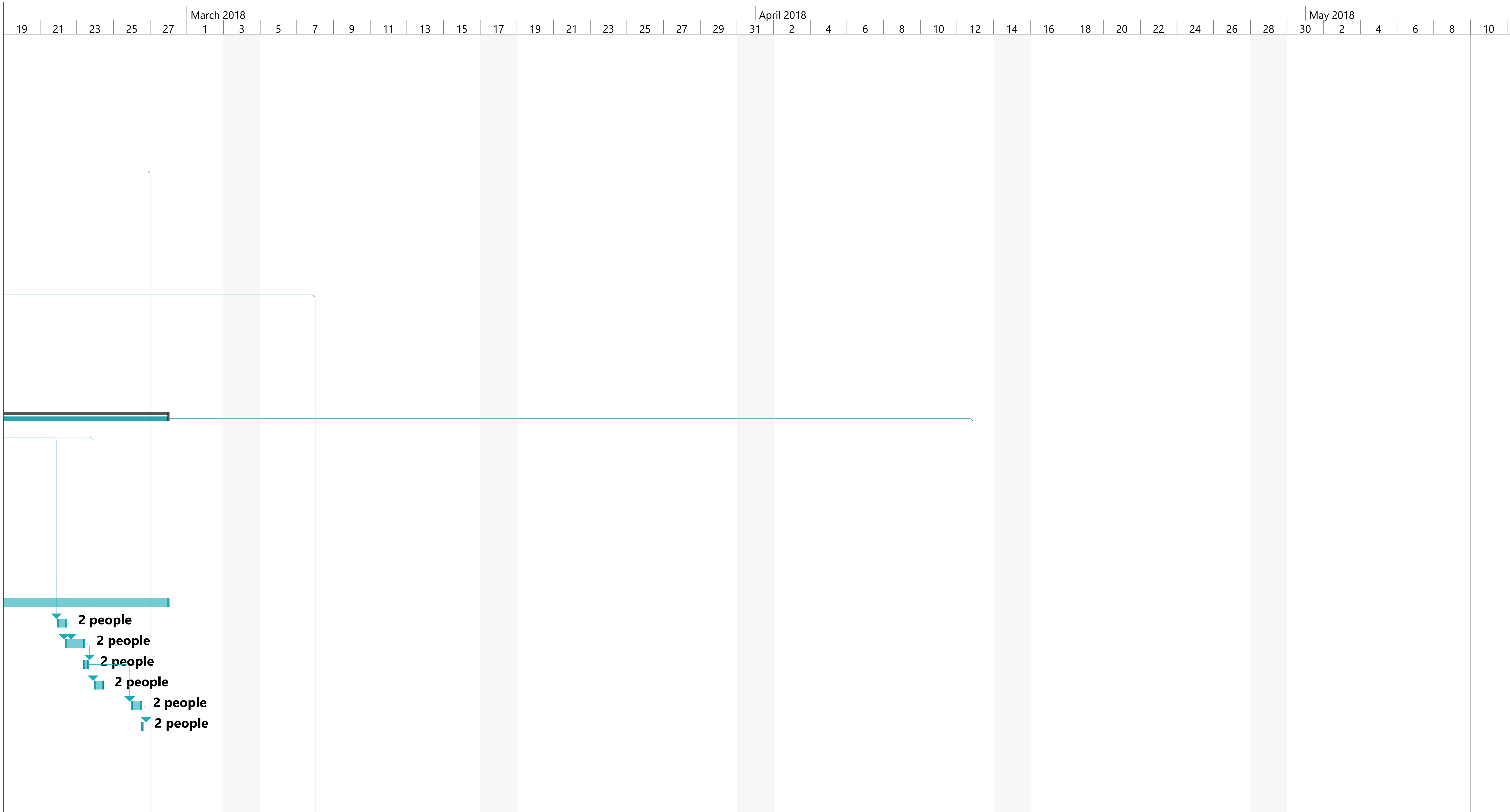
8 10 12 14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15 17

Project: Scheduling2
Date: Tue 11/14/17

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



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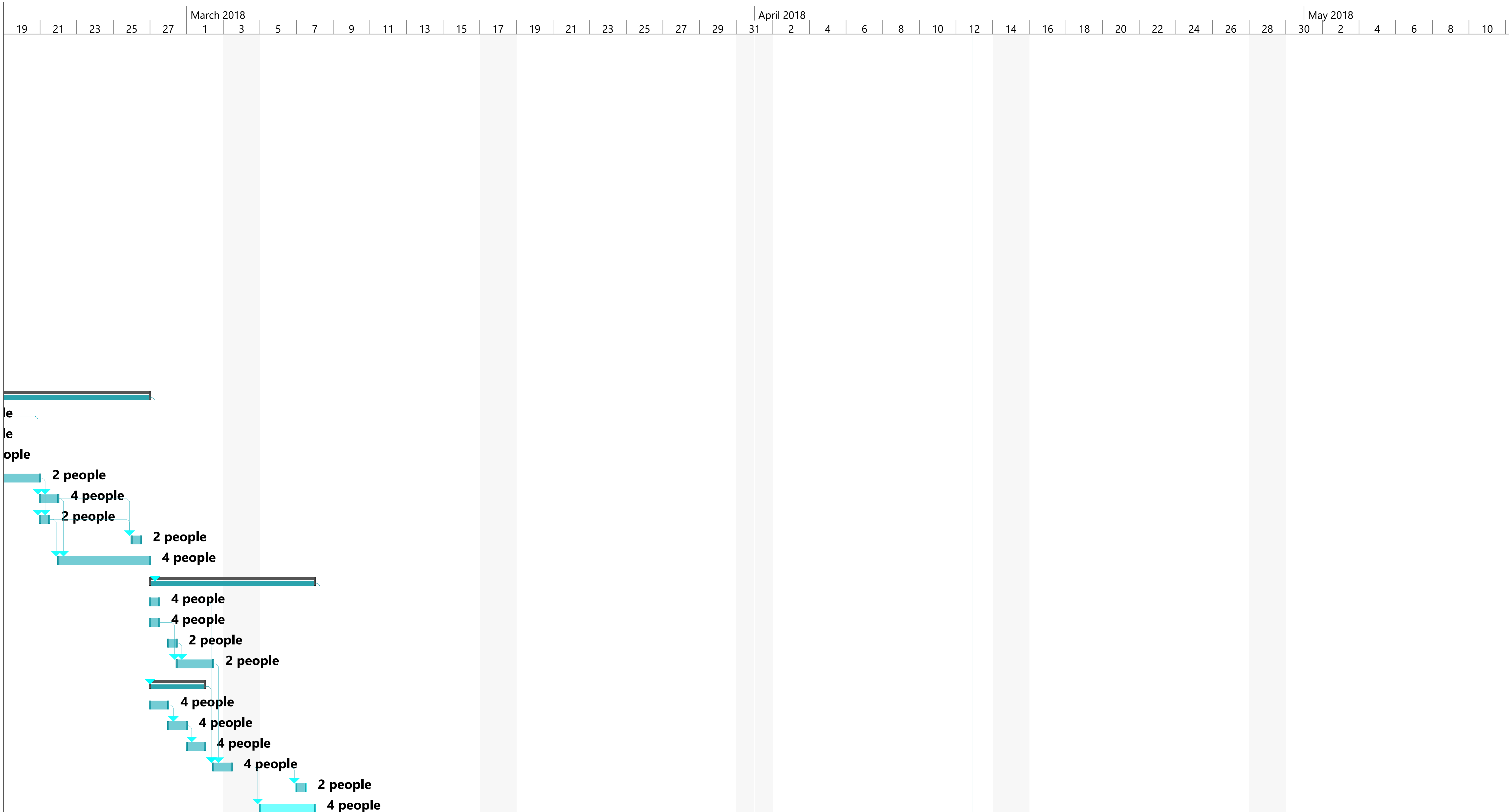
	Task	Project Summary	Manual Task	Start-only	Deadline
	Split	Inactive Task	Duration-only	Finish-only	Progress
	Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
	Summary	Inactive Summary	Manual Summary	External Milestone	



Project: Scheduling2
Date: Tue 11/14/17

Task
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Duration-only
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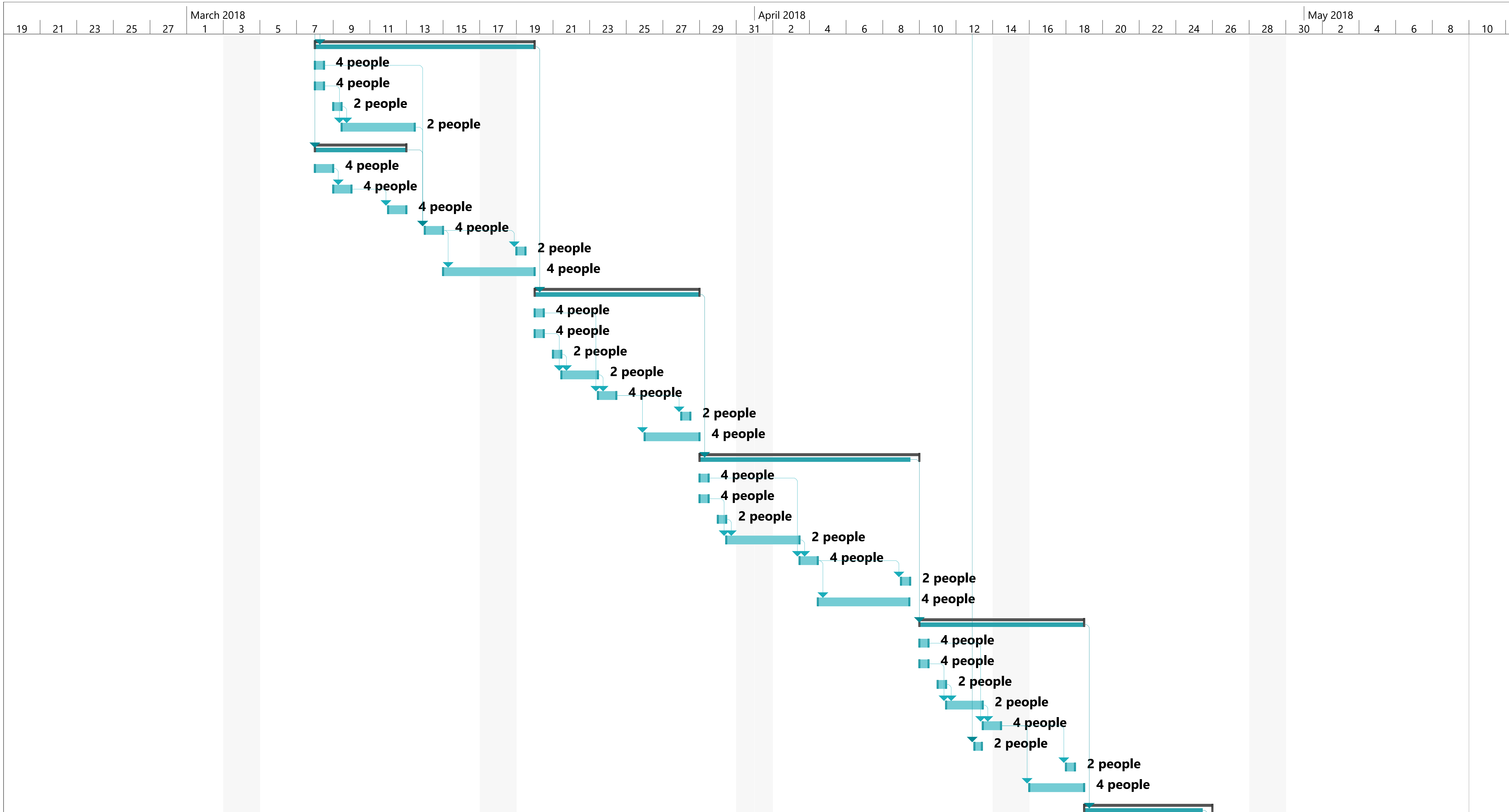
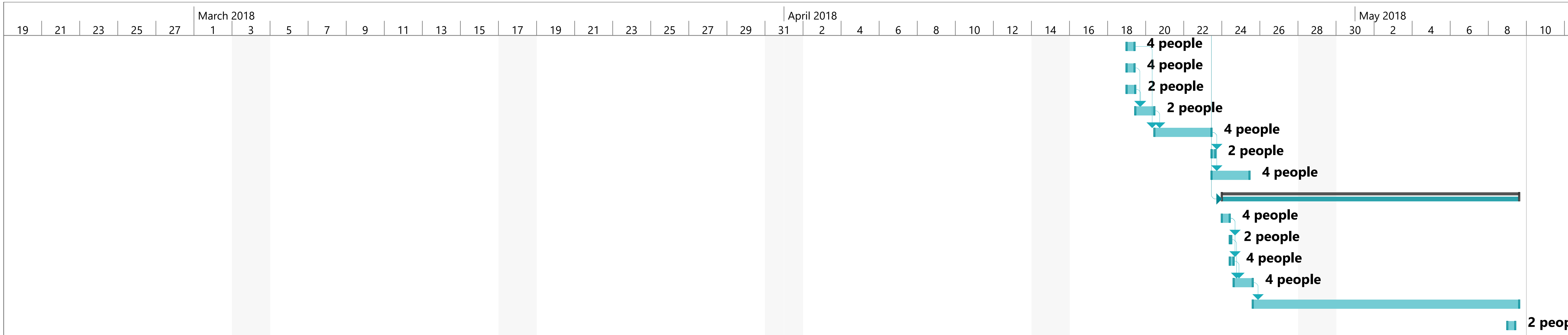
External Tasks
External Milestone
Deadline
Progress
Manual Progress



Project: Scheduling2
Date: Tue 11/14/17

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



Project: Scheduling2
Date: Tue 11/14/17

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

9.12 APPENDIX L: OPERATION AND MAINTENANCE MANUAL

Operation

Water usage should not be an issue with the high spring flow rates that have been recorded, however, taps should still be turned off when not in use to conserve water, especially with 215 people on the system. When filling buckets, they shall not be hung on the tap stand for filling, but instead placed below the tap on the ground in order to maintain longevity of the tap stand. It is permissible to build off of the five designed taps to include showers or other faucets as long as the owner of that tap stand pays for the additions. The system is designed to allow two taps open at once, but depending on flow rates at the tap, more or less may be able to be open with adequate pressure. A test may be performed once the system is up and running by opening taps in succession to see how many taps may be open at once. All open taps stands should receive ample water flow to ensure there is no negative pressure in the line, which could potentially suck in untreated water from outside the pipes if they are not sealed correctly.

Maintenance

The pressure break tank will need to be checked regularly to ensure that the lid is always covering the inside of the tank. The tank should be cleaned every six months so no debris or other materials are plugging the exit pipe. The tank should then be checked for leaks and for water overflowing out of the tank. If water is overflowing, the float valve must be adjusted or replaced. Before tank maintenance, the shut off valve directly upstream of the tank should be shut off. Once the tank is checked and assured to be in proper working order, place the lid back over the tank and turn the shut off valve so water may flow past it.

After the construction of the road and river anchor crossings, the soil around the anchors needs to be taken care of. It should be checked for erosion around the buried portion of the anchor. It is advised that vegetation is planted around the anchors to help against erosion. The cables and sleeves should be checked periodically for wear and fixed immediately if damage is noticed.

The clean out valve must be checked every month to ensure no sediment build up. The time in between checking the clean out valve can be increased to two months if there is very little or no sediment after a couple of checks. If a break occurs up line of the clean out valve, then the valve must be checked within one day of fixing the pipe break. Breaks in the line are unlikely but should be fixed immediately and pipe sealant must be used to seal any joints together.

Occasionally, the *tomas* and storage tank should be cleaned out. The *tomas* can be cleaned by removing the cap on the clean out pipe and allowing all of the water to drain from the spring box until only spring flow leaves the pipe. The tank can be cleaned by opening the cleanout valve and allowing substantial flow out of the tank until all sediment is removed from the bottom of the tank. Once the tank is empty, any remaining debris should be removed and the walls and floor should be scrubbed and rinsed with clean water before closing the cleanout valve and allowing water to build up again.