Aqueduct system for the community of Bajo Gavilan, Bocas del Toro, Panama

Submitted by:

Reasonable Engineering
Megan Farrish
Claira Hart
Kevin Madson
Erika Poli
William Tillmans

Submitted on:
December 12, 2014

Michigan Technological University
Department of Civil and Environmental Engineering
Houghton, MI, USA

Aqueduct system for the community of Bajo Gavilan, Bocas del Toro, Panama

Submitted to:
Dr. David Watkins, PE
Mr. Mike Drewyor, PE, PS
Ms. Christina Duell, PCV

Submitted by:
Reasonable Engineering
Megan Farrish
Claira Hart
Kevin Madson
Erika Poli
William Tillmans

Mission Statement

The mission of Reasonable Engineering is to create sensible and functional designs to improve the quality of life of those living in disadvantaged areas of the underdeveloped world. The highest priority of Reasonable Engineering is to provide access to improved basic resources to people that place a personal and communal responsibility on the construction and maintenance of the systems created.

Purpose

Reasonable Engineering is a group of five undergraduate engineering students from Michigan Technological University's International Senior Design (iDesign) program. In August 2014, these young innovators travelled to Bajo Gavilan, a small Ngäbe community in western Panama, to survey and collect data on a proposed aqueduct system. The proposed system will bring clean and affordable water to this community and increase their overall health and quality of life.

Acknowledgements

Reasonable Engineering is truly thankful to those that supported the team and this project in any way that they could, from preliminary trip planning to the completion of this report. Special thanks to:

Dr. David Watkins, Course Advisor
Mr. Mike Drewyor, Course Advisor
Ms. Kelli Whelan, Course Mentor
Ms. Christina Duell, PCV
Bajo Gavilan Water Committee
Mr. Guillermo, President
Mr. Siderio, Vice President
Mrs. China, Treasurer

Disclaimer

This report, titled "Aqueduct system for the community of Bajo Gavilan, Bocas del Toro, Panama," represents the efforts of Reasonable Engineering, an International Senior Design group of undergraduate students in the Civil and Environmental Engineering Department of Michigan Technological University. Although the students worked under the supervision and guidance of associated faculty members, the contents of this report **should not** be considered professional engineering.

Table of Contents

List of Figures

List of Tables

Executive Summary

Reasonable Engineering is a team of five undergraduate engineering students participating in the International Senior Design Program at Michigan Technological University (MTU). The team travelled to Bajo Gavilan, an indigenous rural community in western Panama, in August 2014 to address concerns associated with water availability and quality. The team was hosted by Christina Duell, a Peace Corps Volunteer who has lived on-site since January 2014.

The overall mission for this project was to improve the health and overall quality of life for community members by providing access to clean water in one section of the community. This mission was accomplished by performing a site assessment and then returning to MTU to model and design a sustainable gravity-fed water distribution system.

The proposed PVC aqueduct system originates from a natural mountain spring source and will travel approximately 1.77 miles to the northwest section of the community, ending at a two-room schoolhouse. The site assessment was conducted by Reasonable Engineering and Christina Duell and involved collecting topographic, flow rate, and water quality data for the proposed aqueduct. The objectives of this project were: (1) to evaluate the feasibility of the spring source and proposed aqueduct route and (2) to model and design the proposed aqueduct system.

Reasonable Engineering evaluated the hydraulic feasibility and modeled the behavior of the aqueduct using two programs, EPANET and Neatwork. EPANET was used to determine the diameter of pipe, locations of break pressure tanks, the location of the storage tank, as well as to simulate pressure at nodes and flows through pipes to predict system performance. Neatwork was used to optimize the diameter of the PVC pipe downstream of the storage tank, and simulate system performance.

The design consists of a low-profile spring box, an aqueduct pipeline, one air release valve, stream crossing methods, five break pressure tanks, one storage tank, one in-line chlorinator, and nine tapstands. Recommendations for the system include: (1) burying the aqueduct, (2) installing an in-line chlorinator, break pressure tank, and storage tank at one location, and (3) testing for chlorine concentration to determine the optimum dosage of chlorine for the system. The total cost for this design is approximately $9,300. Construction of the system is expected to take approximately three months.

The collected data, data analysis, and design recommendations provided in this report will provide essential information that can be considered in the request for funding to install this proposed system. This report and attached appendices can be consulted for recommendations and guidance on how to design, install, operate, and maintain the aqueduct system.

1.0 Introduction

Reasonable Engineering is a team of five undergraduate students of various disciplines, including one civil engineer, one mechanical engineer, and three environmental engineers. The team participated in the International Senior Design (iDesign) program at MTU. In August 2014, the team travelled to Bajo Gavilan, a small indigenous community in western Panama. The team was hosted by Christina Duell, a Peace Corps Volunteer (PCV) that has lived on-site since January 2014. Duell has identified specific concerns for access to clean drinking water in one section of the community. This section currently collects drinking water from streams, which are prone to contamination from runoff. A more in-depth analysis of the community and the problem addressed by this project is provided in Section 2.0.

Community members identified an existing mountain spring as a potential source for an aqueduct system prior to the team's arrival. Reasonable Engineering and Christina Duell evaluated the feasibility of an aqueduct project by hiking to the source to measure flow rate and test the quality of water. Community members led the team through the jungle to establish and survey a proposed route for the aqueduct, from the source to the school located in the northwestern section of the community. The methods and results of data collection are included in Section 3.0.

The collected data was then analyzed at MTU. The system was modeled in EPANET [1] and Neatwork [2], which were used to determine the location, quantities, and specifications of system components such as pipe diameters, and storage and break pressure tanks. A discussion on system modeling is provided in Section 4.0. Air block analysis was also performed to determine the locations of any necessary air release valves.

The final design includes recommendations on system components, including a low-profile spring box, one air release valve, five break pressure tanks, a buried aqueduct line, one in-line chlorinator, one storage tank, and nine tapstands. These recommendations are provided in Section 5.0. Finally, a cost estimate and construction schedule are provided in Section 6.0.

2.0 Background

2.1 Site Description

Bajo Gavilan (9.271938N, -82.500984W) is a community located in the Changuinola District in the Bocas del Toro Province of Panama. The community lies along the Changuinola River and is about 15 miles southwest of Almirante, the nearest city (Population: 8,816 [3]). The location of the community within Panama is shown in Figure 1. A more regional perspective of the community's location is provided in Figure 2.

Figure 1. Map of Panama that shows the location of Bajo Gavilan.

Figure 2. Map of the area surrounding Almirante, including Bajo Gavilan and the Changuinola Dam.

The community is geographically divided into three different sections. Section 1, located about 0.5 miles northwest of sections 2 and 3, includes eight homes and the community schoolhouse. Figure 3 shows each section and the locations of occupied houses and the schoolhouse in the community.

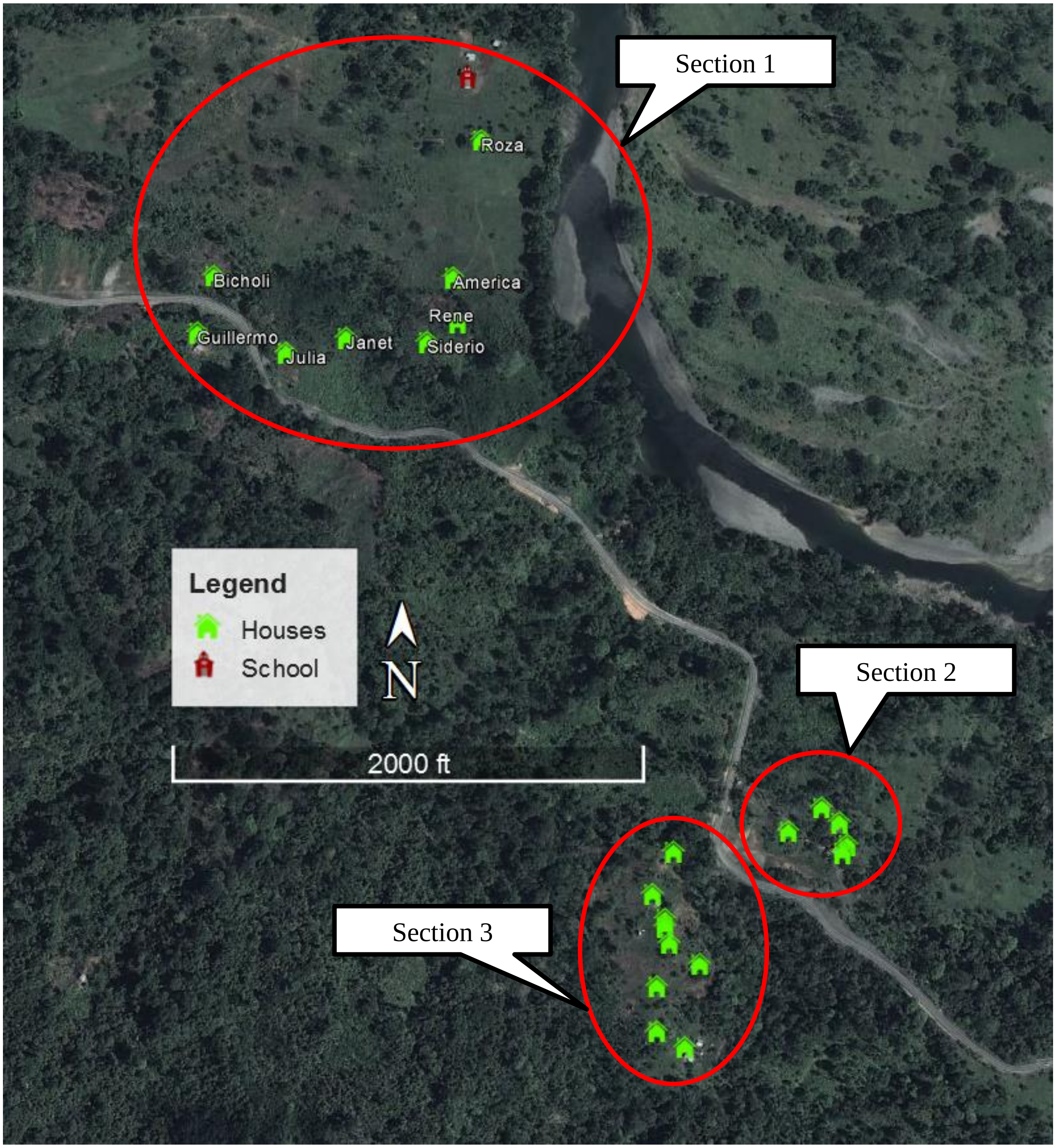


Figure 3. Map of the Bajo Gavilan community, with homeowner names in section 1.

The community is located about 2.25 miles north and downstream of the Changuinola Dam (Figure 2), one of the largest roller-compacted concrete-arch gravity dams in the world. The dam is owned and operated by Applied Energy Services-Changuinola (AES-Changuinola), a subsidiary of AES (a United States electricity generation and distribution corporation). The construction of the dam began in 2007, and has been in operation since 2010. Construction of the dam also resulted in a paved two-lane road that passes through the community.

Land cover in the area is predominantly dense rainforest, with some pasture and farmlands along the Changuinola River. The community sits in the Changuinola River valley, with mountains rising over 1,000 ft above mean sea level (AMSL) to the north and south of the community.

According to the Köppen climate classification system, Bajo Gavilan features a tropical rainforest climate. The area averages 136.1 inches of annual rainfall and daily high temperatures hover around 88°F throughout the year. Climate data for Bocas del Toro, a city about 20 miles west of Bajo Gavilan, is provided in Table 1.

Table 1. Climate data for Bocas del Toro, Panama (1971-2000) [4].

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average High (°F)	87.4	87.3	87.8	88.5	89.4	89.6	88.7	89.2	89.4	89.1	88.9	87.8	88.59
Average Low (°F)	68.7	68.4	68.9	70.5	72	72	71.1	71.2	71.6	71.6	71.2	69.1	70.53
Precip. (in.)	4.9	10.5	3.3	14.5	7.0	10.1	16.5	17.4	12.3	6.0	11.5	22.2	136.1
Avg. Precip. days	16.6	14.6	14.8	15.2	16.7	17.9	20.9	18.4	15.8	16.4	17.0	20.0	204.3

2.2 Community Background

Bajo Gavilan is a small Ngäbe community. Historically, the Ngäbe people lived in small family groups in flat and coastal regions of the country. However, Ngäbe communities were often displaced by other groups of people including Spanish conquistadors, Latino cattle ranchers, and large banana plantation corporations. The majority of Ngäbe people fled to the less desirable and mountainous areas of the country, where the Panamanian government granted them semi-autonomy by establishing the Ngäbe-Buglé comarca in 1997 [5].

The first inhabitants of what is now considered Bajo Gavilan likely settled in the remote Changuinola River valley about 40 years ago. Most residents, however, did not arrive until the road to the Changuinola Dam was constructed. There are currently about 124 residents and 16 households in Bajo Gavilan [6].

Although Bajo Gavilan lies downstream of the dam and is unaffected by its operation, AES-Changuinola constructed a school and an aqueduct system for sections 2 and 3 of the community as partial compensation to the local Ngäbe people. The construction of the school in 2006 serves as the official formation of the community.

Christina Duell, an environmental health PCV, has been living in Bajo Gavilan since January 2014. Her work mainly focuses on water availability and quality concerns in the community. She successfully requested funding from WaterLines, an American non-governmental organization (NGO), for the rehabilitation and extension of the existing aqueduct built by AES-Changuinola. She is also involved with water quality education initiatives, creating the first water committee in the community and teaching residents about the relationship between clean water and human health.

The funding for this proposed aqueduct is also expected to be provided by WaterLines. The maximum monetary award per grant from this organization is $8,000, which serves as the ideal cost ceiling for this project. If the cost of constructing the system exceeds this cost, the project will need to be split up into smaller pieces.

2.2.1 Community Profile and Demographics

The residents of Bajo Gavilan are subsistence farmers, growing various crops including bananas, plantains, cacao, and a variety of root vegetables in addition to raising livestock such as chickens, cattle, and pigs. There is no electricity in the community aside from a few battery and solar-powered devices. Demographic data collected by Duell is provided in Figure 4.

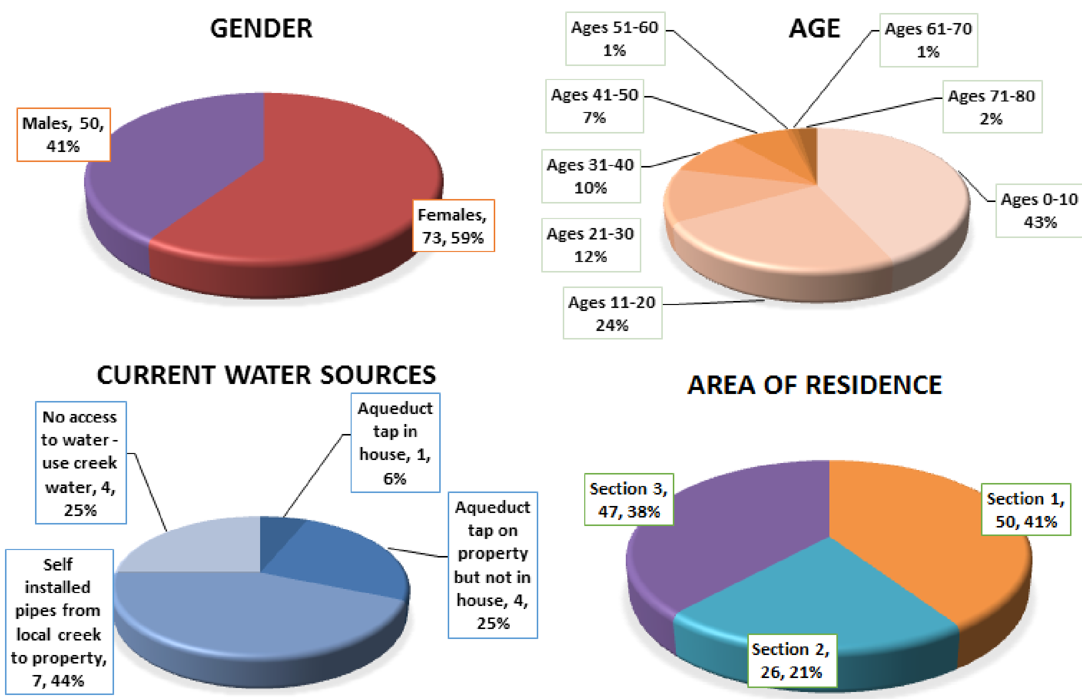


Figure 4. Community characteristics and demographic data for Bajo Gavilan [6].

2.2.2 Community Organization

Bajo Gavilan does not have an appointed leader, but various community members serve in leadership roles in groups within the community. *Padres de Familia*, which functions as a Parent-Teacher Association (PTA), has a large amount of influence due to its relationship to the school, the central feature of the community.

The most relevant organization to this project is the water committee that was created by Duell, which consists of an executive board with a president, vice president, and treasurer. The committee has created a water access contract and has collectively decided that each household should individually provide labor for aqueduct construction, or else be charged a large connection fee. The water committee and its president, Guillermo, are expected to be the main determinants for the success of this project.

2.3 Problem Description

Sections 2 and 3 of the community currently receive clean drinking water from an aqueduct built by AES-Changuinola in 2011. Section 1, the most populous section of the community, does not have access to this aqueduct. With no water distribution system available in section 1, residents collect water from pipes placed in nearby streams and creeks that are prone to contamination from runoff. Figure 5 illustrates the pipe-placement technique typically used by residents in this section.


a) b)

Figure 5. Stream water collection methods (a and b) used by residents in section 1 [6].

Extending the existing aqueduct from sections 2 and 3 in order to meet the needs of section 1 is not feasible according to water supply and demand calculations provided by Duell. A different spring source must be identified and a new aqueduct system designed and constructed in order to deliver water to the homes and the school in section 1 of the community.

2.4 Project Objectives

Prior to Reasonable Engineering's arrival, the water committee identified a new spring source in the highlands south of Bajo Gavilan that could potentially supply sufficient water to meet the needs for section 1 of the community. The objectives of this project were: (1) to evaluate the feasibility of the spring source and proposed aqueduct route, and (2) to model and design a sustainable aqueduct system.

The completion of these objectives will provide Duell with more information for requesting a grant from WaterLines. The information and recommendations provided in this document can also be considered during the installation, operation, and maintenance of the aqueduct.

3.0 Data Collection

Reasonable Engineering collected data on the spring source and the proposed aqueduct route to determine the feasibility of the system. This included flow rate measurements and water quality tests at the source and a topographic survey of the proposed aqueduct route. The following section will briefly describe the methods and results of these measurements. A more detailed discussion on the methods used in the site assessment is provided in Appendix A.

3.1 Water Supply

The proposed water source is a mountain spring located about one mile southwest of section 1. Figure 6 shows the spring source.

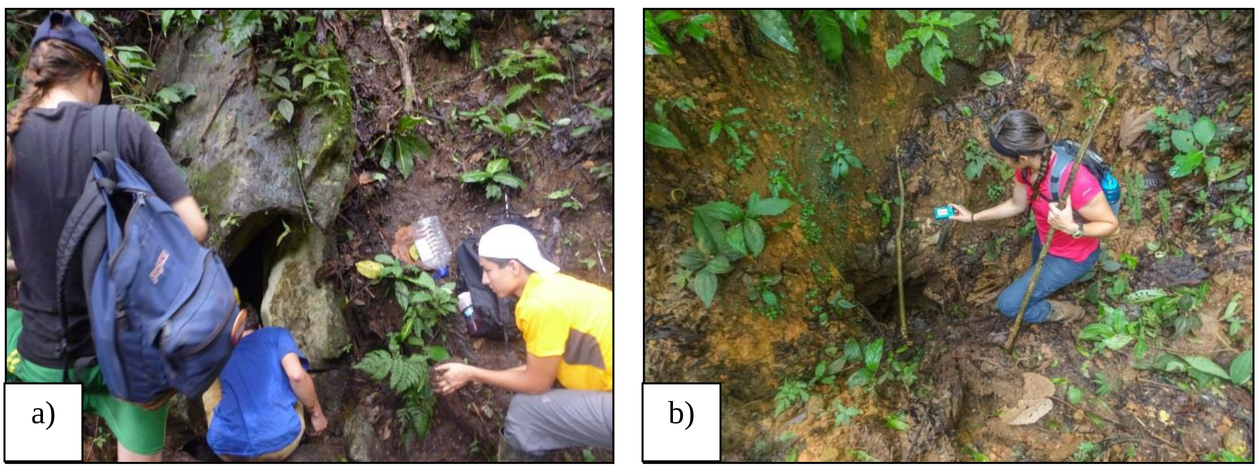


Figure 6. Photographs of the (a) side and (b) top of the spring source.

3.1.1 Flow rate measurement

Flow rate was measured using the volume-time method. A weir was built at the source in an attempt to funnel the water exiting the cave into a container with a known volume, shown in Figure 7 on page 8.

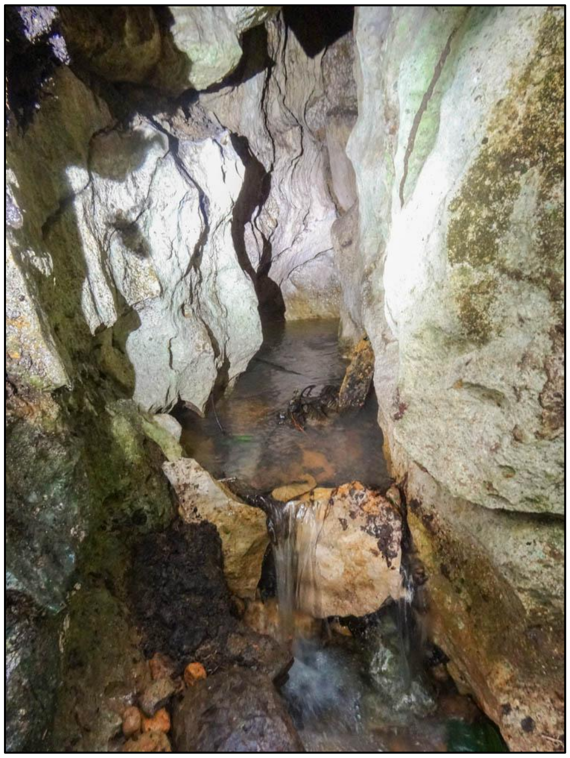


Figure 7. Photograph of the weir that was constructed to measure the flow rate of spring source.

Table 2 shows the average flow rate measurements for the spring source. Raw data for these measurements are available in Appendix B, which also includes the flow rate data for the existing aqueduct. One source of error during flow rate measurement was the construction of the weir. Water was observed flowing through and around the weir, so all measured flow rates are lower than the actual flow rate. This is still acceptable, as values remain conservative for the flow rate supplied by the spring.

Table 2. Average flowrates measured at spring source.

Location	Date	Average Flow Rate (gpm)
Spring source for proposed aqueduct	8/15/2014	7.9
	8/19/2014	6.9

The measured flow rates are the only quantitative data available for this spring source. According to Duell's qualitative observations of the spring during the dry season, the flow rate remains consistent in both the wet and dry seasons. All calculations included in this report, unless otherwise noted, use 6.9 gpm as the water supply flow rate.

3.1.2 Water quality tests

The water quality of the proposed source and current stream sources used in section 1 were tested using 3M® Petrifilm *E. Coli*/Coliform Count Plates. Samples were incubated using an individual's body heat for 24 hours before counts of *E. Coli* and non-*E. Coli* coliforms were performed. Average results for the water quality tests at the proposed spring source and stream sources used by two residents (America and Julia) in section 1 are provided in Figure 8. Raw data for these tests and others locations are provided in Appendix C.

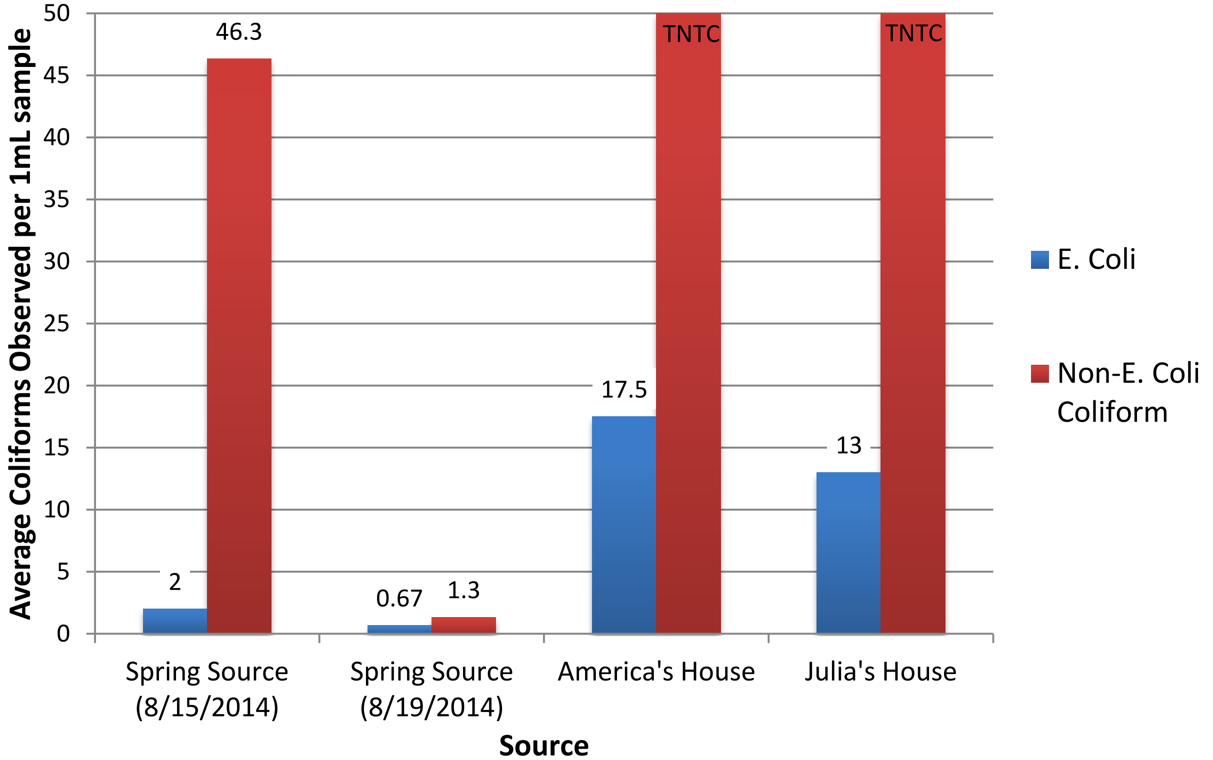


Figure 8. Average water quality test results. TNTC is too numerous to count.

The first set of water quality tests at the spring source were performed on 8/15/2014 and yielded a high amount of non-*E. coli* coliforms. This result could be attributed to weir construction, which disturbed the area and suspended sediments near the cave opening (Figure 6a on page 7). A second test was performed on 8/19/2014, prior to any disturbances, and results showed significantly fewer coliforms.

These results are compared to the quality of the water used by America and Julia, residents in section 1 of the community, who currently utilize stream sources. Both showed significantly higher coliform levels than the spring source. According to United States drinking water regulations, the presence of one *E. coli* colony in water makes it unsuitable for consumption [7]. Figure 8 shows a significant presence of *E. coli* coliforms for both America's and Julia's water sources, which is indicative of unhealthy drinking water.

3.2 Aqueduct Route

The proposed aqueduct route begins at the spring source and ends at the school in section 1 of the community. Members of the water committee, with guidance from Duell, Dr. David Watkins, and Reasonable Engineering, selected the route by considering multiple factors, including: (1) shortest distance to community, (2) avoiding dense jungle, and (3) avoiding steep hills and declines which could compromise the hydraulic feasibility of the system.

3.2.1 Survey Methods

A survey of the proposed aqueduct route was performed to determine whether the system was hydraulically feasible. The team used a variety of surveying tools, including a Garmin eTrex 10 GPS unit, a Nikon Forestry Pro Laser Rangefinder, a CST Abney Level, and a 100-foot open reel measuring tape.

The topography between two waypoints was determined with the rangefinder and a green folder functioning as a target. The horizontal distance, vertical distance, slope or actual distance, and the angle between points were recorded from the rangefinder. Foresight and backsight readings were performed and confirmed for each waypoint to ensure accuracy, and results were later averaged to define the elevation profile of the route. When waypoints were closer than the operating range of the rangefinder, the measuring tape was used to determine the actual or slope distance between waypoints and an Abney level was used to measure the angle between points.

The latitude, longitude, and elevation of each waypoint were recorded using the GPS. Elevation data was not used in analysis for this project, with the exception of approximating the elevation at the spring source. Map processing was performed in ArcGIS® and converted to .kml (Google Earth®) files for viewing and printing.

3.2.2 Survey Results

A total of 118 waypoints were created to survey the proposed aqueduct route. A summary of survey data, including GPS coordinates of waypoints, can be found in Appendix D. Figure 9 on page 11 shows the location of waypoints and the aqueduct route in relation to the community. Figure 10 on page 12 shows a more detailed view of the proposed aqueduct route and location of waypoints in section 1 of the community. The proposed route extends westward from Guillermo's house before turning north to utilize an existing culvert that will allow the aqueduct to cross the road and reach the rest of section 1.

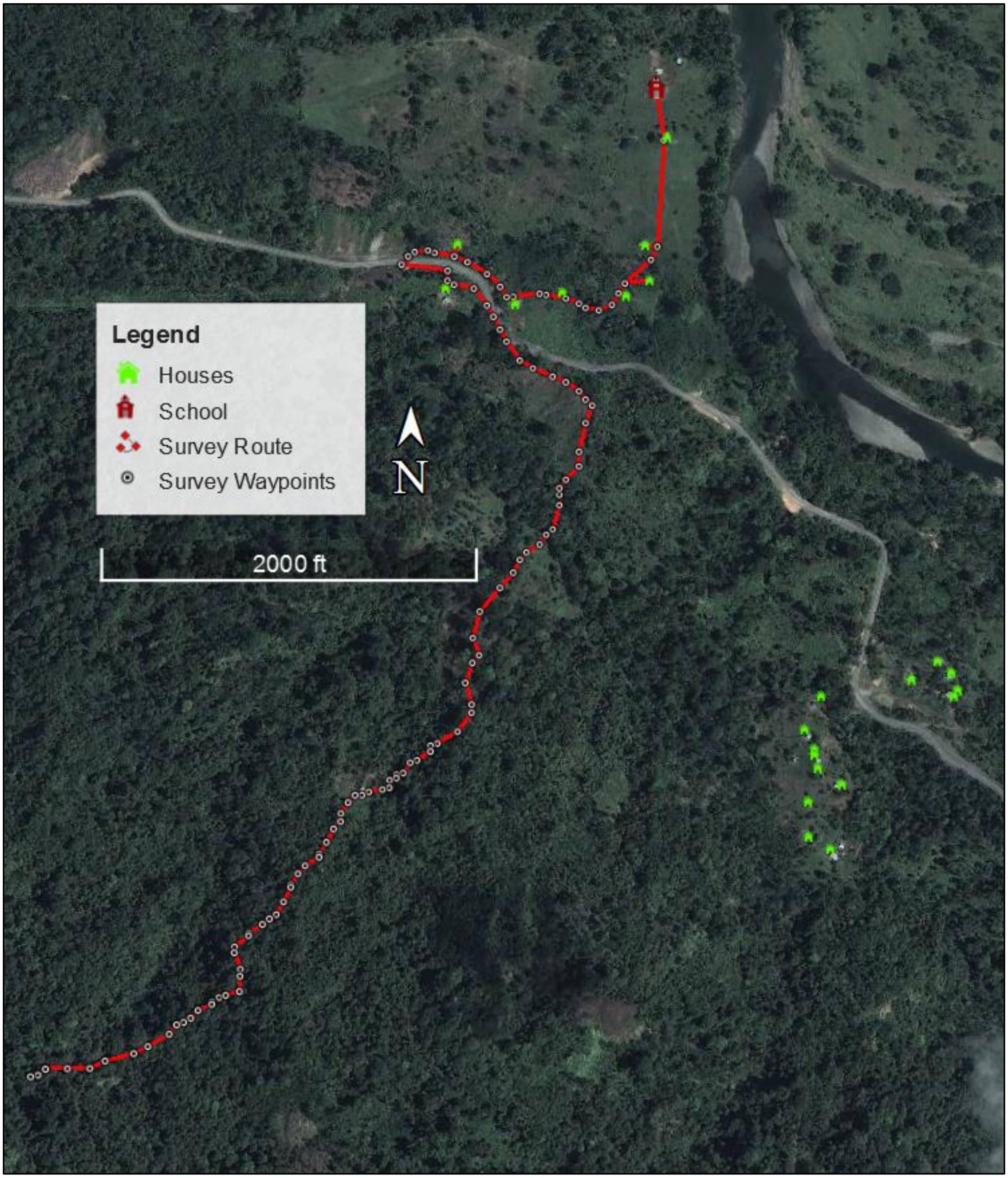


Figure 9. Map of the proposed aqueduct route with waypoints.

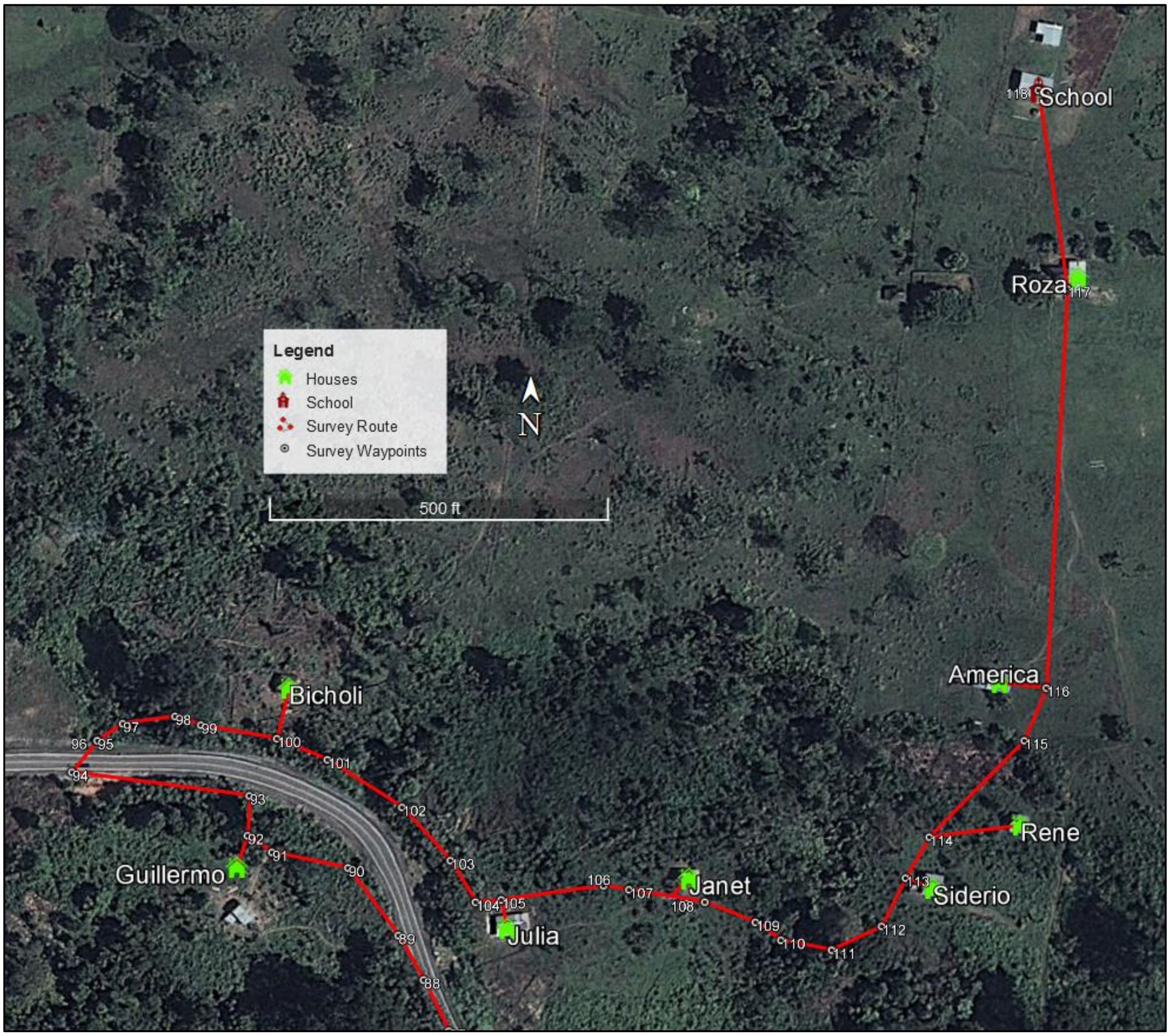


Figure 10. Map of proposed aqueduct route through section 1 of the community.

Figure 11 on page 13 shows the elevation profile for the survey route from the spring source to the school. The elevation values are relative to the GPS-measured elevation at the source, 894 feet AMSL. The last point in the route and proposed aqueduct, the school, has an elevation of about 305 feet. This equates to a net decrease in elevation of 589 feet along the route. The total length of the route is about 1.77 miles, or 1.72 miles in horizontal distance from the source.

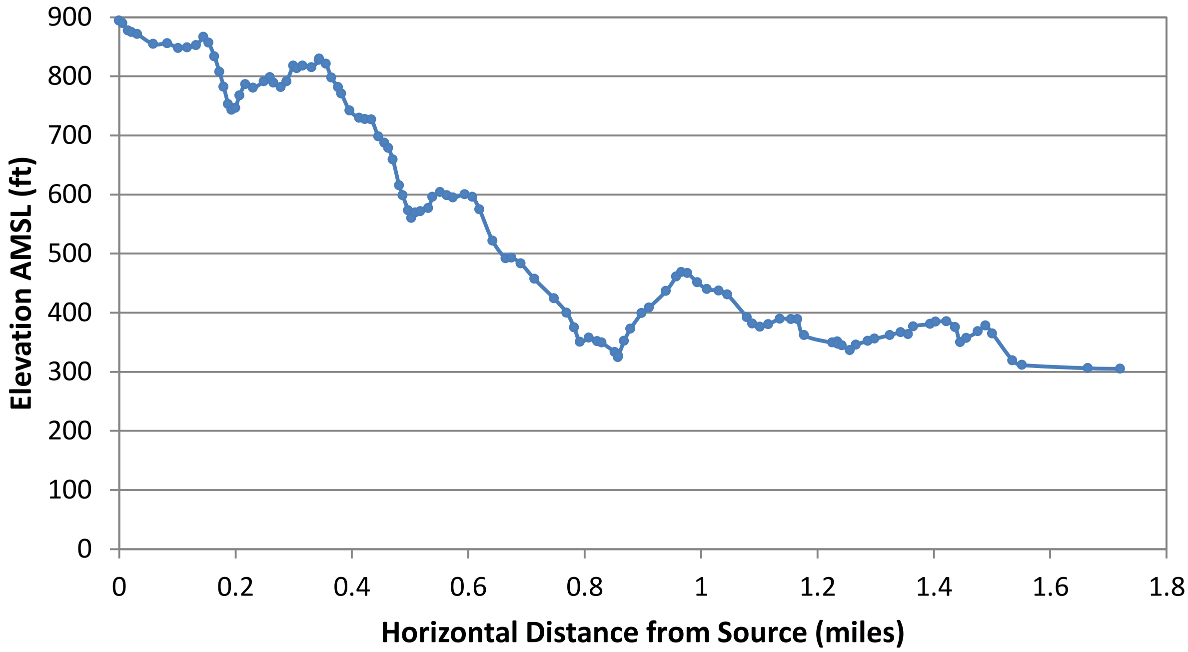


Figure 11. Elevation profile of the proposed aqueduct path. The blue dots represent locations of waypoints.

3.3 Water Demand

Duell conducted a survey of each house in Bajo Gavilan to determine the water demand of the community. Duell asked each household how much water they use each day (or would like to use, if they do not currently have access to water) in terms of five gallon buckets [8]. Residents reported an average use of roughly 35 gallons per person per day [8]. Water demand for the school is assumed to be 2.5 gallons per schoolchild per day, based on World Health Organization (WHO) ideal target uses [8].

There are currently 60 residents in section 1 of the community, and an estimated 33 schoolchildren in the three sections combined [8]. Using these numbers and the growth rate for Panama, the water demand for section 1 of Bajo Gavilan in 20 years is 2.05 gpm. This demand is well below the available flow rate of 6.9 gpm measured at the spring source, which would allow the spring to continue to supply the community with adequate water as the population increases in the future.

4.0 System Modeling

The proposed aqueduct system was modeled using two water distribution system software programs, EPANET [1] and Neatwork [2]. Both are available as a free download. EPANET is well-recognized among water distribution professionals. Neatwork is less recognized, and is mainly used by volunteers in the Peace Corps because it simplifies and optimizes rural gravity-fed water distribution systems.

The major system components between the spring source and storage tank are strictly based on the EPANET model, as Neatwork is not applicable for this section of the system. EPANET and Neatwork were used in tandem to optimize and simulate conditions in the portion of the system downstream of the storage tank.

4.1 EPANET

EPANET was used to model the proposed aqueduct, from the spring source to the community and school. English units were used for all inputs and analysis, and the Hazen-Williams equation was selected for EPANET to use in energy loss calculations. The model was constructed using information gathered in the topographical survey.

4.1.1 Methods

Latitude, longitude, and elevation data for each waypoint in the survey was inputted into EPANET as a junction in the water system. The actual distance between waypoints defined the length of pipe that connects junctions in the model. A reservoir was used to model the spring source at the first waypoint, and a flow control valve set at 6.9 gpm was included immediately downstream to ensure the flow out of the reservoir appropriately represented the flow rate of the spring source.

A tank was added at waypoint 80, the location of the storage tank that was initially selected during this site assessment. Tapstands for all eight houses and the school were also included. The calculated future demand for the community was divided amongst the houses and the school according the number of people in each building. These demands were inputted into EPANET to model the demands of individual households in the community. A demand pattern was defined to predict the use of water throughout the day at each home, and a separate demand pattern was used to predict water use at the school. These demand patterns, along with all other model inputs, are shown in Appendix E-1.

After initial analysis, the pipes upstream of the storage tank were adjusted to a diameter of 1.5” to make them appropriate for the required flow, and analysis of the complete system was used to determine the locations of break pressure tanks.

Pipe sizes downstream of the storage tank were optimized using Neatwork. These pipe sizes were inputted into the EPANET model, and analysis was run to determine if there would be any issues with these pipe sizes.

4.1.2 Results

Results obtained are specific to system specifications of: (1) a pipe diameter of 1.5” between the spring and the storage tank and (2) a storage tank at waypoint 80. Break pressure tanks were determined to be necessary at waypoints 32, 39, 56, and 60. Pipe diameters varied downstream of the storage tank and were determined from Neatwork.

The primary outputs obtained from the EPANET model are: (1) pressure at nodes and (2) flows through pipe segments. A complete set of outputs is provided in Appendix E-2. Figure 12 shows the system map with pressure and flow outputs from EPANET at two different times (12:00 AM and 12:00 PM) throughout the 24-hour analysis period.

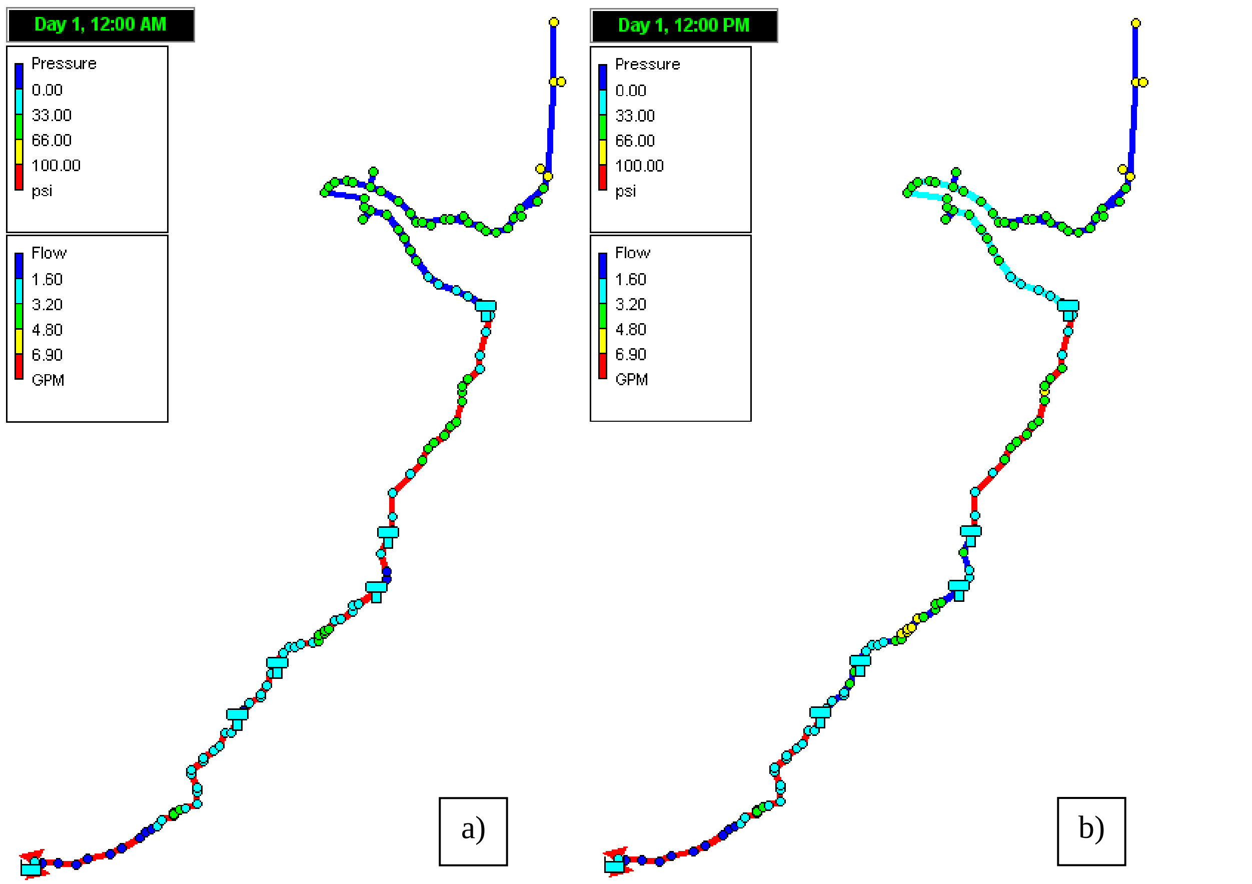


Figure 12. Pressure at nodes and flow in pipes at (a) 12:00AM and (b) 12:00PM during the 24-hour analysis period.

Figure 13 on page 16 shows the water elevation in the storage tank. The tank is defined as empty at the start of the simulation, and is shown to quickly fill and stay almost completely full throughout the day. This demonstrates that the spring source will have adequate flow to meet the needs of the community for the foreseeable future.

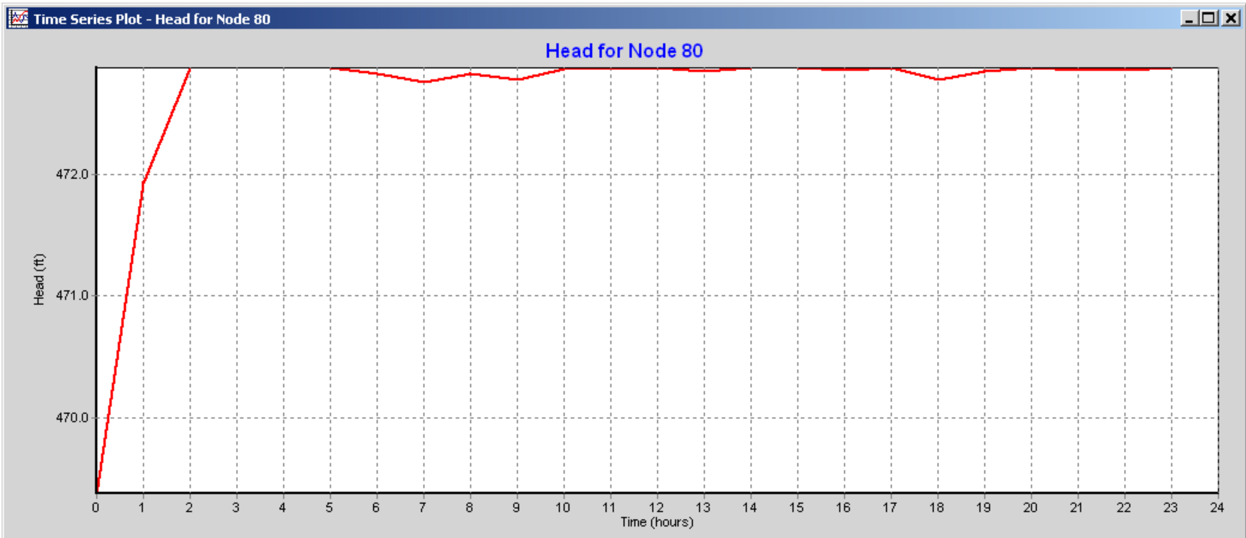


Figure 13. Water elevation in storage tank over the 24-hour analyis period.

The EPANET model showed no cause for concern in the portion of the aqueduct downstream of the storage tank, and indicated the pipe sizes chosen by Neatwork would be sufficient.

4.1.3 Discussion

The final model predicts negative pressures in a few locations along the system due to the assumptions inherent in EPANET's analysis. The most common occurrence of these negative pressures is within the first few junctions downstream of break pressure tanks. These negative pressures can be interpreted as an indication that the pipe will not be flowing full because these sections all have steep downhill slopes. This is not a concern for this system, as these instances do not affect the ability of the water to continue to flow down the aqueduct.

One instance of negative pressure, however, occurred immediately downstream of the reservoir and flow control valve used to model the spring source, between waypoint 2 and waypoint 12. After referencing the elevation profile, this portion of the system did not raise any concerns about the ability of the water to flow through this section. Calculations were performed to confirm that the available head is sufficient to push the water over the first peak at waypoint 11. These calculations can be found in Appendix E-3.

There are also time periods that show a flow of 0 gpm through portions of the aqueduct upstream of the storage tank. The system is gravity-fed and the spring source does not stop flowing, so there is no reason for this zero-flow condition to occur. This is interpreted as another instance where the pipe would not flow full, and is considered a flaw in the model.

4.1.4 Limitations

Despite its widespread use, EPANET's analysis is not without limitations. Though EPANET's modeling assumes the system is pressurized, with all pipes flowing full, this will not always be the case in a system like the one proposed, and results must be interpreted accordingly. In addition, the program does not allow for simple modeling of surface water sources, such as the spring that will be utilized for this system. For this reason, it was necessary to adapt the model to use a reservoir and flow control valve in order to model the spring source.

This program also does not have a built-in option to model break pressure tanks. These tanks are modeled as standard tanks, sized according to the proposed design. Finally, EPANET models the system in equilibrium. This restricts the user's ability to predict behavior immediately after construction, or after any changes in the system (including opening and closing of taps), and requires educated assumptions on how the system will respond to any abrupt changes.

4.2 Neatwork

Neatwork was used to optimize and simulate the system downstream of the storage tank, located at waypoint 80. The program operates in two modules: topography and design. The metric system is used for all inputs, analysis, and outputs. The water distribution system is simplified into nodes and arcs in the topography module. A node is a location where the main line branches to a home, and an arc is the length between nodes (referred to as pipes in EPANET).

4.2.1 Methods

The elevations of the nodes relative to the storage tank and arc lengths between nodes were inputted into the program. Figure 14 shows the tree view or conceptual model of the system from the topography file.

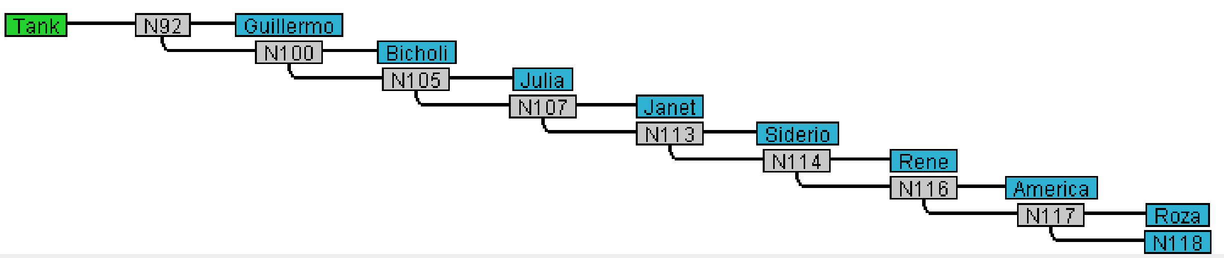


Figure 14. Tree view of the proposed aqueduct system in Neatwork. Blue boxes represent faucets and gray boxes represent nodes which are also survey waypoint numbers.

Next, the topography file was exported to the design module. The design includes various inputs including available hardware (e.g., locally available pipe diameters and diameters of orifices in flow reducers), model parameters (e.g., fraction of open faucets, service quality, target flow rate, water temperature, pipe lengths, orifice coefficient, and faucet coefficient), pipe diameter constraints for any arc lengths, and load factors. Refer to the Neatwork user's guide ([2] and available on CD) for a thorough discussion on the definition and assumptions involved with these inputs. Appendix F-1 provides all inputs (topography and design) used in Neatwork. The topography (*BajoGavilan.tpo*) and design (*BajoGavilan.dsg*) files are also available on CD.

Outputs from the Neatwork model include: (1) an optimization of pipe and orifice diameters and (2) a simulation environment. The simulation environment accepts inputs such as number of simulations, fraction of open faucets, critical flows (high and low), target flow, orifices in use (ideal or commercial), and type of simulation (Monte-Carlo sampling, individual faucets, or user-defined). Refer to the user's guide [2] for a thorough discussion of the definitions and assumptions involved with these inputs. Simulation outputs include: (1) flows at faucets, (2) percentile flows at faucets, (3) speed in pipes, and (4) pressure at nodes.

The minimum, maximum, and average flow rates at each tap are provided along with the variability of flow (standard deviation divided by mean) in flows at faucets. These values are provided based on the number of simulations. Flows at faucets also predicts the number of failures, or the number of no-flow occurrences at a tap. The percentile at faucets output provides more detailed information on the distribution of flow rates predicted in the simulation.

4.2.2 Results

Multiple designs were created and simulated in Neatwork to optimize the pipe and orifice diameters in the system. The final optimized pipe diameters are shown in Table 3. All other outputs are provided in Appendix F-2.

Table 3. Optimized pipe diameters for the proposed aqueduct system.

Segments/Arcs	PVC Pipe
Waypoint 80 (storage tank) to 92	1.5” SDR 26*
Waypoint 92 to 116	1” SDR 26
Waypoint 116 to 118 (school)	0.5” SDR 13.5
Main line to all tapstands	0.5” SDR 13.5

**The pipe diameter between Waypoint 80 and 92 was determined from EPANET.*

Simulation results of this design revealed that the average flow rate for all tapstands is 3.17 gpm. The smallest average flow rate was experienced at Rene’s house, with a flowrate of 3.04 gpm, and the largest average flow rate was experienced at Roza’s house, with a flow rate of 3.48 gpm.

4.2.3 Limitations

Neatwork is designed specifically for cost and resource limited gravity-fed water distribution systems. The program fails to incorporate the conveyance line from the source to the tank and does not account for storage tank design or size. The program should primarily be used for branched systems, as loops are difficult to design and simulate. The program’s design module is mainly focused on reducing costs. However, this method can produce system designs which are difficult to construct and repair if pipe diameters vary from node to node. The design used for this project constrained the pipe diameter in the majority of arc lengths to avoid this issue.

Another limitation to the program is the uncertainty of inputs such as fraction of open faucets, service quality, orifice coefficient, and faucet coefficient. These inputs are difficult to anticipate and/or require further scientific research in order to make educated guesses for their values. The majority of these inputs were left at the default values, which may or may not be representative of true system behavior.

5.0 Proposed Design

The proposed aqueduct system can be split into four major elements: (1) one low-profile spring box, (2) a buried aqueduct line, (3) waypoint 80, and (4) household access. The aqueduct line includes a buried PVC pipeline, one air release valve, two stream crossings, four break pressure tanks, and nine tapstands. Waypoint 80 is the location for the in-line chlorinator, one storage tank, and one break pressure tank. Figure 15 below and Figure 16 on page 20 show the locations of these components on the route map and elevation profile.

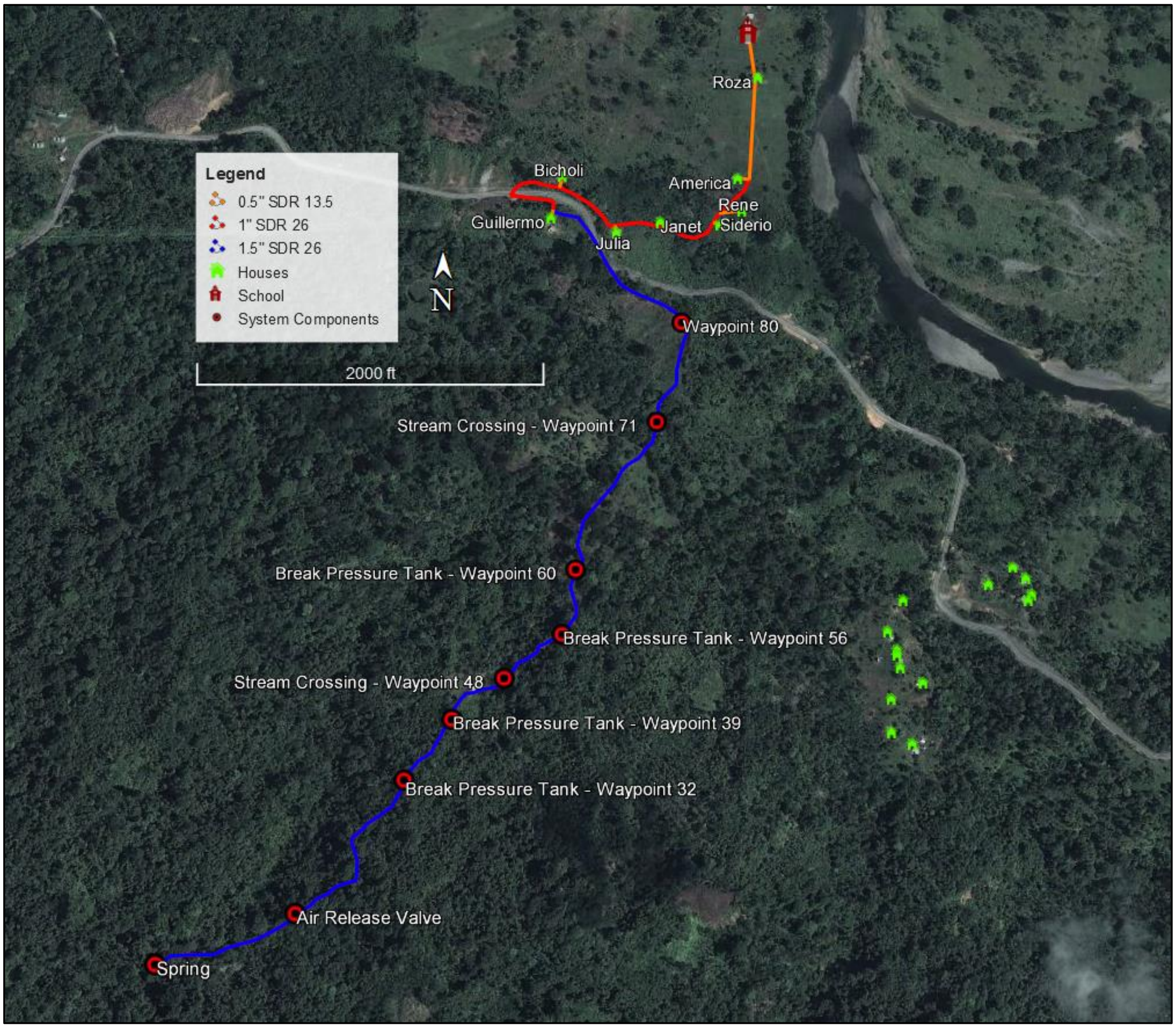


Figure 15. Map with locations of system components and pipe diameters.

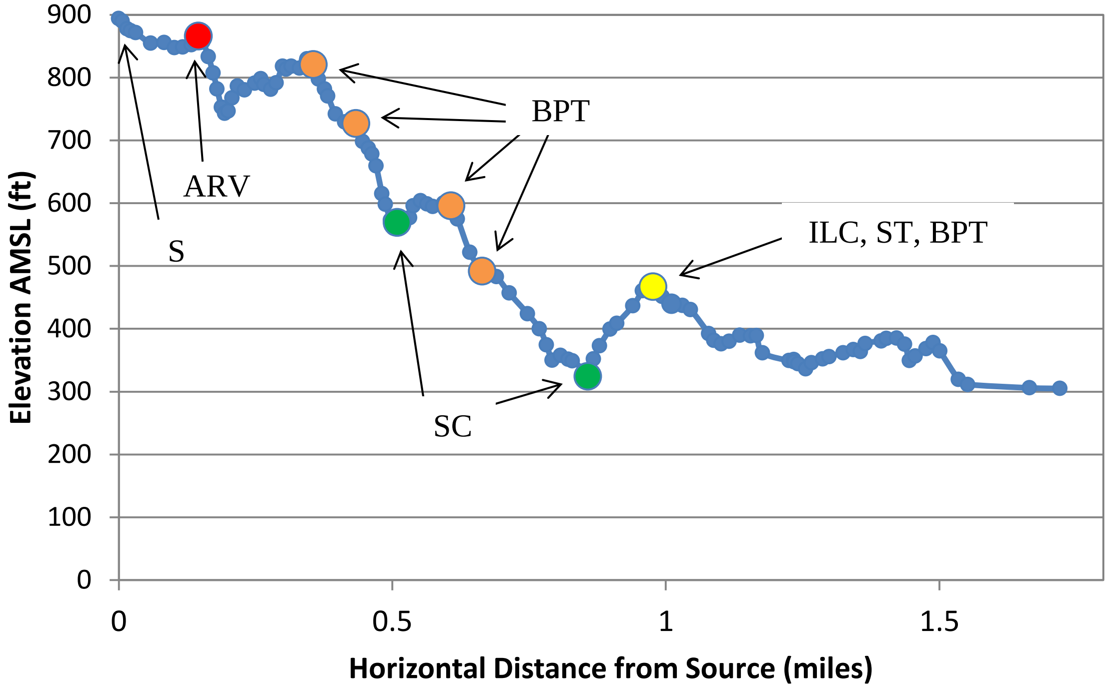


Figure 16. Summary of system components. S=source, SC=stream crossing, ARV=air release valve, BPT=break pressure tank, ILC=in-line chlorinator, and ST=storage tank.

The following subsections describe the basic design recommendations for all components. Further recommendations on how these components should be constructed, installed, and maintained can be found in Appendix L (Construction and Maintenance Manual). Illustrations of components are provided in Appendix M. Detailed engineering drawings for each component are located in Appendix N.

5.1 Spring Box

A spring box will be constructed at the spring source to collect water as it exits the hillside. A low-profile spring box is required due to stipulations mandated by WaterLines. Low-profile spring boxes are a relatively new approach to spring box construction, but are preferred because they enclose the area surrounding the source and reduce the risk of water contamination from runoff. Unlike traditional spring boxes, low-profile spring boxes are ideally installed to match the topography of the site. This ensures that the spring will be a long-term and sustainable water source for the community.

Figure 17 on page 21 shows a schematic of a low-profile spring box. The spring box capture zone (a and b in Figure 17) extends back to the "spring eyes," where the water exits the ground, to maximize water capture into the spring box (e in Figure 17).

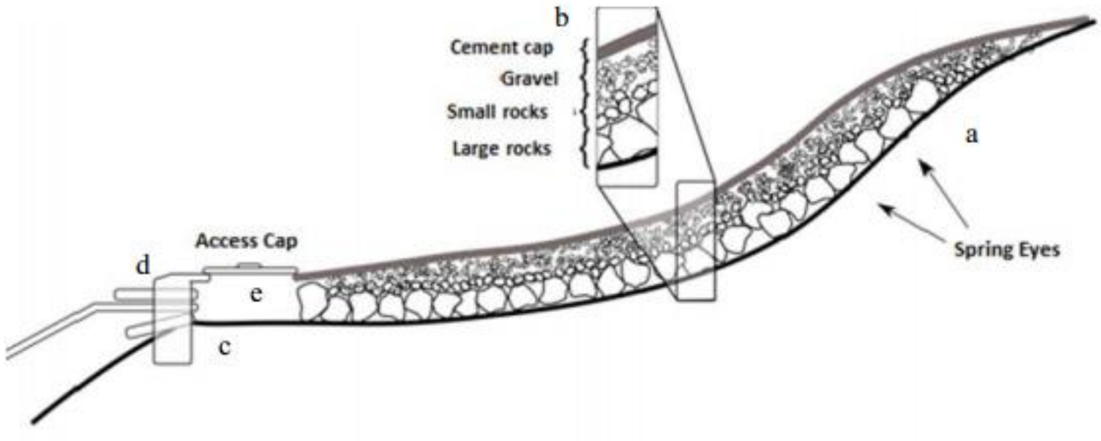


Figure 17. Low-profile spring box and spring capture zone schematic [9].

The team recommends complete excavation of the hillside from both the side and top spring entrances to develop the capture zone. This work will likely be done by hand with shovels, picks, and machetes due to limited resources.

5.2 Aqueduct Line

The main aqueduct line will consist of several diameters of PVC pipe, including 1.5” SDR 26, 1” SDR 26, and 0.5” SDR 13.5 (Table 3 on page 18). It will convey water from the low-profile spring box to section 1 of the community, terminating at the school. The total length of this pipe is 1.77 miles, covering 1.72 miles in horizontal distance.

The portions of the aqueduct from the spring box to the storage tank and from the storage tank to waypoint 92 will use 1.5” SDR 26 PVC. One inch SDR 26 PVC will be placed between waypoint 92 and waypoint 116, and 0.5” SDR 13.5 PVC from waypoint 116 to the school. Pipe diameters downstream of the storage tank were determined by designing, simulating, and optimizing the system in Neatwork. These diameters were deemed adequate with further analysis in EPANET. Figure 18 on page 22 depicts the diameter of all pipes used in the system.

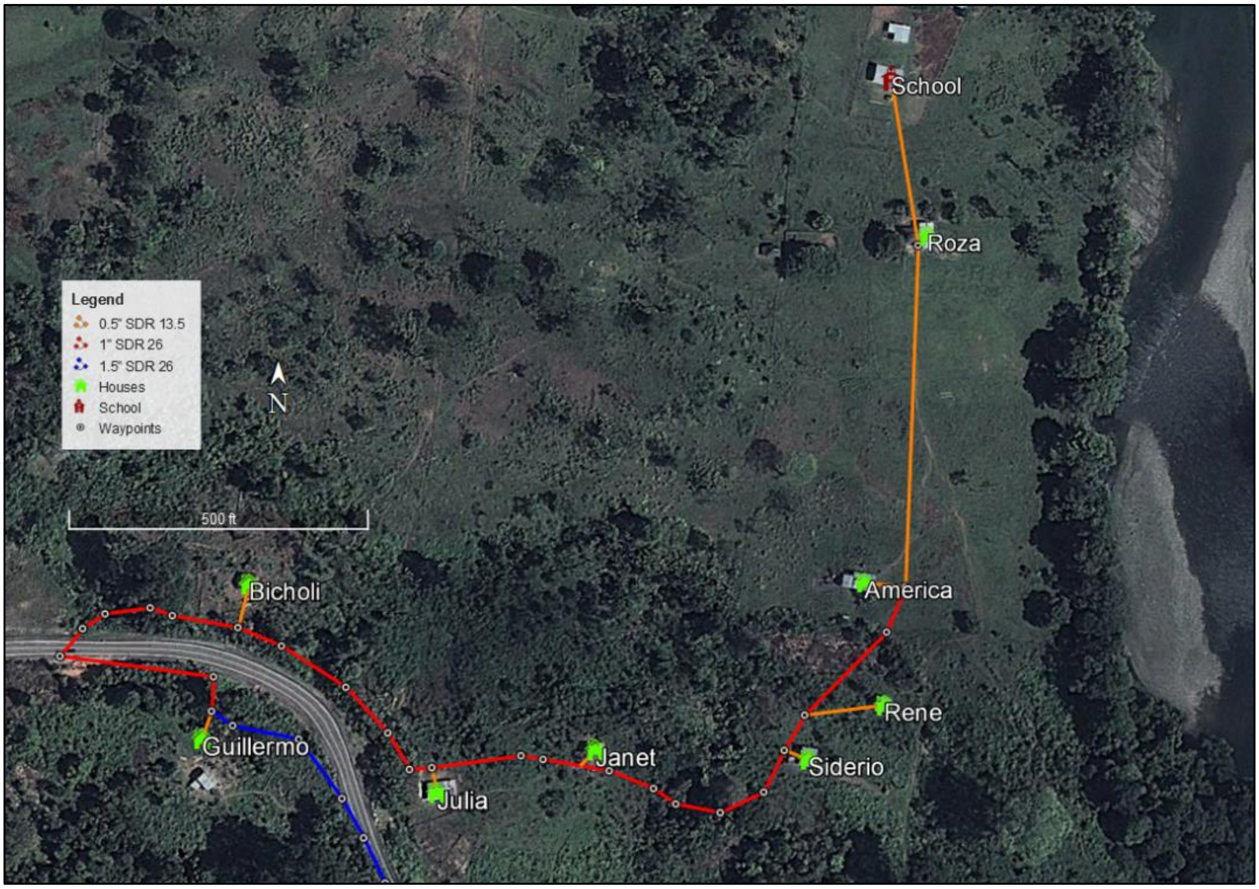


Figure 18. System pipe diameters (from Table 3) in section 1. Not pictured is the rest of the main aqueduct line, which is 1.5" SDR 26.

The aqueduct should be buried due to a number of environmental and social factors such as: (1) the presence of UV light, which can weaken the plastic and reduce durability, (2) human and animal traffic, which could damage the line if stepped on, and (3) human tampering. The team recommends that the entire pipeline be buried approximately 1.5' below the ground surface at all times to maximize the durability of the system. Similar to the capture zone of the spring box, construction will require excavation by hand. The pipe will be laid in the trench and backfilled with native soils.

In October 2014, the community of Bajo Gavilan constructed and buried an extension to the existing aqueduct [10], and this previous experience will be instrumental in the success and efficiency of this project. Figure 19 on page 23 is a photo taken by Duell during the previous work, and shows what a trench with pipe will look like before backfilling.

Figure 19. Photograph showing a pipe within a trench at Bajo Gavilan. The trench will be filled to bury and protect the pipe [10].

5.2.1 Air Release Valve

Air block analysis was performed to determine if air blocks could occur along the aqueduct route and prevent water flow through the system. Although the topography along the route varied significantly, the numerous locations of break pressure tanks addressed many potential air blocks, since these tanks will relieve air pressure. Two potential locations for air blocks were identified: (1) the segment prior to the first break pressure tank at waypoint 32, and (2) the segment after the last break pressure tank at waypoint 80. Calculations for the first potential air block can be found in Appendix G. The process was repeated for the second potential air block.

According to the analysis, an air block will occur at the first segment, requiring an air release valve to be installed at the highest point in this segment (waypoint 11). The installation of the air release valve will ensure that water can flow through this segment and continue to the community. The other potential air block, downstream of the storage tank, will not require an air release valve.

The air release valve that is recommended for the proposed system is the Geoflow Air Vent/Vacuum Relief valve (Part No. APVBK100m), as shown in Figure 20 on page 24. The valve costs $22 and can be purchased through Geoflow. Specifications and the price for this valve and other accessories are provided in Appendix H. This valve uses a floating ball mechanism to release air in the system. They are specifically manufactured for relieving air in subsurface (buried) drip irrigation systems in commercial and residential applications. An air vent box (Part No. AVBOX-6), is also available from Geoflow, which will enable the valve to remain buried and to protect the valve from tampering or other disturbances. The team recommends purchasing two valves and boxes, so there is a replacement option.

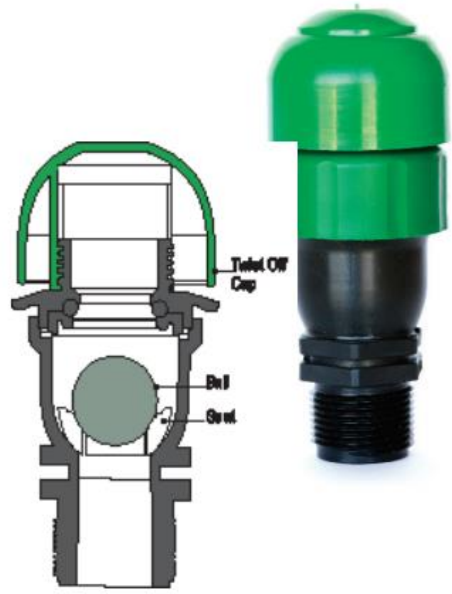


Figure 20. Geoflow Air Vent/Vacuum Relief valve ([11], Appendix H).

Since these valves are not locally available and must be purchased online, instructions on how to build an affordable do-it-yourself (DIY) air release valve are also included. The DIY release valve uses the same floating ball mechanism seen in the Geoflow valves. Instructions on how to create the valve are included in Appendix L.

5.2.2 Stream Crossings

Two streams were encountered along the aqueduct route that warranted specific design considerations. The first crossing, located at waypoint 48, is 53' wide and the second stream crossing, at waypoint 71, is 62' wide. The team recommends that the aqueduct be buried beneath stream crossings for maximum reliability. Burial depth should be at least 2' below the deepest point of the stream bed. Other concepts such as suspension crossings were considered, but the burial of the aqueduct is recommended to protect the system from falling trees or pipe failure due to stress.

The design of these stream crossings is meant to be general so it can be applied at multiple crossings. Since the flow and morphology of the streams encountered in the assessment are similar, adapting the design to both or other crossings should not be a concern. The main purpose of the design is to protect the aqueduct from potential scouring, which can expose the pipe to fast flowing water and debris that can exert large and potentially destructive forces in the direction of stream flow.

Scouring should not occur and the pipe should be protected from any forces in the stream if the pipe is buried at the specified depth. Regardless, galvanized iron pipe (1.5" diameter) will be used for stream crossings to protect against these forces, should they occur. In addition, concrete anchors will be buried 10’ inland from stream banks to prevent the pipe from moving in the direction of stream flow. Figure 21 shows a schematic of the general stream crossing design.

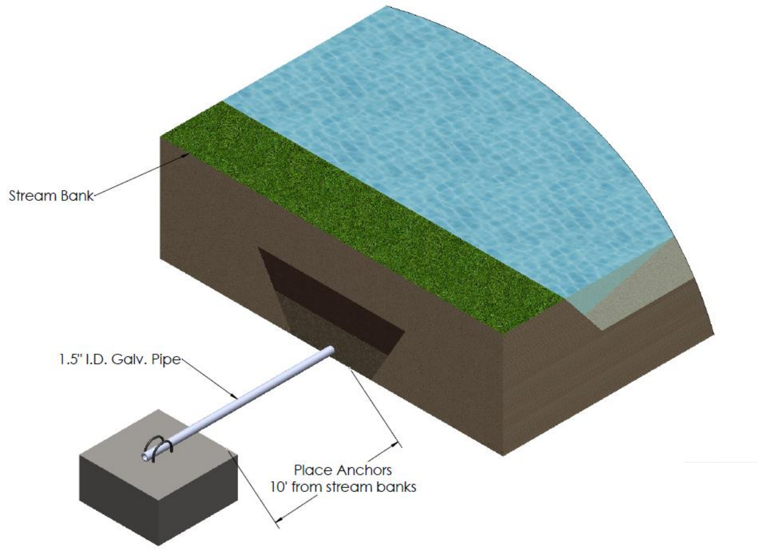


Figure 21. Schematic of stream crossing methods (Appendix N).

5.2.3 Break Pressure Tanks

Break pressure tanks prevent pipe failure by resetting the pressure in the pipes to atmospheric pressure. EPANET was used to determine the number and location of break pressure tanks needed in the system by observing modeled pressures at junctions throughout a 24-hour period.

The maximum working pressure for the 1.5” SDR 26 PVC pipe is 160 psi at 73°F. This working pressure is reduced at elevated temperatures, so an operating temperature of 90°F was assumed. For this temperature, the working pressure was de-rated by a factor of 0.75 [12], and the maximum working pressure for this system was calculated to be 120 psi. However, to be conservative, any junction that reached a pressure above 100 psi was deemed a risk, and break pressure tanks were placed at appropriate locations to relieve these high pressures.

Four break pressure tanks were deemed necessary for the system, located at waypoints 32, 39, 56, and 60. The first, at waypoint 32, reduces the pressure before it has a chance to build and prevents siphoning over the first few peaks in the system. The second, at waypoint 39, relieves pressure along the first steep downhill portion of the system, from waypoint 32 to waypoint 48. The third, at waypoint 56, reduces the pressure before the second steep decline, from waypoint 56 to waypoint 72. The fourth, at waypoint 60, relieves additional pressure along this decline, and is necessary due to the possibility of static pressure when there is no flow through the aqueduct, such as when a valve at the storage tank is closed.

An additional break pressure tank is located at waypoint 80, the same location of the storage tank. This break pressure tank is required in case there is a need to bypass the storage tank, for maintenance or other reasons. Further discussion of this location is provided in Section 5.3.

Figure 22 shows the locations of all five break pressure tanks. Break pressure tanks were placed at the least sloped portion of their respective declines to simplify the design and construction of the tanks. The design of break pressure tanks is relatively arbitrary, as there are no strict criteria that govern them. According to Niskanen [13], the dimensions of the tank are primarily influenced by the size of fittings within it. Fittings are not required for the proposed break pressure tanks in Bajo Gavilan, so the dimensions are flexible. The following design is recommended, as shown in Figure 23.

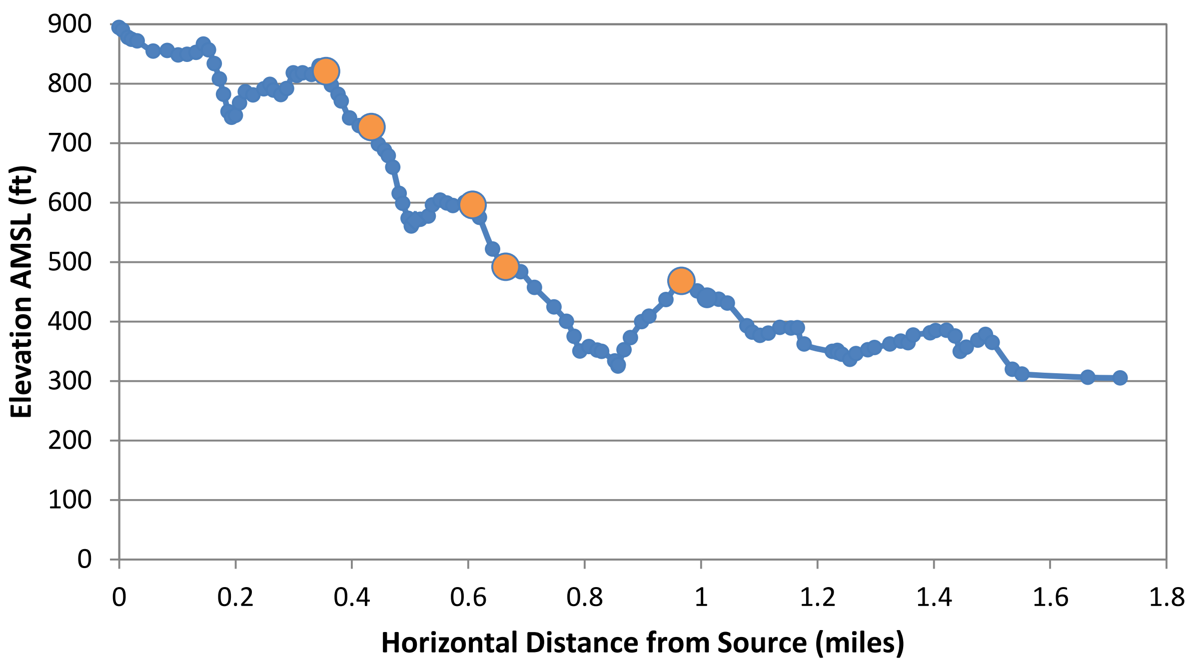


Figure 22. Locations of break pressure tanks on system elevation profile.

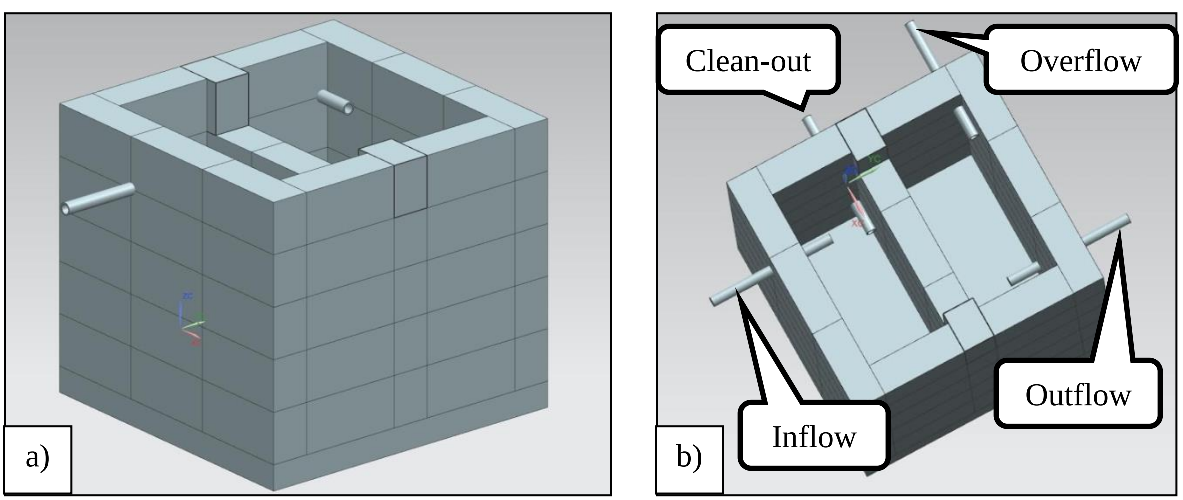


Figure 23. (a) Isometric and (b) top views of the break pressure tank (Appendix N).

The break pressure tank can be constructed of cinder blocks, as shown in Figure 23. A baffle will be installed within the tank to promote sedimentation in the first chamber and to regulate flow into the second chamber. The inflow pipe is placed at the top of the tank, and an outflow pipe is placed at the bottom of the break pressure tank to allow water to continue through the system. The overflow pipe placed at the top of the break pressure tank will prevent pressurization and will be routed to transport excess flows away from the tank structure. A cleanout pipe will be placed on the inlet side of the tank to remove any sediment that may collect in the tank.

5.3 Waypoint 80

Waypoint 80 is a critical location for the aqueduct system because it will consist of the in-line chlorinator, the storage tank, and a break pressure tank. A reinforced concrete pad is recommended to serve as a foundation for these components. Figure 24 illustrates the recommended configuration of these components at this location.

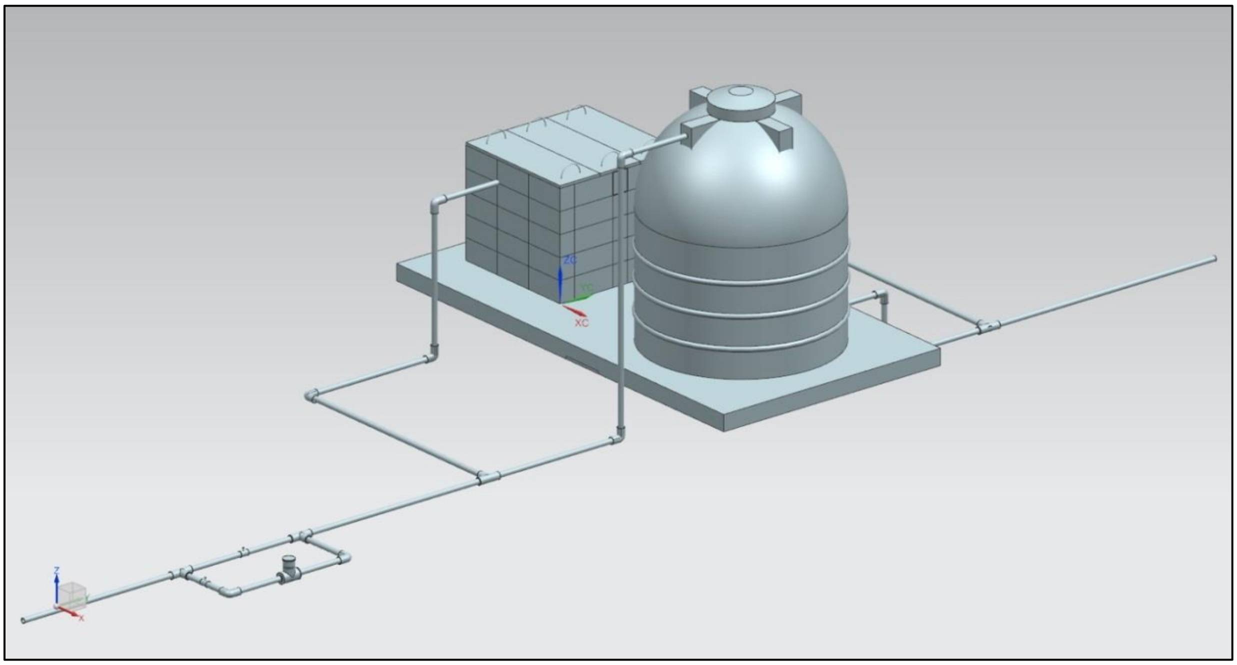


Figure 24. Configuration of in-line chlorinator, storage tank, and break pressure tank at Waypoint 80 (Appendix N).

5.3.1 In-line chlorinator

The water quality of the proposed system can be ensured by chlorination treatment with an in-line chlorinator. Reasonable Engineering recommends using the MINSA (Ministerio de Salud de la República de Panama) in-line chlorinator, which is locally available for $25 [14]. Treatment is initiated when a tablet of calcium hypochlorite is dropped into the cylinder; tablets are available for $2 each [14]. Figure 25 on page 28 shows a schematic and photographs of the chlorinator.

Information regarding purchase, installation, and operation can be found in the User Field Guide for MINSA's In-line Chlorinator ([14] and available on the CD). The in-line chlorinator is installed prior to the storage tank and water flow through the component must be stopped during installation and maintenance tasks (e.g., clean outs and addressing other problems that may arise). As a result, a bypass configuration is recommended and can be seen in Figure 24.

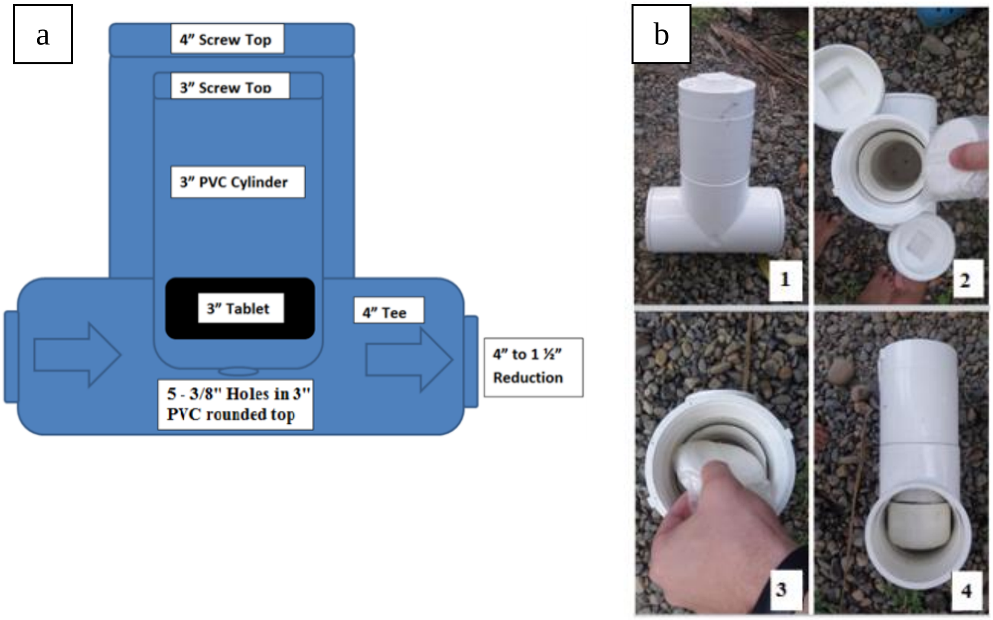


Figure 25. (a) Schematic and (b) photographs of MINSA in-line chlorinator [14].

The effectiveness of chlorine treatment is determined by the C•t (Ct) method, where C is the free chlorine concentration and t is the total contact time [14]. Ct requirements for the destruction of various pathogens are provided in Yoakum [14]. The target Ct value should be equal to or greater than the largest Ct requirement for pathogens, or 35 mg Cl_2·min/L (*E. Histolytica)*. We recommend a more conservative value of 40 mg Cl_2·min/L based on Yoakum [14].

Total contact time can be calculated using the step by step instructions in Yoakum [14]. Example calculations are provided in Appendix I. The determination of chlorine concentration in the water is performed by Hach color wheels, which are available from MINSA [14]. The Ct value is calculated by multiplying total contact time with free chlorine concentration. If the value is below the target value of 40 mg Cl_2·min/L, the dosage of chlorine tablets must increase, and the process must be repeated until the target value is met without exceeding concentrations that are harmful to human health (concentration should be no more than 5 mg Cl_2/L [14]).

5.3.2 Storage and Break Pressure Tank

The team recommends using one of the two storage tanks located at the existing aqueduct for the proposed aqueduct in this project (Figure 26 on page 29). The storage tank is a 4,200 L plastic tank manufactured by EcoTank. During the site assessment, the second tank was not being utilized for its intended purpose of collecting overflow as the first tank was less than one-fifth full. Reasonable Engineering recommends that this second tank be disconnected from the existing aqueduct and relocated to waypoint 80. This location was selected during the site assessment, and its feasibility was confirmed by both EPANET and Neatwork. The transport of the tank will be challenging due to distance and terrain, and it is imperative that the tank not be damaged during this process.

Figure 26. Two 4,200 L storage tanks located at the existing aqueduct.

A reinforced concrete pad (9.7 x 15.9 x 0.5 ft) will be required at waypoint 80 to provide a level and sturdy foundation for the storage tank and break pressure tank. To ensure the durability of the large concrete pad, it will be reinforced with a steel rebar grid of square foot sections.

The fifth break pressure tank will also be located at waypoint 80. The purpose of this tank is to provide an alternative container for water flow during maintenance tasks to protect the downstream system from potentially damaging water pressures.

5.4 House Access

Water from the aqueduct will be distributed to all eight homes in section 1 via branching pipelines leading to tapstands with faucets. These pipes will be 0.5” SDR 13.5 PVC. A PVC tee fitting will be required at each branching location (node) of the main line, as shown in Figure 27 below. A shut-off valve will be installed between the mainline and tapstand so the water committee can restrict water access if monthly fees are not paid.

Figure 27. Tee fitting to branch off 1.5” mainline to tapstands.

Figure 28 is a photograph of a tapstand being built by Bajo Gavilan residents for the aqueduct extension in October 2014 [10]. The team recommends a similar tapstand design for the proposed aqueduct.

Figure 28. Tapstand built in section 3 of the community [10].

5.5 System Sustainability

Reasonable Engineering designed a sustainable aqueduct system that is durable, affordable, easy to maintain, and enduring. These features are highlighted below.

- Durable – The system was designed with durability in mind to prevent potential failures. The aqueduct is buried to minimize damage from UV radiation and human and animal traffic, and stream crossings were buried instead of suspended to prevent damage from falling trees or large debris in streams. An existing culvert will be utilized for the road crossing instead of a suspended method to prevent damage from road vehicles.
- Affordable – The system was optimized to reduce costs. For example, EPANET and Neatwork were used in tandem to determine functional yet cost-effective diameters of PVC pipe needed in the system.
- Repairable/Ease of maintenance – All components were chosen and designed to be easily repaired. A construction and maintenance manual (Appendix L) has been provided to ensure that these components are properly constructed and cared for.
- Enduring – The water supply and demand rate was measured and calculated for section 1 of the community. The water supply rate measured during the site assessment (6.9 gpm) was similar to flow rates observed in the dry season by Duell. This is much larger than the demand rate of 2.05 gpm, a value that accounts for 20 years of population growth in section 1.

6.0 Cost Estimate and Construction Schedule

6.1 Cost Estimate

A summary of the cost estimate for the aqueduct system is shown in Table 4. Materials costs are based upon the prices found in Almirante by Duell. The estimated cost for materials and construction is $7,900 (this does not include the cost of labor, since the labor will be donated by the community). This estimate is just under $8,000, the largest amount WaterLines can allot in one grant to the community. However, it is necessary to include the design and estimate contingency in the cost estimate to account for potential cost increases, missing materials, or unforeseen issues during the construction of the aqueduct. Accounting for contingencies, the total cost estimate for the project is about $9,300. A more detailed cost estimate is provided in Appendix J.

Despite the estimated total amounting to more than the $8,000 limit per grant, Reasonable Engineering is optimistic that the proposed aqueduct can be funded by WaterLines. This can be accomplished by splitting the project into multiple and smaller grants.

Table 4. Summary of cost estimate for proposed aqueduct.

Materials Estimate	
Main Aqueduct Line Piping	$3,200
Air Release Valve	$70
Low Profile Springbox	$120
Break Pressure Tanks	$1,800
Waypoint 80	$1,200
Tapstands	$170
In-Line Chlorinator	$100
Stream Crossings	$500
Estimated Materials Total	*$7,300*
Construction Estimate	
Labor	$2,100
Community Contribution	($2,100)
Transportation	$600
Estimated Construction Subtotal	*$600*
Total Cost Estimate	
Materials and Construction	$7,900
Design Contingency	$800
Estimate contingency	$600
Total Cost Estimate	*$9,300*

6.2 Construction Schedule

The purchase and ordering of materials for the aqueduct system from stores in Almirante is scheduled to be completed in mid-February, to allow time for the shipping of any materials not readily available in town. It is imperative that the construction of major components (e.g., break pressure tanks, the concrete pad at waypoint 80, stream crossings, spring box) be completed during the month of March to capitalize on the low rainfall received during this month. This will allow for the proper setting of concrete pads and components and reduced erosion during excavation and construction of the system.

Once all major components of the aqueduct line have been constructed by community members, the construction of the pipeline will begin. The community has previous experience in the construction and burial of PVC piping due to the recent work at the existing aqueduct, which will prove useful in the construction of the new aqueduct. It is expected that 20 people will work in shifts throughout a six-hour workday, with a workweek no longer than three days. This is due to the difficulty of the terrain and the limited time community members can dedicate to the aqueduct construction while maintaining their livelihoods. This amounts to approximately 260 crew-hours, or 5,200 man-hours. The complete construction of the aqueduct line is scheduled to be complete by the end of April, resulting in an overall construction period of approximately three months. A Gantt chart that illustrates the construction schedule in detail is provided in Appendix K.

7.0 Conclusion

The objectives of this project were: (1) to evaluate the feasibility of the spring source and proposed aqueduct route and (2) to model and design a sustainable aqueduct system. Based on the evaluation of collected data and modeling the system, the system was determined to be feasible. The following design recommendations were provided:

- Creating a low-profile spring box at the spring source
- Burying an aqueduct pipeline from spring source to community, including any stream crossings
- Installing one air release valve
- Constructing and installing five break pressure tanks
- Installing an in-line chlorinator
- Disconnecting one storage tank from the existing aqueduct and transporting it to and installing it at the proposed aqueduct
- Installing nine tapstands at all eight houses and the schoolhouse

These design recommendations can be considered during the installation, construction, and operation of the aqueduct system. The following documents, attached as appendices, are intended to assist in ensuring the success of the project:

- Cost Estimate (Appendix J) - provides a cost estimate for grant requests and budgeting
- Construction Schedule (Appendix K) - provides an estimate of the time required to construct and install the aqueduct
- Construction and Maintenance Manual (Appendix L) - provides assistance for constructing and maintaining components of the aqueduct
- Illustrations of components (Appendix M) – provides a visual layout for each component that is easy to comprehend
- Engineering Drawings (Appendix N) - provides recommended dimensions and specifications for components

Overall, this report will provide PCV Christina Duell and the community of Bajo Gavilan with essential information and analysis that can be considered in the request for funding to construct the proposed gravity-fed water distribution system. Once in operation, the system should be a solution to the water availability and quality concerns currently present in section 1 of the community.

8.0 References

[1] Rossman, L.A. 2000. EPANET 2: User Manual. EPA/600/R-00/057. Available on CD.

[2] Agua Para la Vida (APV). Unknown Date. Neatwork: A user guide. Link: http://neatwork.ordecsys.com/dl/neatworkuserguide.pdf?q=neatwork/dl/neatworkuserguide.pdf. Accessed on 11/4/2014. Also available on CD.

[3] Wikipedia. 2014. "Almirante, Bocas del Toro." Link: http://en.wikipedia.org/wiki/Almirante,_Bocas_del_Toro. Accessed on 11/2/2014.

[4] World Meteorological Organization (WMO). 2014. "Climate data for Bocas del Toro, Panama (1971-2000)." Link: http://worldweather.wmo.int/en/city.html?cityId=1245. Accessed on 11/2/2014.

[5] Minority Rights Group International. 2008. Guaymi (Ngobe-Bugle). Link: http://www.minorityrights.org/4209/panama/guaymi-ngobebugle.html. Accessed on 11/3/2014.

[6] Duell, C. 2014. "Community Analysis and Development Plan." Received via Email communication.

[7] United States Environmental Protection Agency (USEPA). 2014. National Primary Drinking Water Regulations. Link: http://water.epa.gov/drink/contaminants/. Accessed on 12/3/2014.

[8] Duell, C. 2014. "WaterSTAR Report: Aqueduct Analysis for Bajo Gavilán, Panamá." Received via Email communication.

[9] Jones, E.K. 2014. Improvements in Sustainability of Gravity-Fed Water Systems in the Comarca Ngäbe-Buglé, Panama: Spring Captures and Circuit Rider Model, a master's report. Michigan Technological University, Houghton, MI. Link: http://www.mtu.edu/peacecorps/programs/civil/pdfs/JONESE_MSReport.pdf. Available on CD.

[10] Duell, C. 2014. Aqueduct Installation and Water Committee Seminars. Link: http://christinainpanama.blogspot.com/2014/09/aquduct-installation-and-water.html. Accessed on 11/4/2014.

[11] Geoflow. 2011. Air Vent Valves. Link: http://www.geoflow.com/wastewater/w_pdfs2012products/AirVentValves.pdf. Accessed on 11/16/2014.

[12] Georg Fischer Harvel. 2012. Product Specifications: PVC SDR Series Pipe. Link: http://www.harvel.com/sites/www.harvel.com/files/documents/Specifications-PVC_SDR_Series.pdf. Accessed on 11/16/2014.

[13] Niskanen, R.W. 2003. The Design, Construction, And Maintenance of a Gravity-Fed Water System In The Dominican Republic, a thesis report. Michigan Technological University, Houghton, MI. Link: http://www.mtu.edu/peacecorps/programs/civil/pdfs/matt-niskanen-thesis-final.pdf. Also available on CD.

[14] Yoakum, B. 2013. User Field Guide for MINSA's In-Line Chlorinator. Link: http://usfmi.weebly.com/uploads/5/3/9/2/5392099/users_manual_for_minsa_in-line_chlorinator.pdf. Also available on CD.

9.0 Appendices

Appendix A: Detailed Methods
Appendix B: Flow rate data
Appendix C: Water quality data
Appendix D: Summary of survey data
Appendix E: EPANET
 E-1: EPANET Inputs and Assumptions
 E-2: EPANET Outputs
 E-3: EPANET Supporting Calculations
Appendix F: Neatwork
 F-1: Neatwork Inputs and Assumptions
 F-2: Neatwork Outputs
Appendix G: Air Block Analysis
Appendix H: Geoflow Air Release Valve
Appendix I: Chlorination calculations
Appendix J: Cost Estimate
Appendix K: Construction Schedule
Appendix L: Construction and Maintenance Manual
Appendix M: Illustrations of components
Appendix N: Engineering drawings

Appendix A: Detailed methods

Appendix A: Detailed methods

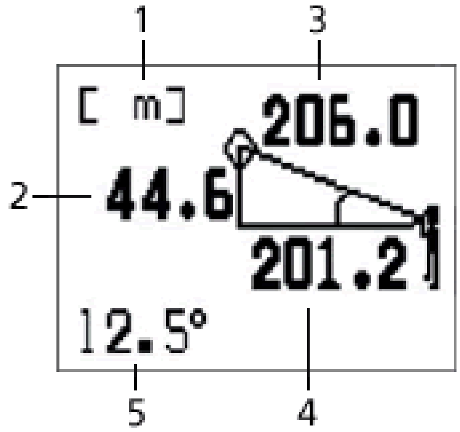
Flow Rate Measurement Methods
Flow rate was measured using the volume-time method. Using the weir constructed at the source, water was funneled into a container of known volume, and the time elapsed to fill the container was recorded. On 8/15/2014, a one-liter Nalgene bottle was used to measure the flow rate. Measurements were repeated on 8/19/2014 using a five-liter container. Multiple individuals timed the process and at least three trials were performed to improve accuracy.

Water Quality Testing Methods
The water quality of the source was tested using 3M Petrifilm *E. Coli*/Coliform Count Plates (St. Paul, MN, USA). Three samples were taken to increase the accuracy of the test. According to 3M guidelines, 1 mL of the sample water should be inoculated onto the plates which must be incubated for 24 +/- 2 hours at 35° C in a horizontal position before being enumerated.

Inoculation of plates was performed using a 1 mL plastic dropper. Due to the lack of controlled conditions for incubation, plates were incubated by placing them next to an individual's body (i.e., placing them in a pocket or between the body and waistband). Plates were placed between two pieces of cardboard, and no more than three plates were incubated at one time in order to maintain consistent temperatures among plates. After 24 hours of incubation, the plates were enumerated. *E. coli* colonies appear blue with gas bubbles, and non *E. coli* coliform colonies appear red with gas bubbles.

Survey Methods
A survey of the proposed aqueduct route was performed to determine whether the system was hydraulically feasible. The survey used relatively few tools, including a Garmin eTrex 10 GPS unit (Olathe, KS, USA), a Nikon Forestry Pro Laser Rangefinder (Melville, NY, USA), a CST Abney Level (Watseka, IL, USA), and a 100-foot open reel measuring tape.

The survey began at the source and the GPS was used to mark the first waypoint. The next waypoint along the route was identified based on the availability of clear sight lines through vegetation and the distance between waypoints, which was limited to distances between 30 feet and 1,000 feet, the operating range of the rangefinder. The rangefinder was used to determine the horizontal distance, vertical distance, slope/actual distance, and the angle between the two waypoints. An example external display for this reading is shown below. All of the parameters provided in the external display were recorded in a field notebook.



Example external display of Nikon Forestry Pro rangefinder where 1=units, 2=vertical distance, 3=slope or actual distance, 4=horizontal distance, and 5=angle.

A bamboo stake with a green folder as a target was placed at the second waypoint to improve consistency and accuracy of the rangefinder data. Another stake (same target height) was placed at the original waypoint so the "shooter" could steady the rangefinder. Foresight and backsight readings were confirmed between all waypoints to ensure accuracy, and these values were later averaged to define the topography of the route.

A measuring tape was used to determine the slope/actual distance between waypoints if it was less than 30 feet, and an Abney level was used to determine the angle between targets. Trigonometric functions were used to calculate horizontal distance given slope distance and angle. Similar to the rangefinder, a foresight and backsight was performed and later averaged.

The GPS was used to record the latitude, longitude, and elevation at each waypoint. The waypoints were recorded using the waypoint averaging function. Each point reached 100% sample confidence before saving. Sample confidence can depend on a variety of environmental conditions, including cloud cover, precipitation, and foliage. Elevation data from the GPS was not used for any analysis for this project except to approximate the elevation of the spring source. Garmin BaseCamp software was used to export GPS location data to a .gpx file, which was converted to a .kml (Google Earth) file. A free online software tool called "Kml2Shp" [1] was used to convert .kml to .shp files for ArcMap processing. A free trial version of an ArcMap toolbar called "ET GeoWizards" [2] was used to create a line or track that connects the waypoints. "Shp2kml 2.0" [3] was used to convert .shp back into .kml files for easier viewing and printing options.

Water Demand Calculations

There are currently 60 residents in section 1 of the community, based on a separate survey by Duell. The number of schoolchildren in the community is estimated to be 33. Using these numbers, the daily water demand can be calculated as follows:

[(60 residents * 35 gallons/person/day) + (33 schoolchildren * 2.5 gallons/schoolchild/day)] * (1 day/1440 minutes) = **1.516 gpm**

The demand is far below the flow measured at the source, and shows that the source should be able to provide adequate water to the community year round.

The demand was recalculated to account for population growth in the next 20 years to ensure the aqueduct is sustainable. The growth rate is 1.503%, and this was assumed to be applicable to both the population and the number of schoolchildren.

The population in Bajo Gavilan in 20 years can be calculated as follows:

$$60 \text{ residents} * (1 + 0.01503)^{20} = \mathbf{81\ residents}$$

$$33 \text{ schoolchildren} * (1 + 0.01503)^{20} = \mathbf{45\ schoolchildren}$$

Based on these new values, the water demand for section 1 of Bajo Gavilan in 20 years can be calculated as follows:

$$[(81 \text{ residents} * 35 \text{ gallons/person/day}) + (45 \text{ schoolchildren} * 2.5 \text{ gallons/schoolchild/day})] * (1 \text{ day}/1440 \text{ minutes}) = \mathbf{2.05\ gpm}$$

This demand of 2.05 gpm is still well below the available flow of 6.9 gpm measured at the spring source, so the spring should continue to be able to supply the community with adequate water as the population increases.

References

[1] Zonum Solutions. 2010. Kml2Shp. Link: http://www.zonums.com/online/kml2shp.php.

[2] Tchoukanski, Ianko. 2014. ET GeoWizards. Link: http://www.ian-ko.com/ET_GeoWizards/gw_main.htm.

[3] Zonum Solutions. Unknown date. Shp2kml 2.0. Link: http://www.zonums.com/shp2kml.html.

Appendix B: Flow rate data

Appendix B: Flow rate data

Location	Date	Time *s*	Volume *L*	Flow Rate *L/s*	Flow Rate *gpm*
Proposed Spring Source	8/15/2014	1.94	1	0.52	8.2
		2.09	1	0.48	7.6
		2.09	1	0.48	7.6
		1.88	1	0.53	8.4
		1.88	1	0.53	8.4
		2.08	1	0.48	7.6
		2.17	1	0.46	7.3
	Average:	**2.0**	**1.0**	**0.5**	**7.9**
	8/19/2014	12.06	5	0.41	6.6
		12.02	5	0.42	6.6
		11.21	5	0.45	7.1
		11.06	5	0.45	7.2
		12.33	5	0.41	6.4
		12.14	5	0.41	6.5
	Average:	**10.4**	**4.4**	**0.4**	**6.9**
Existing Aqueduct: Storage Tank	8/17/2014	40.87	5	0.12	1.9
		40.93	5	0.12	1.9
		40.76	5	0.12	1.9
		40.82	5	0.12	1.9
	Average:	**28.3**	**4.9**	**0.2**	**3.9**

Appendix C: Water quality data

Appendix C: Water quality data

Location	Amount Observed	
	E. Coli	*Non E. Coli Coliform*
Spring Source (8/15/14)	4	41
	1	52
	1	46
Average	**2**	**46.3**
Spring Source (8/19/14)	0	1
	1	1
	1	2
Average	**0.67**	**1.3**
Existing Aqueduct	0	6
	0	2
	0	4
Average	**0**	**4**
Changuinola River	34	tntc
	37	tntc
Average	**35.5**	**50**
America's House	16	tntc
	19	tntc
Average	**17.5**	**50**
Julia's House	16	tntc
	10	tntc
Average	**13**	**50**

Appendix D: Summary of survey data

Appendix D: Summary of survey data

Waypoint(s)	Latitude N	Longitude W	Segment	Average Actual Distance *ft*	Average Horizontal Distance *ft*	Cumulative Horizontal Distance *miles*	Average Vertical Distance *ft (positive = up)*	Angle *	Elevation AMSL *ft*	Notes
1	9.260418	-82.5071	1			0			894	Begin survey on 8/15/2014
2	9.260436	-82.507	1 to 2	32.5	32.5	0.01	-4.0	6.8	890.0	
3	9.260513	-82.5069	2 to 3	49.5	48.0	0.02	-12.5	14.7	877.5	
4	9.260514	-82.5069	3 to 4	32.5	32.5	0.02	-3.0	5.2	874.5	
5	9.260509	-82.5066	4 to 5	51.0	51.0	0.03	-3.0	6.7	871.5	
6	9.260491	-82.5063	5 to 6	146.5	145.5	0.06	-17.0	6.7	854.5	
7	9.260579	-82.5061	6 to 7	129.0	129.0	0.08	1.0	0.2	855.5	
8	9.260671	-82.5057	7 to 8	98.5	98.0	0.10	-7.8	4.5	847.8	
9	9.260769	-82.5055	8 to 9	80.0	80.0	0.12	1.0	0.7	848.8	
10	9.260936	-82.5052	9 to 10	83.0	83.0	0.13	3.5	2.4	852.3	
11	9.261062	-82.5051	10 to 11	69.0	67.5	0.15	14.0	11.4	866.3	
12	9.261096	-82.505	11 to 12	46.5	45.5	0.15	-9.8	12.3	856.5	
13	9.261154	-82.5049	12 to 13	57.5	52.5	0.16	-23.0	23.6	833.5	
14	9.261259	-82.5048	13 to 14	52.0	45.0	0.17	-26.0	29.9	807.5	
15	9.261344	-82.5046	14 to 15	46.5	39.0	0.18	-25.5	33.1	782.0	
16	9.261375	-82.5046	15 to 16	50.5	41.3	0.19	-29.0	35.3	753.0	
17	9.261372	-82.5046	16 to 17	33.0	31.5	0.19	-10.0	17.8	743.0	
18	9.261438	-82.5045	17 to 18	33.0	33.0	0.20	3.5	5.7	746.5	
19	9.261472	-82.5044	18 to 19	43.0	37.5	0.21	21.0	29.2	767.5	
20	9.261531	-82.5042	19 to 20	57.0	54.0	0.22	18.8	19.1	786.3	Last point for 8/15/2014
21	9.261738	-82.5042	20 to 21	69.0	69.0	0.23	-5.8	4.6	780.5	First point for 8/16/2014
22	9.261831	-82.5042	21 to 22	99.0	98.5	0.25	10.5	6.1	791.0	
23	9.262055	-82.5043	22 to 23	57.5	57.0	0.26	7.3	7.2	798.3	
24	9.262133	-82.5043	23 to 24	33.0	31.5	0.27	-9.3	16.3	789.0	
25	9.262291	-82.5041	24 to 25	66.0	65.5	0.28	-7.5	6.5	781.5	
26	9.262325	-82.5041	25 to 26	52.5	51.5	0.29	9.8	10.7	791.3	
27	9.262452	-82.5039	26 to 27	68.0	62.5	0.30	26.8	23.6	818.0	Top of hill
28	9.26253	-82.5038	27 to 28	33.0	32.5	0.31	-4.5	8.0	813.5	
29	9.262592	-82.5037	28 to 29	50.5	50.5	0.32	4.5	5.1	818.0	
30	9.262769	-82.5036	29 to 30	81.0	81.0	0.33	-3.0	2.1	815.0	
31	9.262972	-82.5035	30 to 31	70.0	69.0	0.34	12.3	10.0	827.3	Abney Level
32	9.263006	-82.5035	31 to 32	25.2	2.5	0.34	2.5	5.8	829.8	
33	9.263161	-82.5034	32 to 33	60.0	59.5	0.36	-9.0	8.6	820.8	Dropoff begins
34	9.263273	-82.5033	33 to 34	55.0	49.8	0.36	-23.3	25.2	797.5	
35	9.263392	-82.5031	34 to 35	63.0	61.0	0.38	-15.8	14.5	781.8	
36	9.263434	-82.5031	35 to 36	32.0	30.0	0.38	-11.3	21.7	770.5	
37	9.2636	-82.503	36 to 37	79.0	74.0	0.40	-28.5	21.0	742.0	
38	9.263788	-82.5029	37 to 38	90.0	89.0	0.41	-12.8	8.2	729.3	
39	9.263891	-82.5028	38 to 39	51.0	51.0	0.42	-2.0	2.2	727.3	

40	9.264005	-82.5028	39 to 40	56.5	56.5	0.43	-0.3	0.3	727.0	Trail intersecting steep dropoff, view over house to road
41	9.264158	-82.5027	40 to 41	71.0	64.8	0.45	-29.0	24.3	698.0	
42	9.264261	-82.5026	41 to 42	58.0	57.0	0.46	-10.5	10.1	687.5	Semira's house
43	9.264261	-82.5025	42 to 43	33.5	32.5	0.46	-9.0	15.5	678.5	
44	9.264305	-82.5024	43 to 44	45.5	41.0	0.47	-19.3	25.2	659.3	
45	9.26434	-82.5022	44 to 45	72.5	57.8	0.48	-44.0	37.3	615.3	
46	9.264364	-82.5021	45 to 46	35.5	31.5	0.49	-16.8	28.0	598.5	
47	9.264473	-82.5021	46 to 47	56.5	50.5	0.50	-25.3	26.4	573.3	
48	9.264502	-82.502	47 to 48	33.0	30.5	0.50	-13.0	22.8	560.3	Begin stream crossing, 53' span
49	9.264552	-82.502	48 to 49	34.0	32.8	0.51	9.3	15.8	569.5	
50	9.264574	-82.5019	49 to 50	46.0	46.0	0.52	2.0	2.6	571.5	
51	9.264721	-82.5018	50 to 51	75.0	75.0	0.53	5.5	4.3	577.0	
52	9.264757	-82.5017	51 to 52	40.0	35.5	0.54	18.8	27.8	595.8	
53	9.264884	-82.5015	52 to 53	71.5	71.0	0.55	8.0	6.5	603.8	
54	9.264968	-82.5015	53 to 54	60.5	60.5	0.56	-5.0	4.8	598.8	
55	9.264999	-82.5014	54 to 55	56.0	56.0	0.57	-4.3	3.5	594.5	
56	9.265171	-82.5011	55 to 56	105.5	105.5	0.59	5.8	3.1	600.3	
57	9.265442	-82.5009	56 to 57	70.0	70.0	0.61	-4.3	3.5	596.0	Potential storage tank location, last point for 8/16/2014
58	9.26556	-82.5009	57 to 58	68.0	64.5	0.62	-21.3	18.1	574.8	First point for 8/17/2014
59	9.265874	-82.501	58 to 59	129.0	117.8	0.64	-53.0	24.3	521.8	
60	9.266165	-82.5009	59 to 60	124.0	119.0	0.66	-29.8	16.3	492.0	
61	9.266276	-82.5008	60 to 61	52.5	52.5	0.67	0.8	0.7	492.8	
62	9.26653	-82.5009	61 to 62	87.0	86.5	0.69	-9.5	6.3	483.3	
63	9.266921	-82.5008	62 to 63	125.5	122.8	0.71	-26.3	12.1	457.0	
64	9.267275	-82.5005	63 to 64	181.0	178.0	0.75	-33.0	10.5	424.0	Potential location for break pressure tank
65	9.267502	-82.5003	64 to 65	116.5	114.0	0.77	-24.0	11.8	400.0	
66	9.267695	-82.5002	65 to 66	73.0	68.5	0.78	-25.3	20.1	374.8	
67	9.267807	-82.5001	66 to 67	59.0	53.5	0.79	-24.5	24.6	350.3	
68	9.267924	-82.4999	67 to 68	82.0	81.5	0.81	7.5	5.4	357.8	
69	9.268072	-82.4998	68 to 69	75.0	74.5	0.82	-6.3	4.7	351.5	Barbed wire fence
70	9.268153	-82.4997	69 to 70	40.0	40.0	0.83	-2.3	3.5	349.3	
71	9.268516	-82.4996	70 to 71	119.0	118.0	0.85	-16.0	7.8	333.3	Stream crossing, see field notes for diagram
72	9.268665	-82.4996	71 to 72	32.0	30.5	0.86	-8.8	15.7	324.5	Abney Level
73	9.268674	-82.4996	72 to 73	30.3	2.4	0.86	2.4	4.5	326.9	
74	9.268769	-82.4996	73 to 74	56.0	52.5	0.87	25.3	27.1	352.1	
75	9.268897	-82.4995	74 to 75	61.5	58.0	0.88	20.8	19.6	372.9	
76	9.269096	-82.4993	75 to 76	106.5	103.0	0.90	26.5	14.5	399.4	
77	9.269312	-82.4993	76 to 77	65.0	64.5	0.91	9.3	8.0	408.6	
78	9.269739	-82.4992	77 to 78	157.5	155.0	0.94	28.0	10.3	436.6	
79	9.27	-82.4991	78 to 79	96.5	93.5	0.96	24.3	14.6	460.9	
80	9.270089	-82.4992	79 to 80	47.0	46.5	0.97	7.5	9.2	468.4	Potential location for storage tanks
81	9.270215	-82.4993	80 to 81	53.0	53.0	0.98	-1.3	0.7	467.1	
82	9.27035	-82.4995	81 to 82	92.5	91.0	0.99	-15.8	9.8	451.4	
83	9.270434	-82.4997	82 to 83	88.0	87.3	1.01	-11.5	7.5	439.9	
84	9.270561	-82.5	83 to 84	106.5	106.5	1.03	-2.5	1.3	437.4	

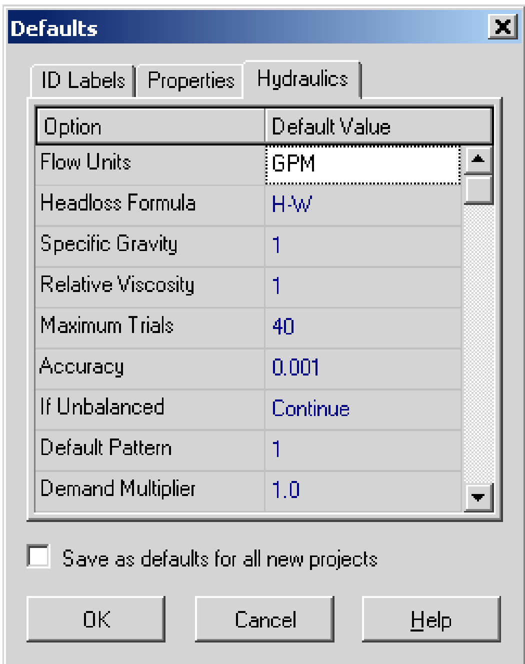
85	9.270679	-82.5002	84 to 85	79.5	79.0	1.05	-6.8	4.9	430.6	View over Christina's host family's house
86	9.270962	-82.5004	85 to 86	180.0	176.0	1.08	-38.3	12.3	392.4	
87	9.271143	-82.5005	86 to 87	51.0	50.0	1.09	-10.8	12.1	381.6	Next to road
88	9.271337	-82.5006	87 to 88	71.0	71.0	1.10	-5.5	4.4	376.1	
89	9.271507	-82.5007	88 to 89	74.5	74.5	1.12	4.0	3.1	380.1	
90	9.271765	-82.5009	89 to 90	104.0	103.5	1.14	9.5	5.2	389.6	
91	9.271824	-82.5012	90 to 91	103.5	103.5	1.15	-0.8	0.5	388.9	
92	9.271886	-82.5013	91 to 92	57.0	57.0	1.17	0.3	0.3	389.1	20' to Guillermo's House, Last point for 8/17/2014
93	9.272036	-82.5013	92 to 93	60.0	60.0	1.18	-27.3	12.5	361.9	Road, First point for 8/18/2014
94	9.272128	-82.502	93 to 94	256.0	255.8	1.23	-12.5	2.8	349.4	Culvert, 2.5' wide, need an elbow
95	9.272251	-82.5019	94 to 95	46.5	46.5	1.23	1.5	1.9	350.9	Abney Level
96	9.272252	-82.5019	95 to 96	9.0	3.7	1.24	-3.4	24.3	347.5	End of culvert
97	9.272317	-82.5018	96 to 97	37.0	37.0	1.24	-3.0	4.9	344.5	
98	9.272343	-82.5016	97 to 98	75.0	74.5	1.26	-8.3	6.4	336.3	
99	9.272308	-82.5015	98 to 99	56.5	55.5	1.27	9.5	9.8	345.8	
100	9.272254	-82.5012	99 to 100	107.0	107.0	1.29	6.5	3.6	352.3	71' to Bicholis
101	9.272171	-82.501	100 to 101	60.5	60.5	1.30	3.5	3.4	355.8	
102	9.271988	-82.5007	101 to 102	138.0	138.0	1.32	6.3	2.6	362.0	
103	9.271791	-82.5005	102 to 103	99.0	99.0	1.34	4.8	2.8	366.8	
104	9.271632	-82.5004	103 to 104	67.0	67.0	1.36	-3.0	2.4	363.8	Small ceek at Julia's house
105	9.271639	-82.5003	104 to 105	49.0	47.0	1.36	13.0	15.6	376.8	30' to Julia's
106	9.271687	-82.4999	105 to 106	153.0	153.0	1.39	4.0	1.5	380.8	
107	9.27167	-82.4998	106 to 107	50.0	50.0	1.40	3.8	4.2	384.5	20' to Janet's
108	9.271618	-82.4995	107 to 108	98.0	98.0	1.42	0.5	0.2	385.0	
109	9.271541	-82.4993	108 to 109	79.0	78.5	1.44	-9.5	6.9	375.5	
110	9.271475	-82.4992	109 to 110	52.5	45.8	1.45	-25.8	29.4	349.8	Small stream crossing
111	9.271438	-82.499	110 to 111	58.0	57.5	1.46	7.0	7.1	356.8	
112	9.271524	-82.4988	111 to 112	105.0	104.3	1.48	11.5	6.3	368.3	
113	9.271703	-82.4987	112 to 113	69.0	68.3	1.49	10.0	8.3	378.3	20' to Siderio's
114	9.271856	-82.4986	113 to 114	64.0	62.5	1.50	-13.5	12.0	364.8	133' to Rene's
115	9.272225	-82.4982	114 to 115	188.5	182.3	1.54	-45.5	14.0	319.3	
116	9.272431	-82.4981	115 to 116	87.5	87.0	1.55	-7.8	5.2	311.5	40' to America's
117	9.274053	-82.498	116 to 117	596.5	596.5	1.66	-5.5	0.6	306.0	10' to Roza's, Last point for 8/18/2014
118	9.27486	-82.49812	117 to 118	293	293	1.72	-1		305	School

Appendix E: EPANET

Appendix E: EPANET

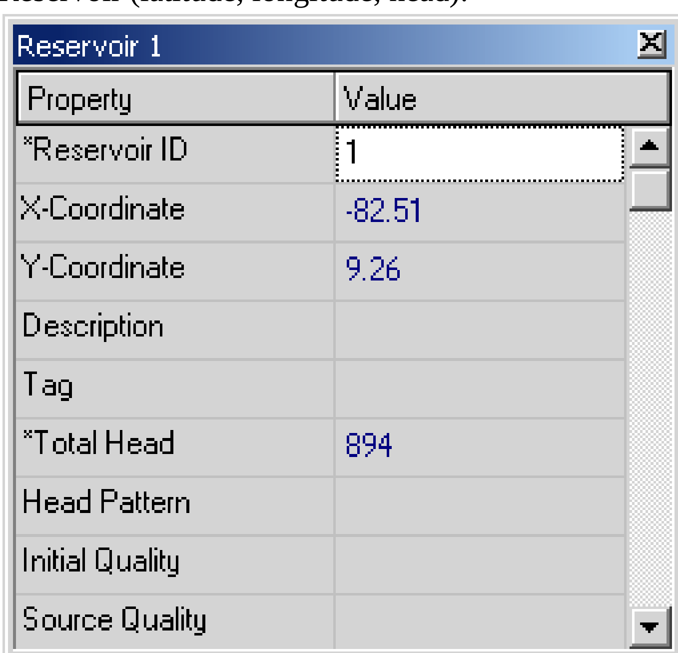
Appendix E-1: EPANET Inputs and Assumptions

Project defaults

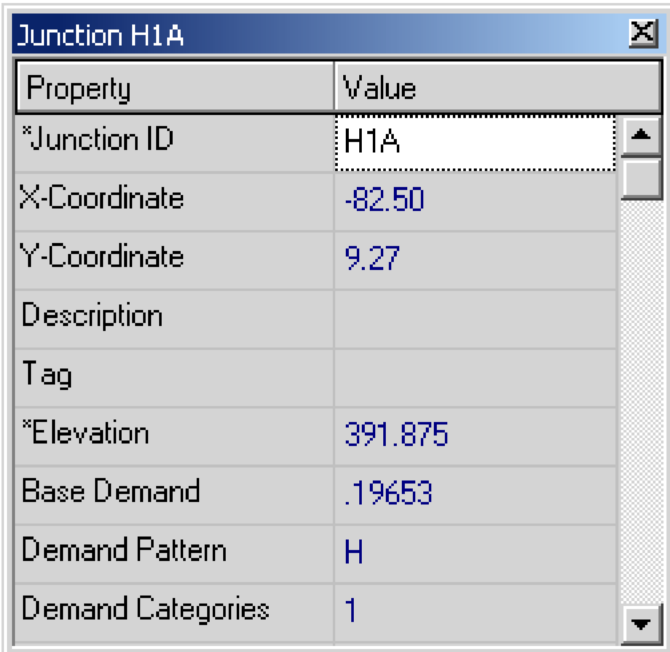


Sample Inputs

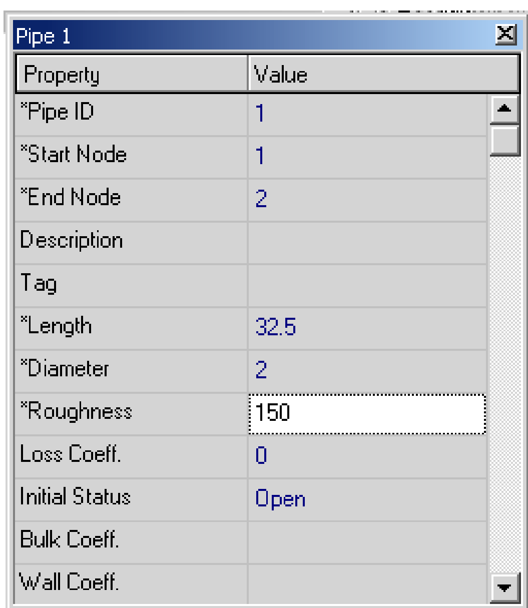
Reservoir (latitude, longitude, head):



Node (latitude, longitude, elevation, demand/demand pattern if applicable):



Pipe (length, diameter, roughness):



System Pipe Diameters:

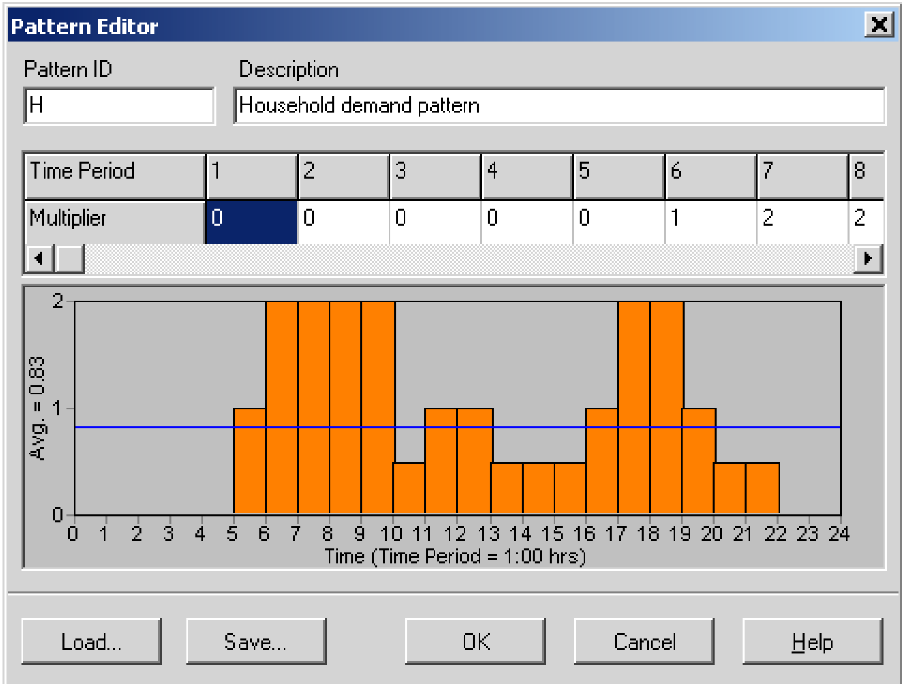
Waypoints	Pipe Diameter
Reservoir to #92	1.5in
#92 to #116	1in
#116 to #118, all branches for individual homes	0.5in

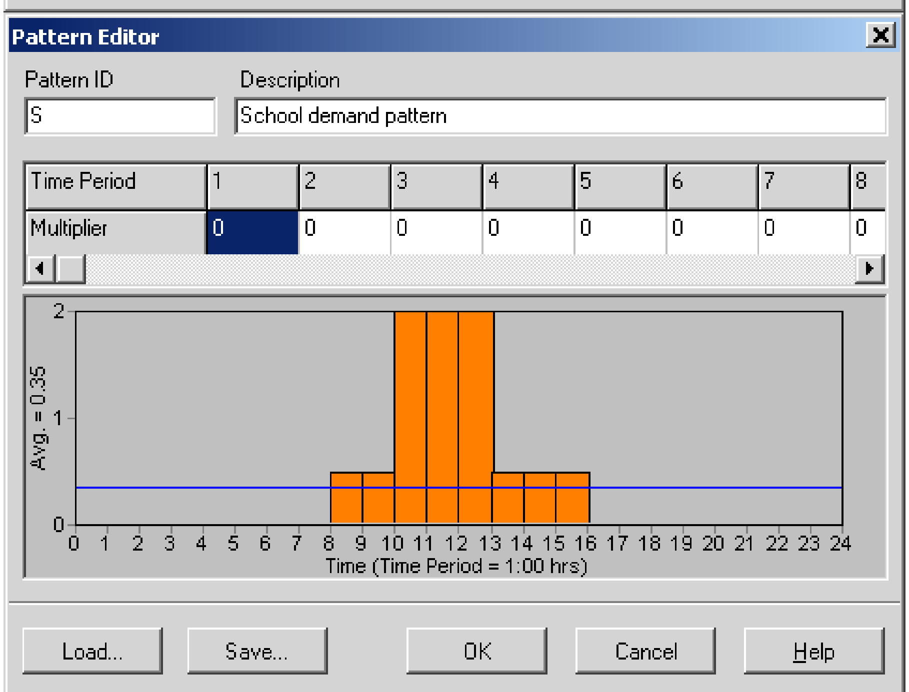
Base Flow Inputs

House	Number of Residents	Percent of Total	Demand (gpm)
H1 - Guillermo	6	0.100	0.1969
H2 - Julia	9	0.150	0.2953
H3 - Bicholi	6	0.100	0.1969
H4 - Janet	7	0.117	0.2297
H5 - Siderio	13	0.217	0.4266
H6 - Renee	4	0.067	0.1313
H7 - America	10	0.167	0.3281
H8 - Roza	5	0.083	0.1641
Total	**60**	**1**	**1.9688**

School:
(45 schoolchildren * 2.5 gallons/schoolchild/day)] * (1 day/1440 minutes) = **0.0781 gpm**

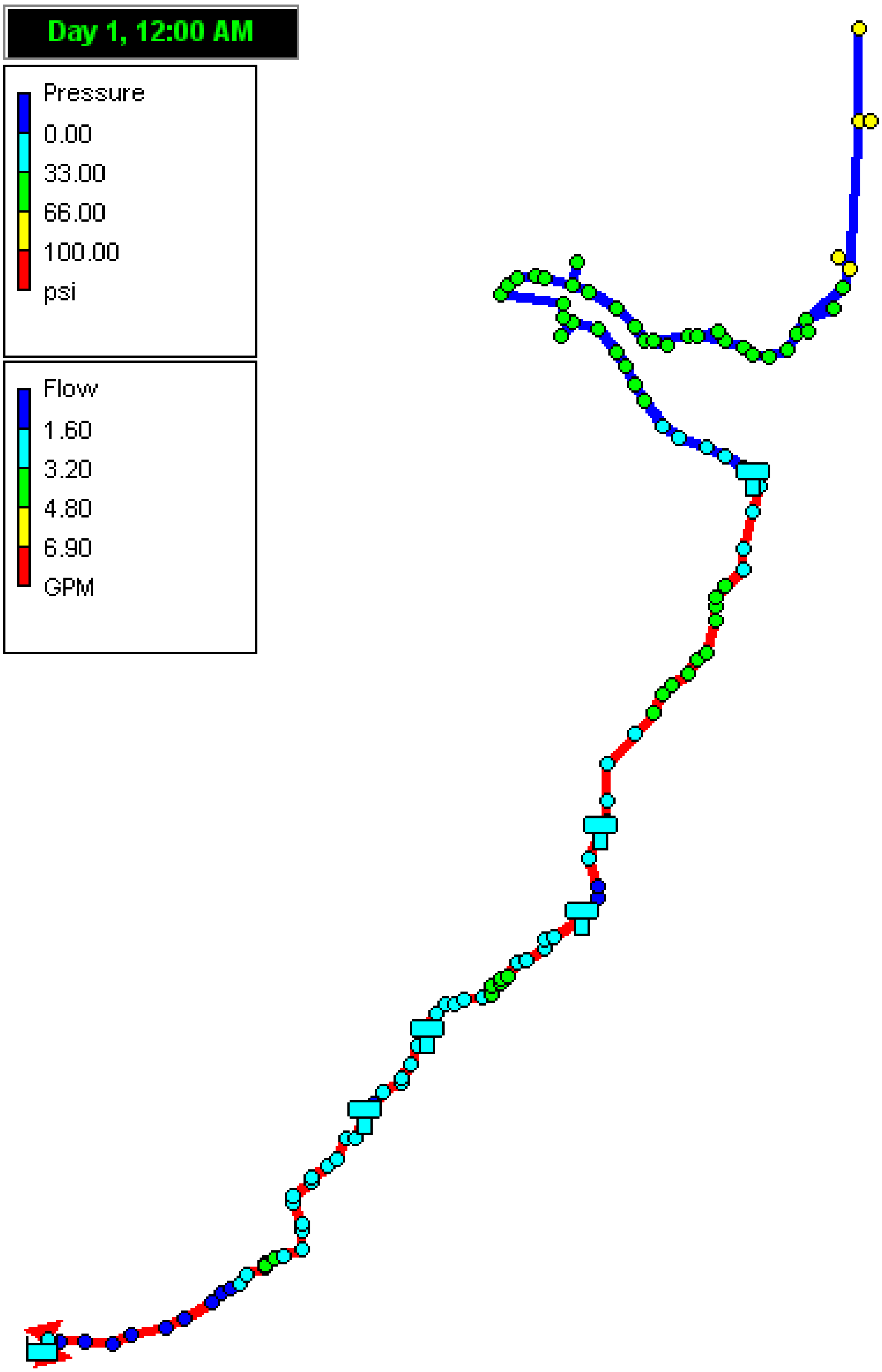
Demand Patterns

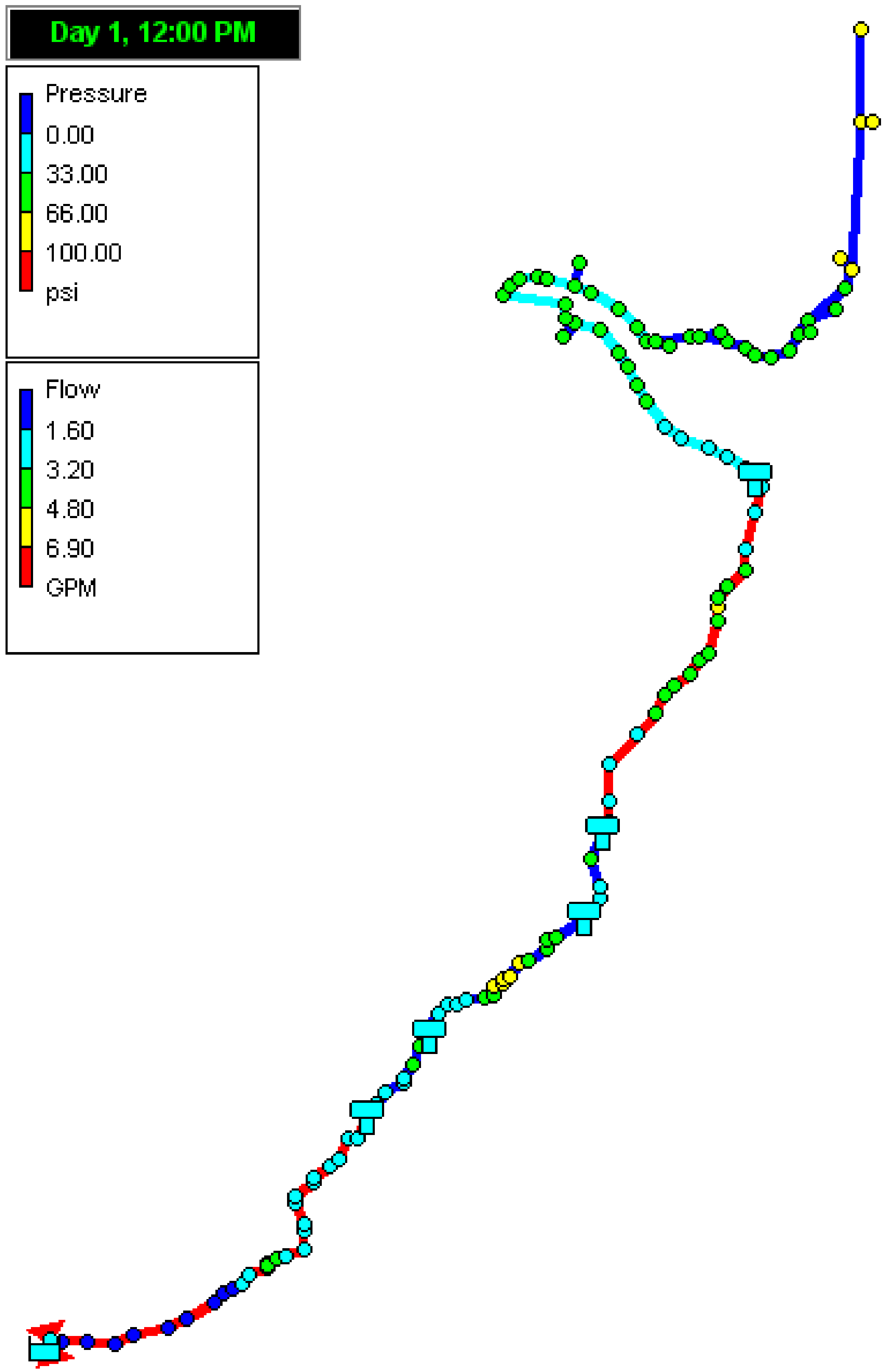




Appendix E-2: EPANET Outputs

Visual Output: node pressures and pipe flows




Day 1, 12:00 PM
Pressure
0.00
33.00
66.00
100.00
psi
Flow
1.60
3.20
4.80
6.90
GPM

Appendix E-3: EPANET Supporting Calculations

To ensure the proposed aqueduct system is feasible, additional analysis is required to address modeling issues between the spring source and the first peak in the system at waypoint 11. To investigate whether this peak is too high for the water to flow over, the head loss between the spring and the peak will be calculated and compared to the available head in the same segment, or the change in elevation between the two points.

There are no fittings in this portion of the system, and the pipe will likely not flow full immediately from the spring source, so the head loss calculation will be simplified to include only the head loss due to friction. This value can be calculated by the Darcy-Weisbach equation.

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

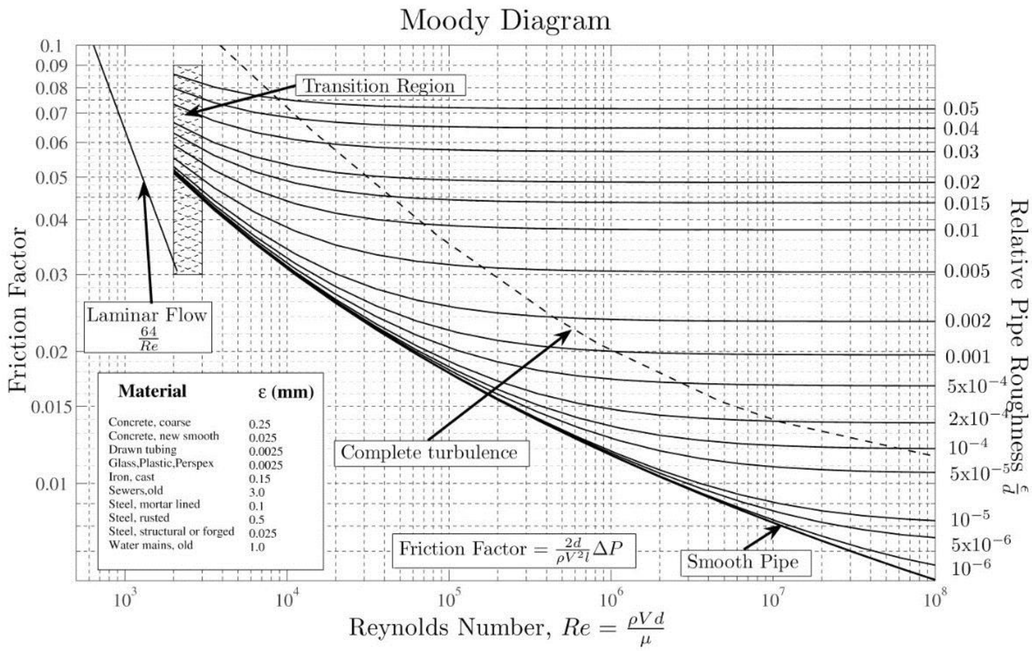
Where:

$$f = Darcy - Weisbach\ friction\ factor$$
$$L = length\ of\ pipe = 736\ ft$$
$$D = pipe\ diameter = 1.5\ in * \frac{1\ ft}{12\ in} = 0.125\ ft$$
$$V = flow\ velocity$$
$$g = acceleration\ due\ to\ gravity = 32.2\ ft/s^2$$

The flow velocity, V, can be calculated using the flow rate in the pipe and the pipe area, both of which are known values. This calculation is shown below.

$$V = \frac{Q}{A}$$
$$Q = flow\ rate = 6.9gpm * \frac{1\ ft^3}{7.481\ gallons} * \frac{1\ min}{60\ s} = 0.015372\ \frac{ft^3}{s}$$
$$A = area\ of\ pipe = \frac{\pi d^2}{4} = \pi * \frac{(0.125\ ft)^2}{4} = 0.01227\ ft^2$$
$$V = \frac{Q}{A} = \frac{0.015372\ {ft^3}/{s}}{0.01227 ft^2} = 1.253\ {ft}/{s}$$

The last unknown in the Darcy-Weisbach equation is f, the friction factor. This must be determined using a Moody diagram, shown below.



To use the Moody diagram to find the friction factor, the Reynolds number and relative pipe roughness must be calculated.

$$Re = \frac{\rho V D_H}{\mu}$$

Where:

$$\mu = dynamic\ viscosity\ of\ water$$
$$\rho = density\ of\ water$$
$$V = flow\ velocity\ in\ pipe$$
$$D_H = hydraulic\ diameter\ of\ pipe$$

For a circular pipe, the hydraulic diameter is equal to the physical diameter. Dynamic viscosity and density can be related using kinematic viscosity, as shown below.

$$v = kinematic\ viscosity\ of\ water = \frac{\mu}{\rho} = 1.05 * 10^{-5}\, {ft^2}/{s}$$

Using these relationships, the Reynolds number can be calculated as follows.

$$Re = \frac{Vd}{v} = \frac{\left(1.253\ {ft}/{s}\right)(0.125\ ft)}{1.05 * 10^{-5}\ {ft^2}/{s}} = \mathbf{14,914}$$

To use the Moody diagram, the relative roughness of the pipe must also be calculated.

$$Relative\ roughness = \frac{\varepsilon}{d}$$
$$\varepsilon = pipe\ roughness\ for\ PVC = 0.00006\ in = 0.000005\ ft$$
$$d = pipe\ diameter = 1.5\ in = 0.125\ ft$$
$$Relative\ roughness = \frac{0.000005ft}{0.125ft} = \mathbf{4 * 10^{-5}}$$

The friction factor can now be determined. Referring back to the Moody diagram, the Darcy-Weisbach friction factor was determined to be **0.028**.
The head loss due to friction can now be calculated.

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

Where:

$$f = Darcy - Weisbach\ friction\ factor = 0.028$$
$$L = length\ of\ pipe = 736\ ft$$
$$D = pipe\ diameter = 0.125\ ft$$
$$V = flow\ velocity = 1.253\ ft/s$$
$$g = acceleration\ due\ to\ gravity = 32.2\ ft/s^2$$

With these values, the head loss due to friction can calculated as:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} = 0.028\frac{(736\ ft)}{0.125\ ft}\frac{(1.253\ ft/s)^2}{2 * 32.2\ ft/s^2} = \mathbf{4.02\ ft}$$

To determine whether water will be able to flow over the first peak, this head loss is compared to the available head, or the elevation (z) difference between the spring and the first peak.

$$z_{spring} - z_{peak} = 894\ ft - 866.25\ ft = \mathbf{27.75\ ft}$$

Since the available head, 27.75 ft, is greater than the head loss due to friction in this segment of the system, 4.02 ft, it is reasonable to conclude that the water will be able to flow over this peak in the system and the proposed route is feasible.

Appendix F: Neatwork

F-1: Neatwork Inputs

F-2: Neatwork Outputs

Appendix F: Neatwork

Appendix F-1: Neatwork Inputs

1.0 Topography Module

Node list:

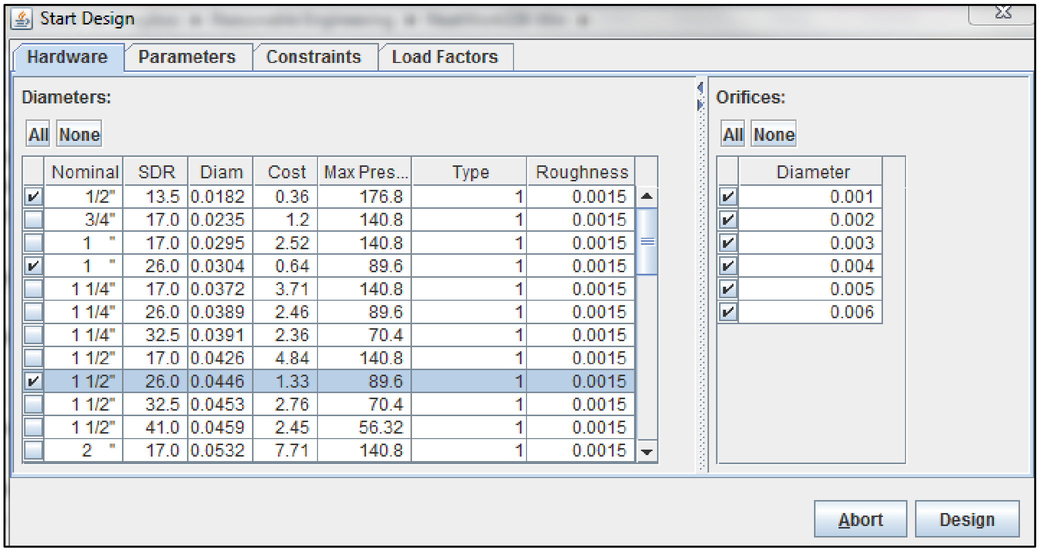
ID	Height	X	Y	# of faucets	Nature
Tank	0.0	0.0	0.0	0	TANK
N92	-24.16158537	0.0	0.0	0	BRANCHING NODE
N100	-35.40217861	0.0	0.0	0	BRANCHING NODE
N105	-27.93266641	0.0	0.0	0	BRANCHING NODE
N107	-25.56986153	0.0	0.0	0	BRANCHING NODE
N113	-27.47534934	0.0	0.0	0	BRANCHING NODE
N114	-31.591203	0.0	0.0	0	BRANCHING NODE
N116	-47.82595909	0.0	0.0	0	BRANCHING NODE
N117	-49.50278836	0.0	0.0	0	BRANCHING NODE
Guillermo	-24.16158537	0.0	0.0	1	FAUCET NODE
Bicholi	-35.40217861	0.0	0.0	1	FAUCET NODE
Julia	-27.93266641	0.0	0.0	1	FAUCET NODE
Janet	-25.56986153	0.0	0.0	1	FAUCET NODE
Siderio	-27.47534934	0.0	0.0	1	FAUCET NODE
Rene	-31.591203	0.0	0.0	1	FAUCET NODE
America	-47.82595909	0.0	0.0	1	FAUCET NODE
Roza	-49.50278836	0.0	0.0	1	FAUCET NODE
N118	-49.80946023	0.0	0.0	1	FAUCET NODE

Arc list:

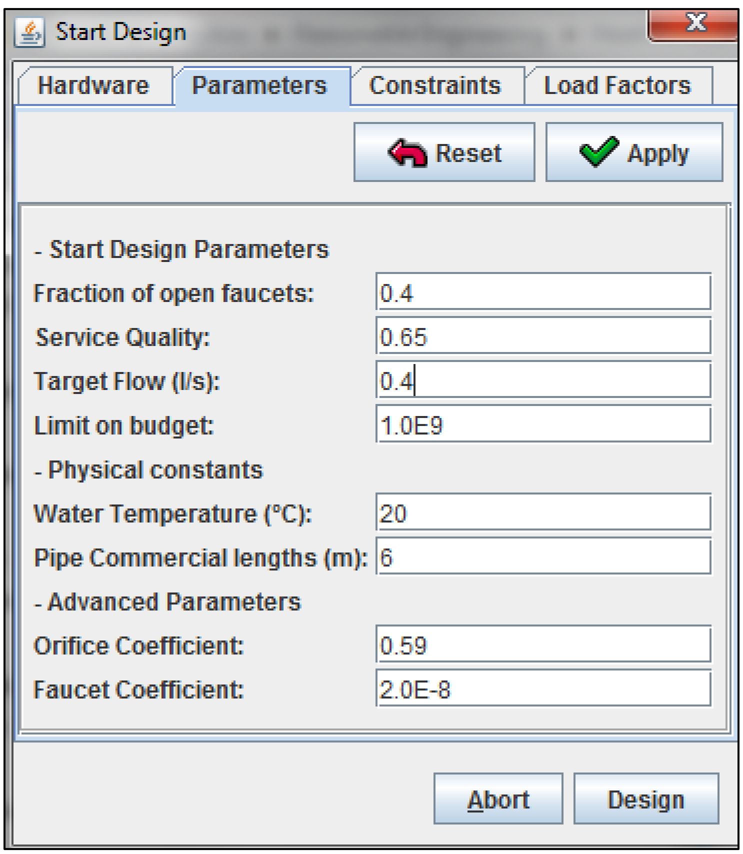
Begin	End	Length
Tank	N92	323.3231707
N92	Guillermo	20.0
N92	N100	197.2560976
N100	Bicholi	71.0
N100	N105	126.0670732
N105	Julia	30.0
N105	N107	61.8902439
N107	Janet	20.0
N107	N113	140.7012195
N113	Siderio	20.0
N113	N114	19.51219512
N114	Rene	133.0
N114	N116	84.14634146
N116	America	40.0
N116	N117	181.8597561
N117	Roza	10.0
N117	N118	89.32926829

2.0 Design Module

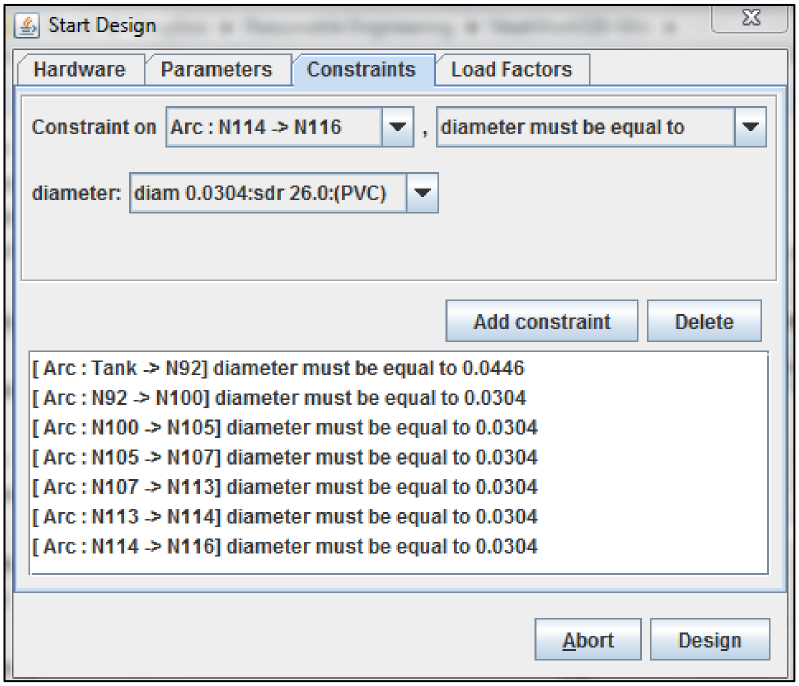
2.1 Hardware



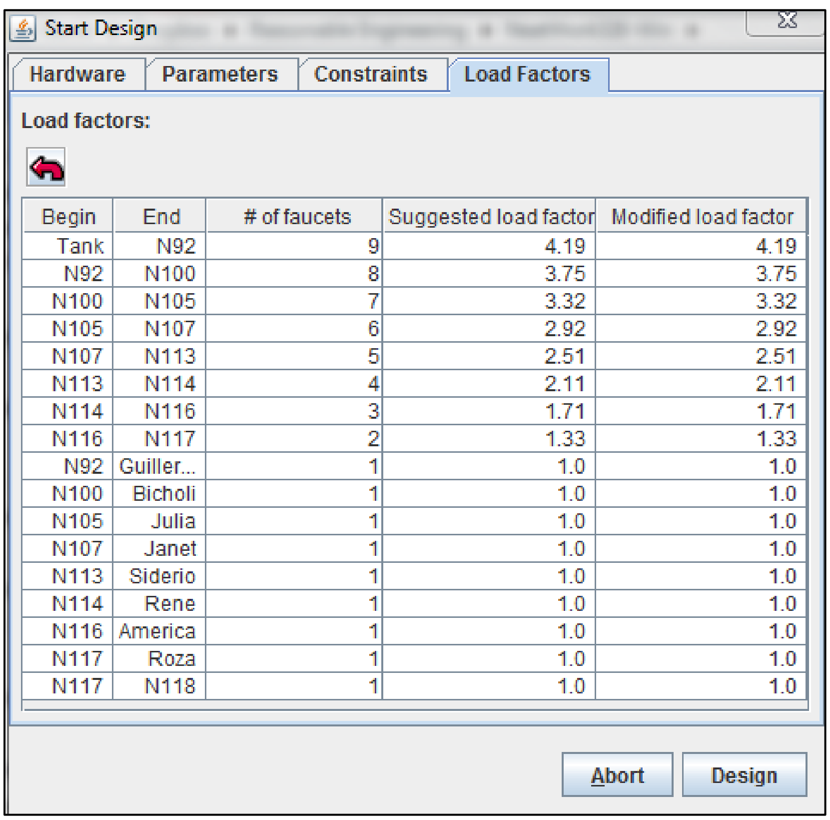
2.1 Parameters



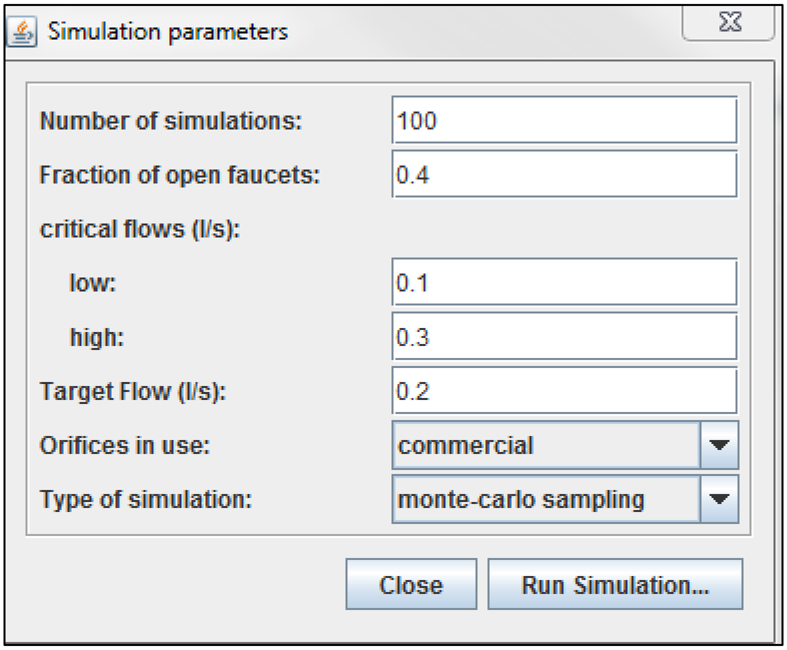
2.2 Constraints



2.3 Load Factors



3.0 Simulation Module



Appendix F-2: Neatwork Outputs

1.0 Design Module: Pipe Diameter and Orifice Optimization

NeatWork

File Design Database Help

Tables | Simulation | TreeView | Text

Node list:

ID	Height	X	Y	Ideal Orifice	Commercial Orifice	Nature
Tank	0.0	0.0	0.0	0	0	TANK
N92	-24.16158537	0.0	0.0	0	0	BRANCHING N...
N100	-35.40217861	0.0	0.0	0	0	BRANCHING N...
N105	-27.93266641	0.0	0.0	0	0	BRANCHING N...
N107	-25.56986153	0.0	0.0	0	0	BRANCHING N...
N113	-27.47534934	0.0	0.0	0	0	BRANCHING N...
N114	-31.591203	0.0	0.0	0	0	BRANCHING N...
N116	-47.82595909	0.0	0.0	0	0	BRANCHING N...
N117	-49.50278836	0.0	0.0	0	0	BRANCHING N...
Guillermo	-24.16158537	0.0	0.0	0.00405243	0.004	FAUCET NODE
Bicholi	-35.40217861	0.0	0.0	0.00401527	0.004	FAUCET NODE
Julia	-27.93266641	0.0	0.0	0.00485449	0.005	FAUCET NODE
Janet	-25.56986153	0.0	0.0	0.00554726	0.006	FAUCET NODE
Siderio	-27.47534934	0.0	0.0	0.0058907	0.006	FAUCET NODE
Rene	-31.591203	0.0	0.0	0.00670242	0.006	FAUCET NODE
America	-47.82595909	0.0	0.0	0.00384381	0.004	FAUCET NODE
Roza	-49.50278836	0.0	0.0	0.00460378	0.005	FAUCET NODE
N118	-49.80946023	0.0	0.0	0.00507939	0.005	FAUCET NODE

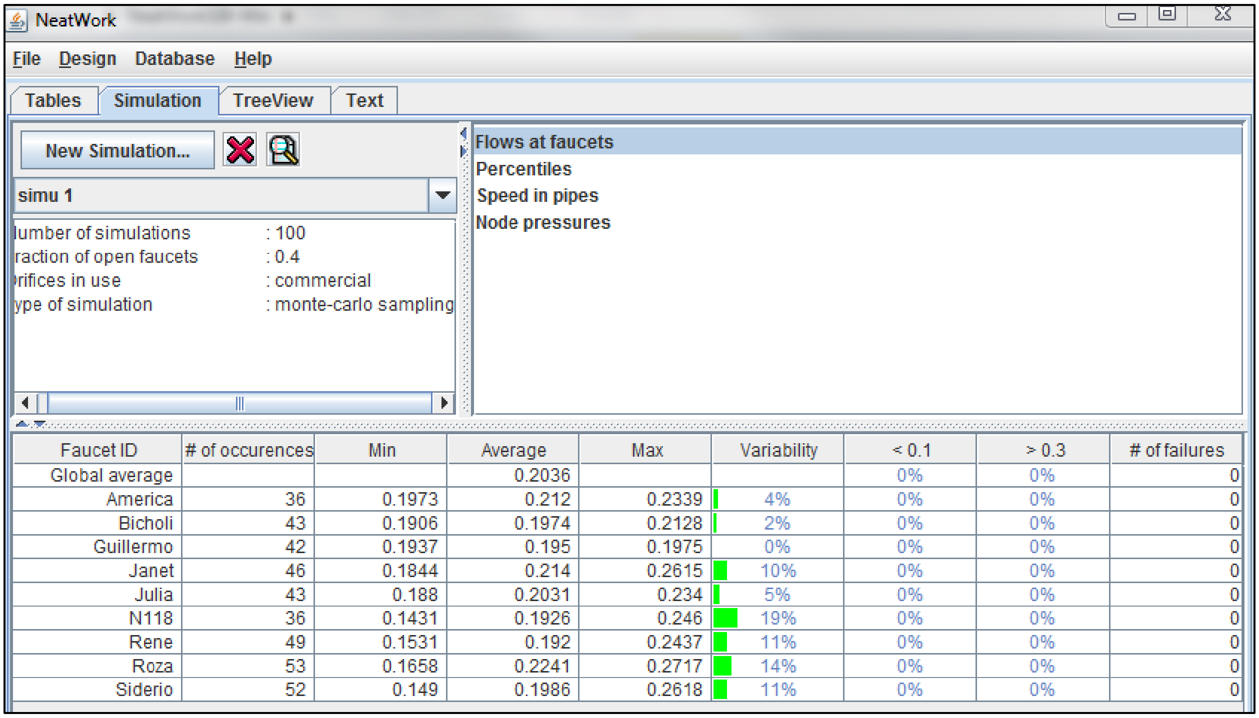
Arc (segment) list:

Begin	End	Length	Length 1	Diam 1	Length 2	Diam 2
Tank	N92	323.3231...	323.323	0.0446	0.0	-
N92	N100	197.2560...	197.256	0.0304	0.0	-
N100	N105	126.0670...	126.067	0.0304	0.0	-
N105	N107	61.89024...	61.89	0.0304	0.0	-
N107	N113	140.7012...	140.701	0.0304	0.0	-
N113	N114	19.51219...	19.512	0.0304	0.0	-
N114	N116	84.14634...	84.146	0.0304	0.0	-
N116	N117	181.8597...	181.86	0.0182	0.0	-
N92	Guillermo	30.0	30.0	0.0182	0.0	-
N100	Bicholi	71.0	71.0	0.0182	0.0	-
N105	Julia	30.0	30.0	0.0182	0.0	-
N107	Janet	20.0	20.0	0.0182	0.0	-
N113	Siderio	20.0	20.0	0.0182	0.0	-
N114	Rene	133.0	133.0	0.0182	0.0	-
N116	America	40.0	40.0	0.0182	0.0	-
N117	Roza	10.0	10.0	0.0182	0.0	-
N117	N118	89.32926...	89.329	0.0182	0.0	-

Design total cost: 1,058

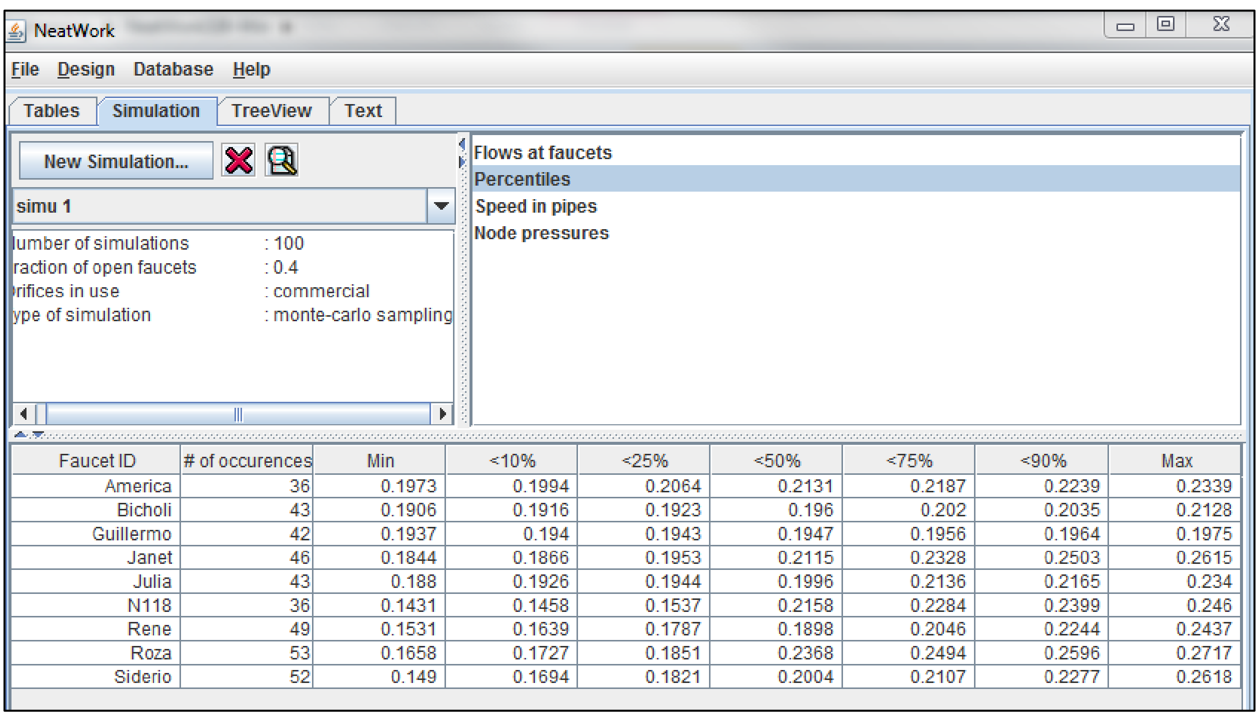
2.0 Simulation

2.1 Flows at faucets (in L/s)



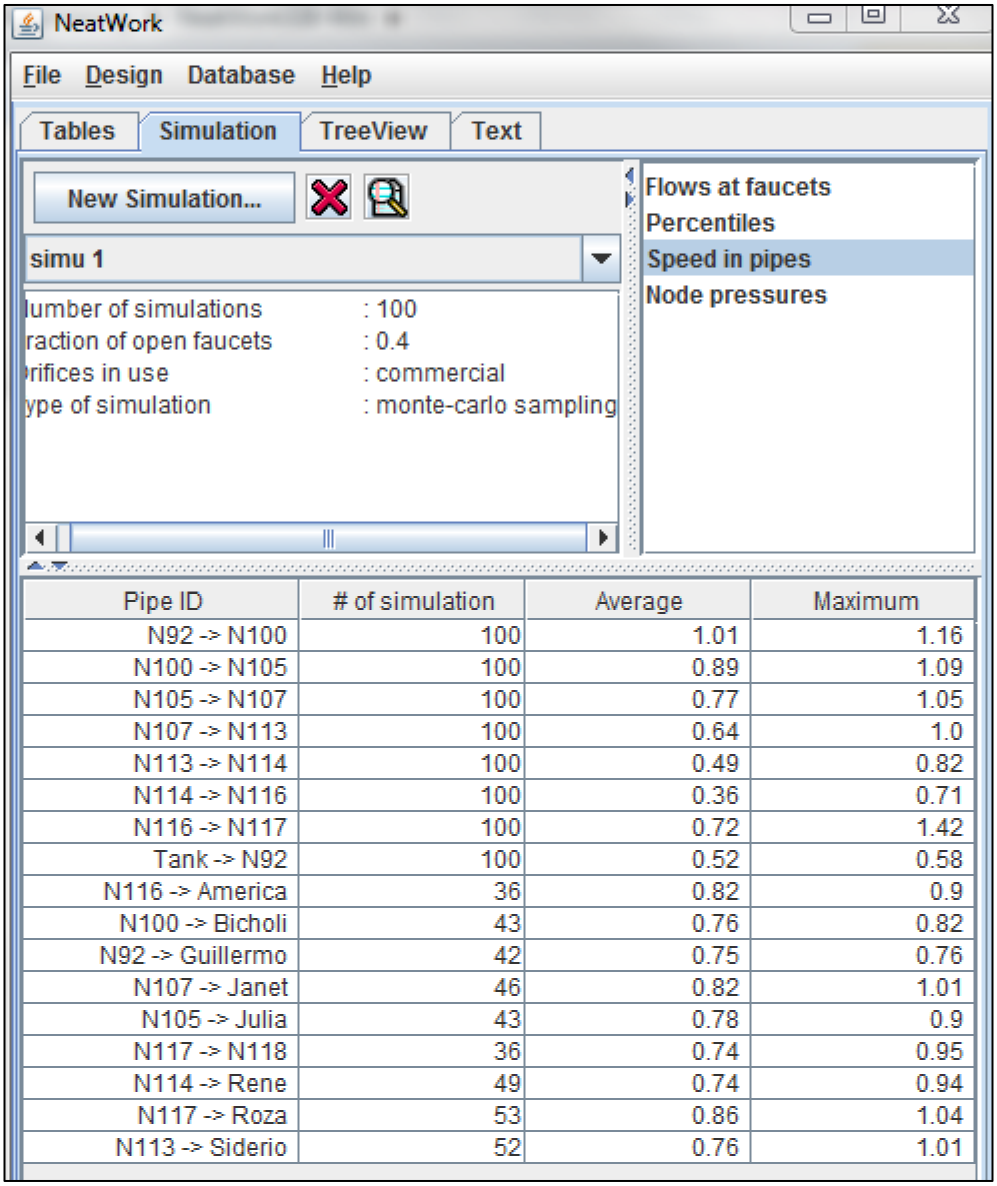
Faucet ID	# of occurences	Min	Average	Max	Variability	< 0.1	> 0.3	# of failures
Global average			0.2036			0%	0%	0
America	36	0.1973	0.212	0.2339	4%	0%	0%	0
Bicholi	43	0.1906	0.1974	0.2128	2%	0%	0%	0
Guillermo	42	0.1937	0.195	0.1975	0%	0%	0%	0
Janet	46	0.1844	0.214	0.2615	10%	0%	0%	0
Julia	43	0.188	0.2031	0.234	5%	0%	0%	0
N118	36	0.1431	0.1926	0.246	19%	0%	0%	0
Rene	49	0.1531	0.192	0.2437	11%	0%	0%	0
Roza	53	0.1658	0.2241	0.2717	14%	0%	0%	0
Siderio	52	0.149	0.1986	0.2618	11%	0%	0%	0

2.2 Percentiles (of flow in L/s)



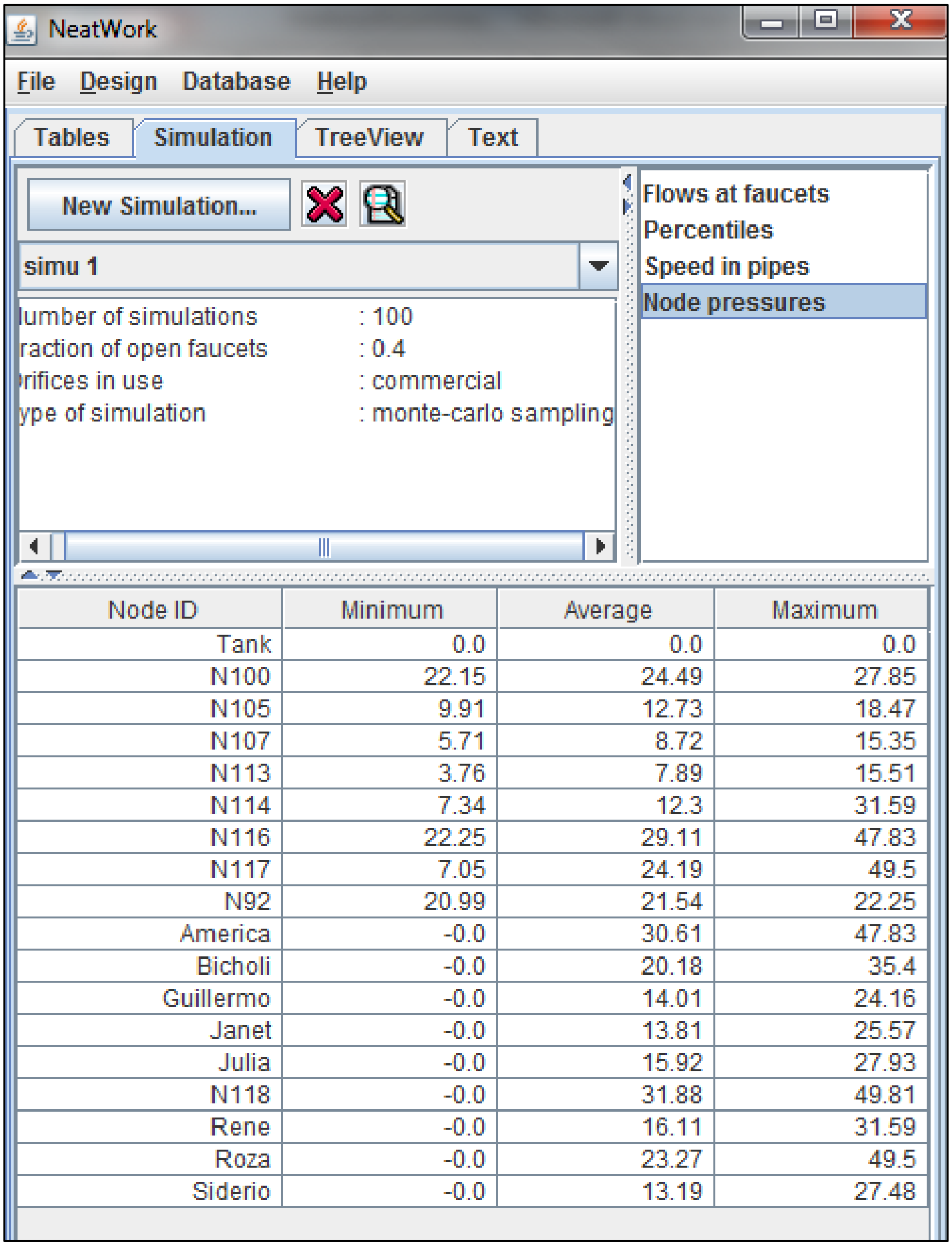
Faucet ID	# of occurences	Min	<10%	<25%	<50%	<75%	<90%	Max
America	36	0.1973	0.1994	0.2064	0.2131	0.2187	0.2239	0.2339
Bicholi	43	0.1906	0.1916	0.1923	0.196	0.202	0.2035	0.2128
Guillermo	42	0.1937	0.194	0.1943	0.1947	0.1956	0.1964	0.1975
Janet	46	0.1844	0.1866	0.1953	0.2115	0.2328	0.2503	0.2615
Julia	43	0.188	0.1926	0.1944	0.1996	0.2136	0.2165	0.234
N118	36	0.1431	0.1458	0.1537	0.2158	0.2284	0.2399	0.246
Rene	49	0.1531	0.1639	0.1787	0.1898	0.2046	0.2244	0.2437
Roza	53	0.1658	0.1727	0.1851	0.2368	0.2494	0.2596	0.2717
Siderio	52	0.149	0.1694	0.1821	0.2004	0.2107	0.2277	0.2618

2.3 Speed in pipes (m/s)



Pipe ID	# of simulation	Average	Maximum
N92 -> N100	100	1.01	1.16
N100 -> N105	100	0.89	1.09
N105 -> N107	100	0.77	1.05
N107 -> N113	100	0.64	1.0
N113 -> N114	100	0.49	0.82
N114 -> N116	100	0.36	0.71
N116 -> N117	100	0.72	1.42
Tank -> N92	100	0.52	0.58
N116 -> America	36	0.82	0.9
N100 -> Bicholi	43	0.76	0.82
N92 -> Guillermo	42	0.75	0.76
N107 -> Janet	46	0.82	1.01
N105 -> Julia	43	0.78	0.9
N117 -> N118	36	0.74	0.95
N114 -> Rene	49	0.74	0.94
N117 -> Roza	53	0.86	1.04
N113 -> Siderio	52	0.76	1.01

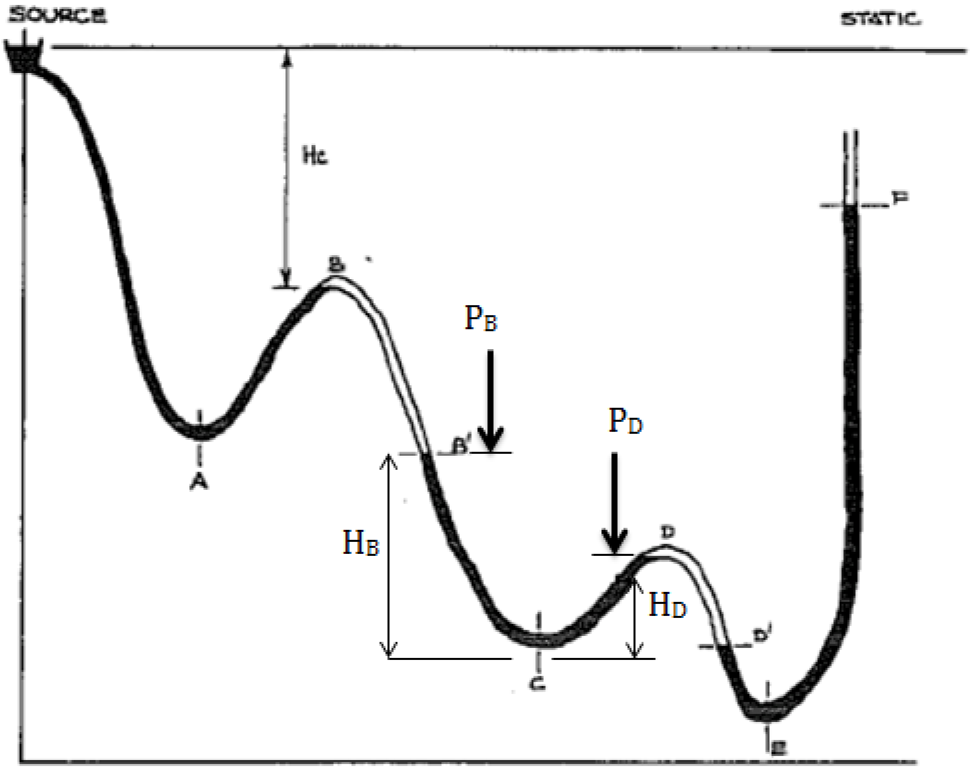
2.4 Node pressures (m of head)



Node ID	Minimum	Average	Maximum
Tank	0.0	0.0	0.0
N100	22.15	24.49	27.85
N105	9.91	12.73	18.47
N107	5.71	8.72	15.35
N113	3.76	7.89	15.51
N114	7.34	12.3	31.59
N116	22.25	29.11	47.83
N117	7.05	24.19	49.5
N92	20.99	21.54	22.25
America	-0.0	30.61	47.83
Bicholi	-0.0	20.18	35.4
Guillermo	-0.0	14.01	24.16
Janet	-0.0	13.81	25.57
Julia	-0.0	15.92	27.93
N118	-0.0	31.88	49.81
Rene	-0.0	16.11	31.59
Roza	-0.0	23.27	49.5
Siderio	-0.0	13.19	27.48

Appendix G: Air block analysis

Appendix G: Air block analysis



1) Determine Compression Head, Hc

$$H_c = 894ft - 866.25ft = 27.75ft$$

2) Compute Compressed Air Pressure

$$p_{\boldsymbol{B}} = p_{B'} = 33.9 + H_C = 33.9 + 27.75\ ft\ H_2 0 = 61.65ft\ H_2 0$$

3) Compute Volume of Compressed Air

-First find length of B-C

$$Length^{B-C} = \sum Actual\ Distance = 80 + 83 + 69 + 46.5 = 286ft$$

-Calculate Volume

$$V_o^{B-C} = L^{B-C} * \frac{\pi D^2}{4}$$

$$V_o^{B-C} = 286ft * \frac{\pi * \left(1.5in * \left(\frac{1ft}{12in}\right)\right)^2}{4} = 3.5ft^3$$

-Boyle's Law

$$V_1^{B-B\prime} = V_0^{B-C} * \left(\frac{p_{atm}}{p_B'}\right) = v_0^{B-C} * \frac{33.9}{33.9 + H_C} = 3.5ft$$

$$V_1^{B-B'} = 3.5ft^2 * \left(\frac{33.9ft}{33.9ft + 27.75ft}\right) = 1.93ft^3$$

4) Find elevation at B'

$$L^{B-B'} = L^{B-C} * \frac{V_1^{B-B'}}{V_0^{B-C}}$$

$$L^{B-B'} = 286ft * \left(\frac{1.93ft^3}{3.5ft^3}\right) = 157ft$$

5) Pressure in next downstream air block

$$p_B + H_B = p_D + H_D$$

$$p_D = p_B + H_B - H_D$$

$$p_D = 27.75ft + (866 - 753 - 27.75\text{ft}) - (798 - 753\text{ft}) = 68\text{ft}$$

6) Steps repeated for all air blocks

7) Compute "equivalent head" (H_e) of last air block

$$H_e = p_D' - p_{atm}$$
$$H_e = 68 - 33.9\ ft\ H_2O = 34.1\ ft\ H_2O$$

8) Calculate final head

$$H_f = H_e - h_L$$

-Darcy-Weisbach equation

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

$$h_L = 0.1 * \left(\frac{1567.5ft}{1.5in * \left(\frac{1ft}{12in} \right)} \right) * \frac{\left(0.73 \frac{ft}{s} \right)^2}{2 * \frac{32.174ft}{s^2}} = 10.39\ ft\ H_2O$$

$$H_f = 34.1 - 10.39\ ft\ H_2O = 23.8\ ft\ H_2O$$

9) Final elevation

$$Final\ elevation = z_D' + H_f = (798 - 68\ ft\ H_2O) + 23.8 = 754\ ft$$

-If final elevation < downstream tank elevation, need an air release valve

$$Downstream\ tank\ elevation = 829\ ft$$
$$> Final\ Elevation, install\ air\ release\ valve\ at\ waypoint\ 10$$

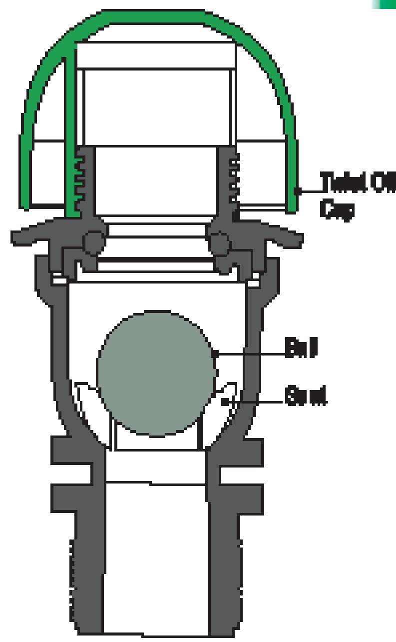
Appendix H: Geoflow air release valve

Air Vent / Vacuum Relief Valve

UPDATED

Description

Air release occurs when air escape the system at startup and vacuum relief allows air to enter during shutdown. The air vent vacuum breakers are installed at the highest points in the drip field to keep soil from being sucked into the emitters due to back siphoning and back pressure. This is an absolute necessity with underground drip systems. They are also used for proper drainage of the supply and return manifolds. Use one on the high point of the supply manifold and one on the high point of the return manifold and any high points of the system.

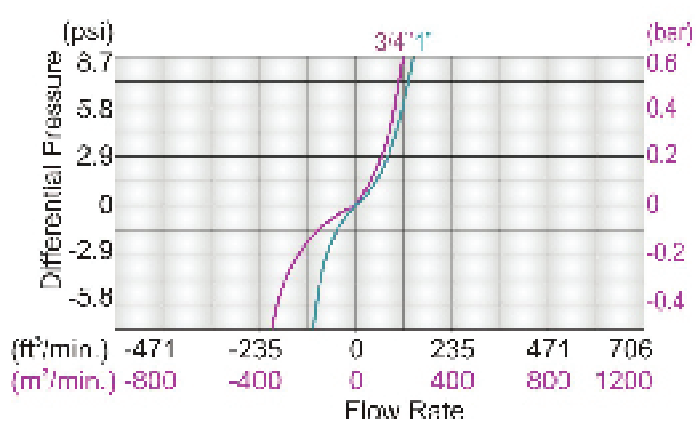


Features

Geoflow's new kinetic air vacuum breakers have a twist off cap that is easy to take apart for cleaning. No need to remove the valve to maintain it. The large clear passageway allows lots of air to flow in and out easily. The protected mushroom cap is ideal for wastewater, directing spray downward.

Part No.	APVBK75m	APVBK100m
Inlet	3/4"	1"
Max. Flow Rate	30 gpm	
Max Pressure	80 psi/185 ft.	80 psi/185 ft.
Max Temp	140 oF	140 oF
Height	5"	5.5"
Weight	1 oz.	1.2 oz.

Air and Vacuum Flow Rate



Specification

The Air Vacuum Breaker bady and ball shall be made of molded plastic. The ball shall be removable for easy cleaning. The Air Vacuum Breaker shall be part number APVBK75m or APVBK100m as supplied by Geoflow, Inc.

Product Sheets-2011 AirVentVacuumRelief(ir) 11E05.indd

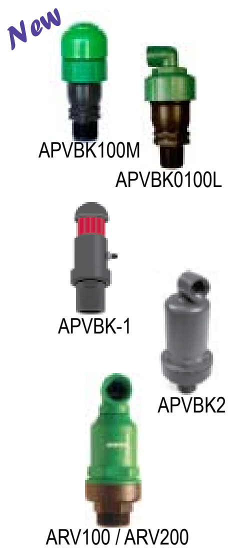
Geoflow, Inc. Tel 415-927-6000 / 800-828-3388 Fax 415-927-0120 www.geoflow.com

Look for the Genuine Geoflow stamp of quality

ACCESSORIES

Part Number	Description	Min. Qty	Weight (lbs.)	Suggested List Price

Air Vents



Part Number	Description	Min. Qty	Weight (lbs.)	Suggested List Price
APVBK100M	1" MPT kinetic air vacuum /relief valve For use in zone	1	0.3	22.00
APVBK100L	1" MPT kinetic air vacuum /relief valve with elbow For use in zone	1	0.3	22.00
APVBK1	1" MPT kinetic air/vacuum relief valve For use in zone	1	0.3	21.19
APVBK2	2" MPT kinetic air/vacuum relief valve For use in zone	1	2.5	75.00
ARV100	1" MPT continuous airvent/vacuum relief valve For use upstream of subzone valve	1	2.5	85.00
ARV200	2" MPT continuous airvent/vacuum relief valve For use upstream of subzone valve	1	2.5	111.00

Air Vent Box

Part Number	Description	Min. Qty	Weight (lbs.)	Suggested List Price
AVBOX-6	6" round box - commercial grade	1	1.5	11.00
AVBOX-10	10" round box - commercial grade	1	2.5	45.00

Solenoid Valves

Part Number	Description	Min. Qty	Weight (lbs.)	Suggested List Price
SVLVB-100	1" Solenoid valve. 24VAC, FPT, NC	1	0.8	88.20
SVLVB-100X	1" Solenoid valve, 24VAC, FPT, NC, External plumbing	1	1.0	148.00
SVLVB-150	1.5" Solenoid valve. 24VAC, FPT, NC	1	2.4	151.30
SVLVB-150X	1.5" Solenoid valve, 24VAC, FPT, NC, External plumbing	1	2.6	211.00
SVLVB-200	2" Solenoid valve. 24VAC, FPT, NC, External Plumbing	1	3.4	309.00
SVLVB-300	3" Solenoid valve. 24VAC, FPT, NC, External Plumbing.	1	4.4	484.50

Note: NC = Normally Closed valves. Normally open (NO) valves available upon request.
Replacement coils and diaphragms available. Please call Geoflow directly.

New

Actuated Valves

Part Number	Description	Min. Qty	Weight (lbs.)	Suggested List Price
BVLVACT-100	1" slip motorized ball valve with 120VAC. Indicator light	1	2.5	1000.00
BVLVACT-150	1.5" slip motorized ball valve with 120VAC. Indicator light	1	3.0	1200.00
BVLVACT-200	2" slip motorized ball valve with 120VAC. Indicator light	1	4.0	1240.00

3", 4" and 6" valves as well as 24 VAC options available upon request

Appendix I: Chlorination calculations

Appendix I: Chlorination calculations

The following discussion and calculations are adapted from the "User Field Guide for MINSA's In-Line Chlorinator" by Benjamin Yoakum, 2013.

1.0 Introduction

Chlorine treatment in the proposed water system is a function of chlorine concentration and contact time. A simple method to predict and evaluate the effectiveness of chlorine treatment in a water system is by using the C*t or Ct method. In this method, C, the free chlorine concentration, and t, the total contact time. The Ct value is determined by multiplying C and t at multiple locations within the system. Calculated Ct values are compared to Ct values required to kill common water-borne pathogens. If the calculated Ct value is insufficient, C, t, or both C and t, must be increased.

The following calculation is used to calculate Ct:

$$Ct = C * t$$

Where:

C is the "free chlorine concentration" in units of (mg Cl_2/L)

t is the "total contact time" in units of (min)

Ct is the "Ct value" in united of (min*mg Cl_2 /L)

Ct values for common water-borne pathogens may be found in Table 1.

Table 1. Ct requirements for destruction of common pathogens.

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

As seen in Table 1, we need a Ct value of 35 min*mg Cl_2/L to kill *E. Histolytica*. Thus, the target minimum Ct value to kill all pathogens will be conservatively set at 40 min*mg Cl_2/L. In other words, Ct values throughout the system must be equal to or greater than 40 min*mg Cl_2/L if chlorine treatment is effective.

2.0 Determining C, free chlorine concentration

Free chlorine is the category of chlorine that is available to disinfect the water and kill pathogens. Thus, we are only interested in measuring the free chlorine concentration in the system. Currently, MINSA in the Ngäbe-Bugle Comarca uses Hach color wheels to determine the free chlorine concentrations. It is assumed that these color wheels can be purchased.

Three values are important to consider when taking free chlorine measurements:

1. *Maximum Total Chlorine Concentration at any Location*: The World Health Organization (WHO) states that the maximum residual disinfectant level (MRDL) or the maximum level the concentration of "Total Chlorine" should reach is 5 mg Cl_2/L. Drinking water with concentrations above this may cause health problems. However, in the Ct method, we are only sampling "Free Chlorine" concentrations. Therefore, a good rule of thumb is to limit the level of free chlorine to 3 mg Cl_2/L. Samples to determine if you are exceeding the *Maximum Total Chlorine Concentration at any Location* should be taken from the influent pipe into the distribution tank. This water will have this highest chlorine concentration in the entire system. Residuals should be less than 1 mg Cl_2/L to avoid taste and odor problems.

2. *Minimum Free Chlorine Concentration*: The minimum free chlorine concentration recommended is 0.2 mg Cl_2/L at the last house receiving water in your distribution system. The last house is chosen to test for this value as it has the greatest chance of having the lowest free chlorine concentration value due to the chlorine being used up while sitting in the system. It is important to have some chlorine in all locations in your system so that if for example from a pipe is broken there will be some chlorine available to disinfect the water at that location. Again samples to determine the *Minimum Free Chlorine Residual* should be taken from the faucet of the last house in the system.

3. *Free Chlorine Concentration to Meet the Required Ct Value*: Finally, you need a free chlorine concentration value that is large enough to give you a Ct value that is sufficient to disinfect the water in your system. Samples to determine the *Free Chlorine Concentration to Meet the Required Ct Value* should be taken from the cleanout valve of the distribution tank. By sampling water from the clean out valve you have the best estimate of the concentration of "Free Chlorine" leaving your storage tank. However, it is advised that you leave the exit valve open for 3 minutes before taking a sample so that dirt does not enter your sample.

3.0 Determining t, contact time

The total contact time in the water system is the sum of the contact time in the storage tank and in the pipes between the storage tank and the first faucet, or home.

3.1 Contact time for storage tank

The equation for determining the contact time in the storage tank is:

$$Contact\ time\ in\ storage\ tank\ (min) = \frac{\text{Tank Volume (L)}}{Influent\ Flowrate\ (\frac{L}{min})} * 0.3$$

The value 0.3 is the tank's "baffling factor," which accounts for incomplete mixing of chlorinated water into the tank.

3.2 Contact time for piped system

The contact time for the water in pipes between the storage tank and first faucet depends on the volume of pipe. The equation for determining the volume in a pipe is:

$$Volume\ (L) = Length\ of\ pipe\ (ft) * \pi * \left(\frac{Pipe\ Diameter\ (in)}{2}\right)^2 * \left(\frac{\frac{28.31L}{ft^3}}{\frac{144\ in^2}{ft^2}}\right)$$

This equation needs to be used multiple times if the pipe diameter changes. Thus:

$$Total\ volume\ in\ piped\ system\ (L) = Volume\ in\ Pipe\ 1 + Volume\ in\ Pipe\ 2 + \cdots Volume\ in\ Pipe\ n$$

The contact time in pipes is:

$$Contact\ time\ in\ pipes\ (\text{min}) = \frac{\text{Total volume in piped system (L)}}{Influent\ flowrate\ \left(\frac{L}{min}\right)}$$

3.3 Total contact time

Total contact time is the sum of contact time in the storage tank and pipes.

4.0 Determining Ct

Ct should be calculated at three locations within the community based on the three values discussed above: (1) influent – water entering the storage tank, (2) effluent – water exiting the storage tank or cleanout valve, and (3) at the last faucet. Also, it is especially important to measure concentration on Day 1 (2 hours after chlorine tablet(s) have been inserted), Day 2 (24 hours after chlorine tablet(s) have been inserted), Day 6, and Day 7. However, more measurements are favored.

The Ct value for each location is calculated using the total contact time and free chlorine concentration in the first equation provided in this Appendix.

5.0 Determining number of chlorine tablets

The number of chlorine tablets is based on an iterative approach to satisfy the various requirements described above. Figure 1 illustrates this approach.

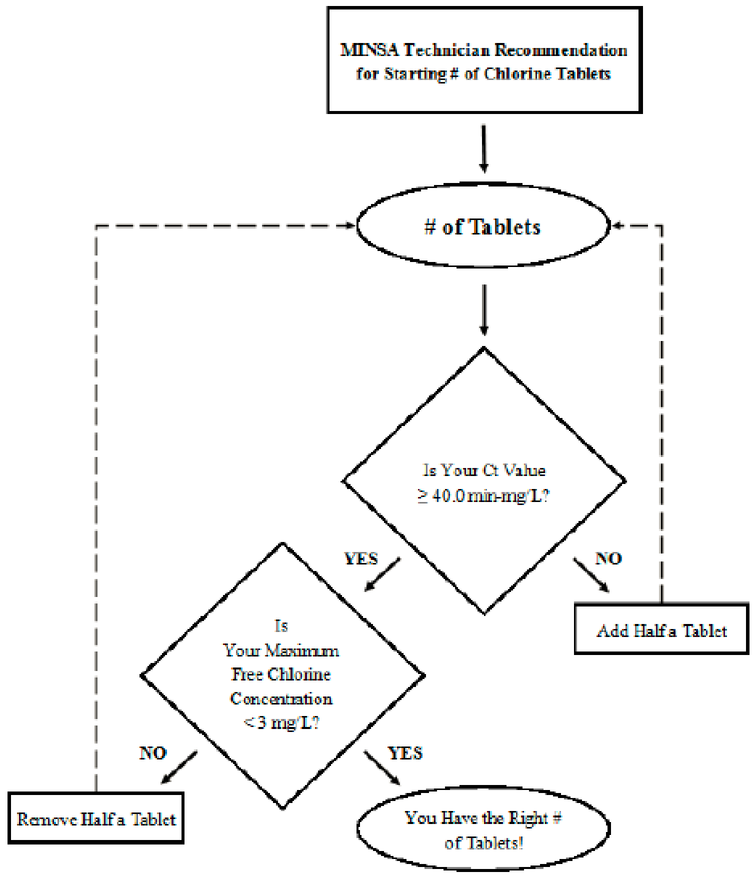


Figure 1. Flowchart - how to determine the correct number of tablets for the MINSA in-line chlorinator.

The flowchart starts with a recommendation from a MINSA technician. If such a recommendation is not given, it is recommended that the first iteration start with one chlorine tablet.

6.0 Example Problem

Assume the following concentrations were measured in the proposed water system at Bajo Gavilan:

Time of Sample	Free Chlorine Concentration ($mg\ Cl_2/L$)		
	Influent	Effluent	Last House
Hour 2	0.30	0.20	0.01
Day 1	0.15	0.03	0.02
Day 2	0.15	0.09	0.15
Day 3	0.34	0.06	0.03
Day 4	0.30	0.11	0.08
Day 5	0.17	0.09	0.10
Day 6	0.10	0.04	0.01
Day 7	0.06	0.02	0.00

We need to calculate Ct values for each sample. We are missing total contact time. First, the contact time in the storage tank will be calculated:

$$Contact\ time\ in\ storage\ tank\ (min) = \frac{\text{Tank Volume (L)}}{Influent\ Flowrate\ \left(\frac{L}{min}\right)} * 0.3$$

$$Contact\ time\ in\ storage\ tank\ (min) = \frac{4200\ \text{L}}{\frac{0.4L}{s} * \frac{60s}{1min}} * 0.3 = 52.5\ min$$

Next, the contact time in pipes to the first faucet or Guillermo's house. This depends on the volume of the pipes:

$$Total\ volume\ in\ piped\ system\ (L) = Volume\ in\ Pipe\ 1 + Volume\ in\ Pipe\ 2 + \cdots Volume\ in\ Pipe\ n$$

where the volume is:

$$Volume\ (L) = Length\ of\ pipe\ (ft) * \pi * \left(\frac{Pipe\ Diameter\ (in)}{2}\right)^2 * \left(\frac{\frac{28.31L}{ft^3}}{\frac{144\ in^2}{ft^2}}\right)$$

Pipe 1 (main line from storage tank (#80) to Guillermo's node (#92)):

$$Volume\ (L) = 1059ft * \pi * \left(\frac{1.5''}{2}\right)^2 * \left(\frac{\frac{28.31L}{ft^3}}{\frac{144\ in^2}{ft^2}}\right) = 367.9L$$

Pipe 2 (from node (#92) to Guillermo's tapstand):

$$Volume\ (L) = 20ft * \pi * \left(\frac{0.5''}{2}\right)^2 * \left(\frac{\frac{28.31L}{ft^3}}{\frac{144\ in^2}{ft^2}}\right) = 0.77L$$

Total volume:

$$Total\ volume\ in\ piped\ system\ (L) = 367.9 + 0.77 = 368.7\ L$$

The contact time in pipes:

$$Contact\ time\ in\ pipes\ (\text{min}) = \frac{\text{Total volume in piped system (L)}}{Influent\ flowrate\ \left(\frac{L}{min}\right)}$$

$$Contact\ time\ in\ pipes\ (\text{min}) = \frac{368.7\ \text{L}}{\frac{0.4L}{s} * \frac{60s}{1min}} = 15.4\ min$$

The total contact time in the system is:

$$Total\ contact\ time(min) = 52.5\,\text{min} + 15.4\ min = 67.9\ min$$

With total contact time known, this can be multiplied by the free chlorine concentration measurement for each effluent sample to produce the following table:

Time of Sample	Effluent Chlorine Concentration (mg/L)	Total Chlorine Contact time (min)	Ct (min*mg Cl_2 /L)
Hour 2	0.20	67.9	13.58
Day 1	0.03	67.9	2.04
Day 2	0.09	67.9	6.11
Day 3	0.06	67.9	4.07
Day 4	0.11	67.9	7.47
Day 5	0.09	67.9	6.11
Day 6	0.04	67.9	2.72
Day 7	0.02	67.9	1.36

As seen in the table above, none of the Ct values equals or exceeds our target Ct value of 40 min*mg Cl_2/L. Thus, ½ more of a chlorine tablet should be added (1.5 tablets total) and sampling should be repeated. This process continues until all effluent Ct values are greater than 40 min*mg Cl_2/L AND all influent and last house concentrations satisfy the requirements shown in section 2.0.

Appendix J: Cost estimate

Preliminary Opinion Of Probable Costs
PROJECT ESTIMATE SUMMARY

SYSTEMS FORMAT

Materials Estimate			
	Main Aqueduct Line Piping		$3,225
	Air Release Valve		$68
	Low Profile Springbox		$126
	Break Pressure Tanks		$1,834
	Waypoint 80		$1,225
	Tapstands		$170
	In-Line Chlorinator		$101
	Stream Crossings		$534
	Materials Subtotal		$7,281
Construction Estimate			
	Labor		$2,080
	Transportation		$600
Community Contribution	Labor		($2,080)
	Construction Subtotal		$600
	Materials and Construction Estimate Total		$7,881
	Design Contingency	10%	$788.11
	Estimate contingency	8%	$630.49
	Estimated Total		**$9,300**

Preliminary Opinion Of Probable Costs

SYSTEMS FORMAT

ITEM	ELEMENT	QUANTITY	UNITS	UNIT COST	COST	SUBTOTALS
Main Aqueduct Line Piping	PVC SDR 13.5 0.5"	46	6m pipe	$2.15	$98.90	
	PVC SDR 26 1"	105	6m pipe	$3.85	$404.25	
	PVC SDR 26 1.5"	325	6m pipe	$8.00	$2,600.00	
	Elbow PVC 1"	10	elbow	$1.98	$19.80	
	Elbow PVC 1.5"	25	elbow	$1.28	$32.00	
	Staking Ribbon	2	roll	$5.00	$10.00	
	PVC Glue	10	bottle	$6.00	$60.00	$3,224.95
Air Release Valve	Tee PVC 1.5"	1	tee	$1.60	$1.60	
	Geoflow AirVent Box	2	box	$11.00	$22.00	
	Geoflow Air Vent/ Vacuum Relief Valve	2	valve	$22.00	$44.00	$67.60
Low Profile Springbox	Concrete	7	50lb bag	$10.50	$73.50	
	PVC SDR 26 1.5"	2	6m pipe	$8.00	$16.00	
	Gravel	20	bag	$0.33	$6.67	
	Sand	20	bag	$0.17	$3.33	
	Waterproofing Admixture	2	gallon	$10.00	$20.00	
	Reinforcing Bar Steel	30	foot	$0.20	$6.00	$125.50
Break Pressure Tanks	Concrete	100	50lb bag	$10.50	$1,050.00	
	PVC SDR 26 1.5"	10	6m pipe	$8.00	$80.00	
	Elbow PVC 1.5"	25	elbow	$1.28	$32.00	
	Reinforcing Bar Steel	360	foot	$0.20	$72.00	
	Cinderblocks	300	block	$2.00	$600.00	$1,834.00
Waypoint 80	Concrete	100	50lb bag	$10.50	$1,050.00	
	PVC SDR 26 1.5"	6	6m pipe	$8.00	$48.00	
	Elbow PVC 1.5"	12	elbow	$1.28	$15.36	
	Reinforcing Bar Steel	300	foot	$0.20	$60.00	
	Tee PVC 1.5"	2	tee	$1.60	$3.20	
	Forms (cut boards and nails)	80	feet	$0.60	$48.00	$1,224.56
Tapstands	Shutoff Valve 0.5"	10	valve	$1.28	$12.80	
	Plastic Faucets	25	faucet	$2.00	$50.00	
	Tee PVC 1.5"	25	tee	$1.60	$40.00	
	Elbow PVC 0.5"	45	elbow	$0.16	$7.20	
	PVC SDR 13.5 0.5"	25	6m pipe	$2.15	$53.75	
	PVC Glue	1	bottle	$6.00	$6.00	$169.75
In-Line Chlorinator	Shutoff Valve PVC 1.5"	2	valve	$3.24	$6.48	
	Tee PVC 1.5"	2	tee	$1.60	$3.20	
	Elbow PVC 1.5"	2	elbow	$1.28	$2.56	
	PVC SDR 26 1.5"	3	6m pipe	$8.00	$24.00	
	MINSA In-Line Chlorinator System	1	system	$25.00	$25.00	
	Calcium Hypochlorite Tablet	20	tablet	$2.00	$40.00	$101.24
Stream Crossings	Gravel	60	bag	$0.33	$20.00	
	Concrete	15	50lb bag	$10.50	$157.50	
	Reinforcing Bar Steel	10	foot	$0.20	$2.00	
	Forms (cut boards, nails)	40	foot	$0.60	$24.00	
	Galvanized Steel Pipe 1.5"	22	10 ft pipe	$15.00	$330.00	$533.50
	Materials Subtotal					**$7,281.10**

REASONABLE ENGINEERING
PROPOSED New Aqueduct and Distribution System in Bajo Gavilan, PANAMA

Preliminary Opinion Of Probable Costs

SYSTEMS FORMAT

ITEM	ELEMENT	QUANTITY	UNITS	UNIT COST	COST	SUBTOTALS
Labor	Preliminary Construction	16	Crew-Hours	$8.00	$128.00	
	Site Preparation	6	Crew-Hours	$8.00	$48.00	
	Springbox Construction	25	Crew-Hours	$8.00	$200.00	
	Storage Tank Relocation and Waypoint 80 Pad	16	Crew-Hours	$8.00	$128.00	
	Stream Crossing Construction	50	Crew-Hours	$8.00	$400.00	
	Break Pressure Tank Consturction	75	Crew-Hours	$8.00	$600.00	
	Pipeline and Tapstand Construction and Burial	72	Crew-Hours	$8.00	$576.00	$2,080.00
Transportation	Truck from Almirante	20	Trip	$25.00	$500.00	
	Shipping of Additional Supplies	10	Trip	$10.00	$100.00	$600.00
Community Contribution	Labor					($2,080.00)
	Construction Subtotal					**$600.00**
	Materials and Construction Subtotal					**$7,881.10**
	Design Contingency	10%				$788.11
	Estimate contingency	8%				$630.49
	Estimated Total					**$9,299.70**

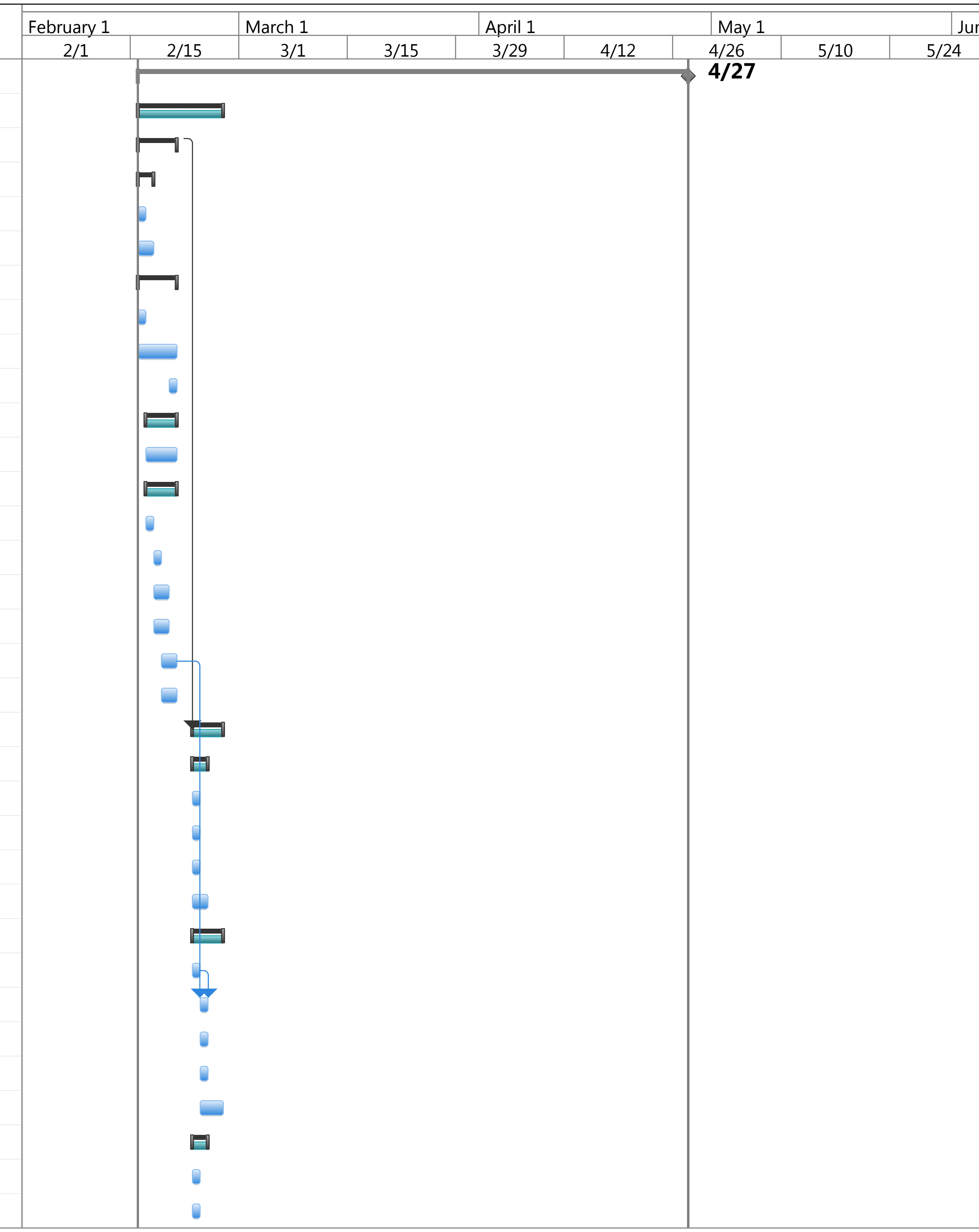
Appendix K: Construction schedule

Bajo Gavilan Aqueduct Design

Gantt Chart

Reasonable Engineering

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
0		**Bajo Gavilan Aqueduct Line Construction**	**51 days**	**Mon 2/16/15**	**Mon 4/27/15**	
1		**Preliminary Steps**	**9 days**	**Mon 2/16/15**	**Thu 2/26/15**	
2		**Material Purchase**	**5 days**	**Mon 2/16/15**	**Fri 2/20/15**	
3		**Readily Available Materials and Equipment**	**2 days**	**Mon 2/16/15**	**Tue 2/17/15**	
4		Shopping and Purchase in Almirante	1 day	Mon 2/16/15	Mon 2/16/15	
5		Transport to Bajo Gavilan	2 days	Mon 2/16/15	Tue 2/17/15	
6		**Unavailable Materials and Equipment**	**5 days**	**Mon 2/16/15**	**Fri 2/20/15**	
7		Order and Purchase	1 day	Mon 2/16/15	Mon 2/16/15	
8		Shipping Time to Almirante	5 days	Mon 2/16/15	Fri 2/20/15	
9		Transport to Bajo Gavilan	1 day	Fri 2/20/15	Fri 2/20/15	
10		**Site Planning**	**4 days**	**Tue 2/17/15**	**Fri 2/20/15**	
11		Aqueduct Path Clearing	4 days	Tue 2/17/15	Fri 2/20/15	
12		**Staking Key Component Locations during Clearing**	**4 days**	**Tue 2/17/15**	**Fri 2/20/15**	
13		Springbox Marking and Planning	1 day	Tue 2/17/15	Tue 2/17/15	
14		Air Release Valve Marking	1 day	Wed 2/18/15	Wed 2/18/15	
15		Break Pressure Tank Location Marking	2 days	Wed 2/18/15	Thu 2/19/15	
16		Stream Crossing Marking and Planning	2 days	Wed 2/18/15	Thu 2/19/15	
17		Storage Tank Pad Staking	2 days	Thu 2/19/15	Fri 2/20/15	
18		Community Staking	2 days	Thu 2/19/15	Fri 2/20/15	
19		**Concrete Construction**	**4 days**	**Mon 2/23/15**	**Thu 2/26/15**	**2**
20		**Break Pressure Tank Lids**	**2 days**	**Mon 2/23/15**	**Tue 2/24/15**	
21		Construct wooden forms	1 day	Mon 2/23/15	Mon 2/23/15	
22		Make concrete and cut rebar	1 day	Mon 2/23/15	Mon 2/23/15	
23		Pour concrete with placed rebar	1 day	Mon 2/23/15	Mon 2/23/15	
24		Allow to set	2 days	Mon 2/23/15	Tue 2/24/15	
25		**Storage Tank Pad Form**	**4 days**	**Mon 2/23/15**	**Thu 2/26/15**	
26		Construct wooden forms	1 day	Mon 2/23/15	Mon 2/23/15	
27		Transport form and cement to pad site	1 day	Tue 2/24/15	Tue 2/24/15	26,17
28		Mix concrete	1 day	Tue 2/24/15	Tue 2/24/15	
29		Pour concrete	1 day	Tue 2/24/15	Tue 2/24/15	
30		Allow to set	3 days	Tue 2/24/15	Thu 2/26/15	
31		**Stream Crossing Anchors**	**2 days**	**Mon 2/23/15**	**Tue 2/24/15**	
32		Construct wooden forms	1 day	Mon 2/23/15	Mon 2/23/15	
33		Make concrete and cut rebar	1 day	Mon 2/23/15	Mon 2/23/15	



Project: Bajo Gavilan
Date: Wed 12/10/14

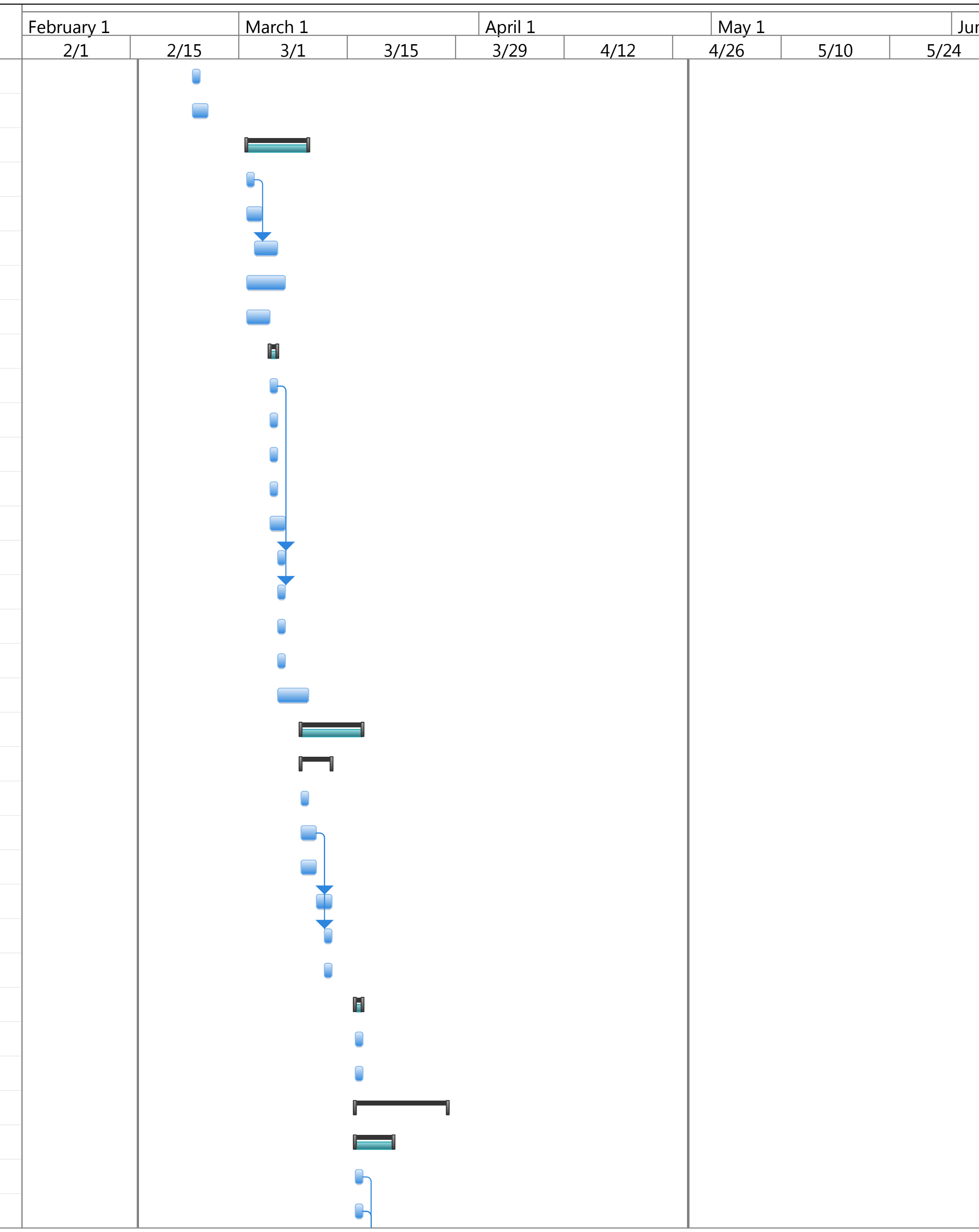
Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

Bajo Gavilan Aqueduct Design

Gantt Chart

Reasonable Engineering

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
34		Pour concrete with placed rebar	1 day	Mon 2/23/15	Mon 2/23/15	
35		Allow to set	2 days	Mon 2/23/15	Tue 2/24/15	
36		**Spring Box Construction**	**6 days**	**Mon 3/2/15**	**Mon 3/9/15**	
37		Equipment Transportation	1 day	Mon 3/2/15	Mon 3/2/15	
38		Hillside foliage clearing	2 days	Mon 3/2/15	Tue 3/3/15	
39		Hillside excavation	3 days	Tue 3/3/15	Thu 3/5/15	37
40		Water Diversion	5 days	Mon 3/2/15	Fri 3/6/15	
41		Boulder and small rock collection	3 days	Mon 3/2/15	Wed 3/4/15	
42		**Spring Box Layering**	**1 day**	**Thu 3/5/15**	**Thu 3/5/15**	
43		Transport construction materials	1 day	Thu 3/5/15	Thu 3/5/15	
44		Add large rocks	1 day	Thu 3/5/15	Thu 3/5/15	
45		Add small rocks	1 day	Thu 3/5/15	Thu 3/5/15	
46		Add Gravel	1 day	Thu 3/5/15	Thu 3/5/15	
47		Dig Wall Trench	2 days	Thu 3/5/15	Fri 3/6/15	
48		Add Ventalation Tubes	1 day	Fri 3/6/15	Fri 3/6/15	43
49		Mix concrete	1 day	Fri 3/6/15	Fri 3/6/15	43
50		Construct front Springbox Wall	1 day	Fri 3/6/15	Fri 3/6/15	
51		Seal Springbox with cement cap	1 day	Fri 3/6/15	Fri 3/6/15	
52		Allow to set	2 days	Fri 3/6/15	Mon 3/9/15	
53		**Storage Tank**	**6 days**	**Mon 3/9/15**	**Mon 3/16/15**	
54		**Storage Tank Transportation**	**4 days**	**Mon 3/9/15**	**Thu 3/12/15**	
55		Detach from Existing Aqueduct	1 day	Mon 3/9/15	Mon 3/9/15	
56		Make Preliminary Plan of Movement	2 days	Mon 3/9/15	Tue 3/10/15	
57		Clear Cut Path from Existing Location to New site	2 days	Mon 3/9/15	Tue 3/10/15	
58		Rig for transportation	2 days	Wed 3/11/15	Thu 3/12/15	56
59		Transport storage tank	1 day	Thu 3/12/15	Thu 3/12/15	56
60		Secure storage tank	1 day	Thu 3/12/15	Thu 3/12/15	
61		**In-Line Chlorinator**	**1 day**	**Mon 3/16/15**	**Mon 3/16/15**	
62		Piping installation to storage tanking	1 day	Mon 3/16/15	Mon 3/16/15	
63		Installation of In-line chlorinator system	1 day	Mon 3/16/15	Mon 3/16/15	
64		**Stream Crossing Construction**	**10 days**	**Mon 3/16/15**	**Fri 3/27/15**	
65		**Stream Crossing, Waypoint #48**	**5 days**	**Mon 3/16/15**	**Fri 3/20/15**	
66		Foliage Clearing	1 day	Mon 3/16/15	Mon 3/16/15	
67		Stream Water Diversion	1 day	Mon 3/16/15	Mon 3/16/15	



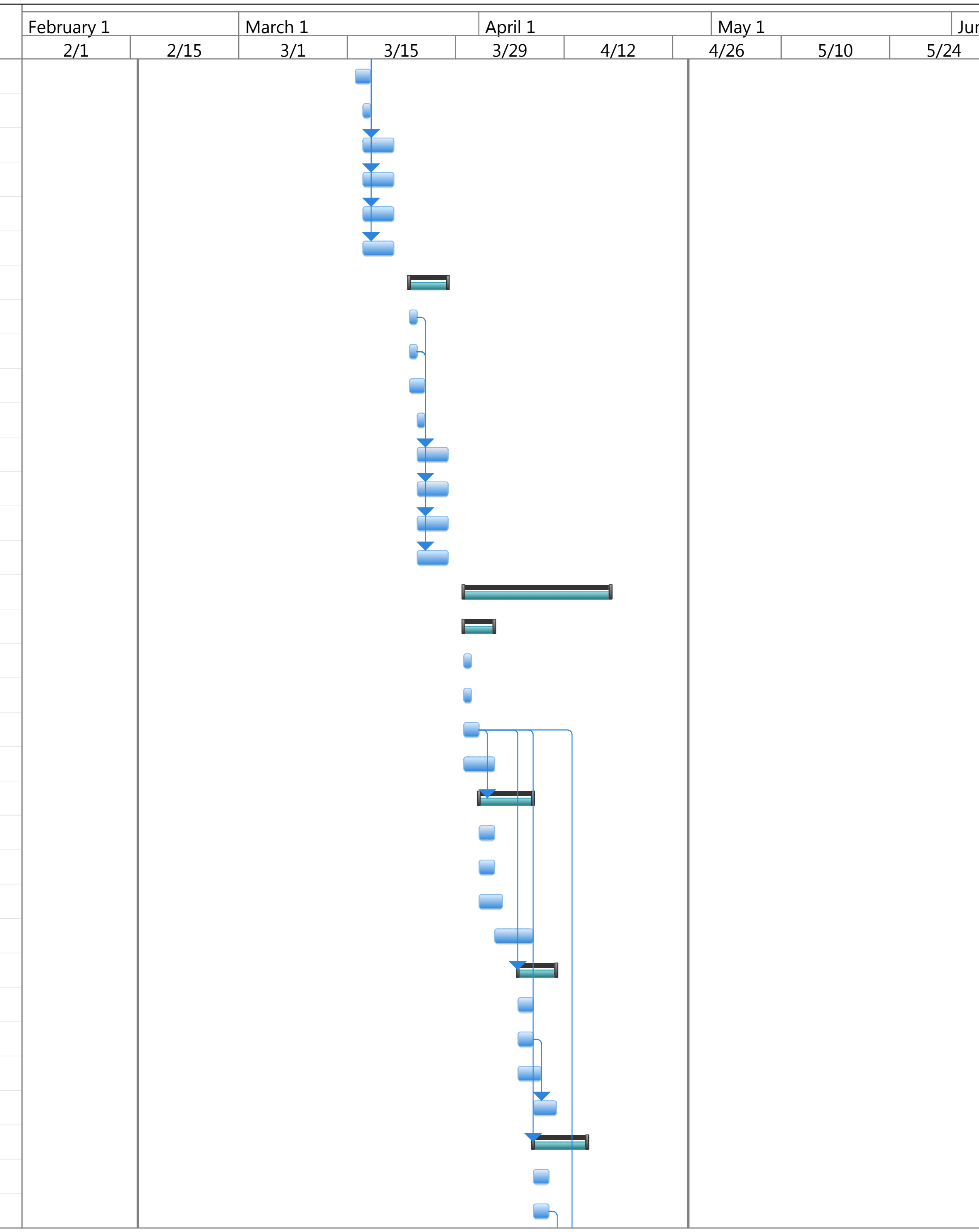
Project: Bajo Gavilan
Date: Wed 12/10/14

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	

Bajo Gavilan Aqueduct Design

Gantt Chart

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
68		Dig and Excavate for cement anchor locations	2 days	Mon 3/16/15	Tue 3/17/15	
69		Place and secure cement anchors (do not bury)	1 day	Tue 3/17/15	Tue 3/17/15	
70		Dig and Excavate creek bed	4 days	Tue 3/17/15	Fri 3/20/15	67
71		Place 10ft lengths of galvanized pipe	4 days	Tue 3/17/15	Fri 3/20/15	67
72		Cover with outlined materials	4 days	Tue 3/17/15	Fri 3/20/15	67
73		Bury and secure pipe	4 days	Tue 3/17/15	Fri 3/20/15	66
74		**Stream Crossing, Waypoint #71**	**5 days**	**Mon 3/23/15**	**Fri 3/27/15**	
75		Foliage Clearing	1 day	Mon 3/23/15	Mon 3/23/15	
76		Stream Water Diversion	1 day?	Mon 3/23/15	Mon 3/23/15	
77		Dig and Excavate for cement anchor locations	2 days	Mon 3/23/15	Tue 3/24/15	
78		Place and secure cement anchors (do not bury)	1 day?	Tue 3/24/15	Tue 3/24/15	
79		Dig and Excavate creek bed	4 days	Tue 3/24/15	Fri 3/27/15	76
80		Place 10ft lengths of galvanized pipe	4 days	Tue 3/24/15	Fri 3/27/15	76
81		Cover with outlined materials	4 days	Tue 3/24/15	Fri 3/27/15	76
82		Bury and secure pipe	4 days	Tue 3/24/15	Fri 3/27/15	75
83		**Pressure Break Tank Construction**	**15 days**	**Mon 3/30/15**	**Fri 4/17/15**	
84		**Pressure Break Tank Construction, Waypoint #80**	**4 days**	**Mon 3/30/15**	**Thu 4/2/15**	
85		Material Transportation to site	1 day	Mon 3/30/15	Mon 3/30/15	
86		Mixing Cement, Mortar, and cutting Rebar and PVC	1 day	Mon 3/30/15	Mon 3/30/15	
87		Tank Construction	2 days	Mon 3/30/15	Tue 3/31/15	
88		Setting Time	4 days	Mon 3/30/15	Thu 4/2/15	
89		**Pressure Break Tank Construction, Waypoint #32**	**5 days**	**Wed 4/1/15**	**Tue 4/7/15**	**87**
90		Material Transportation to site	2 days	Wed 4/1/15	Thu 4/2/15	
91		Mixing Cement, Mortor, and cutting Rebar and PVC	2 days	Wed 4/1/15	Thu 4/2/15	
92		Tank Construction	3 days	Wed 4/1/15	Fri 4/3/15	
93		Setting Time	3 days	Fri 4/3/15	Tue 4/7/15	
94		**Pressure Break Tank Construction, Waypoint #39**	**5 days**	**Mon 4/6/15**	**Fri 4/10/15**	**87**
95		Material Transportation to site	2 days	Mon 4/6/15	Tue 4/7/15	
96		Mixing Cement, Mortor, and cutting Rebar and PVC	2 days	Mon 4/6/15	Tue 4/7/15	
97		Tank Construction	3 days	Mon 4/6/15	Wed 4/8/15	
98		Setting Time	3 days	Wed 4/8/15	Fri 4/10/15	96
99		**Pressure Break Tank Constuction, Waypoint #56**	**5 days**	**Wed 4/8/15**	**Tue 4/14/15**	**87**
100		Material Transportation to site	2 days	Wed 4/8/15	Thu 4/9/15	
101		Mixing Cement, Mortor, and cutting Rebar and PVC	2 days	Wed 4/8/15	Thu 4/9/15	



Project: Bajo Gavilan
Date: Wed 12/10/14

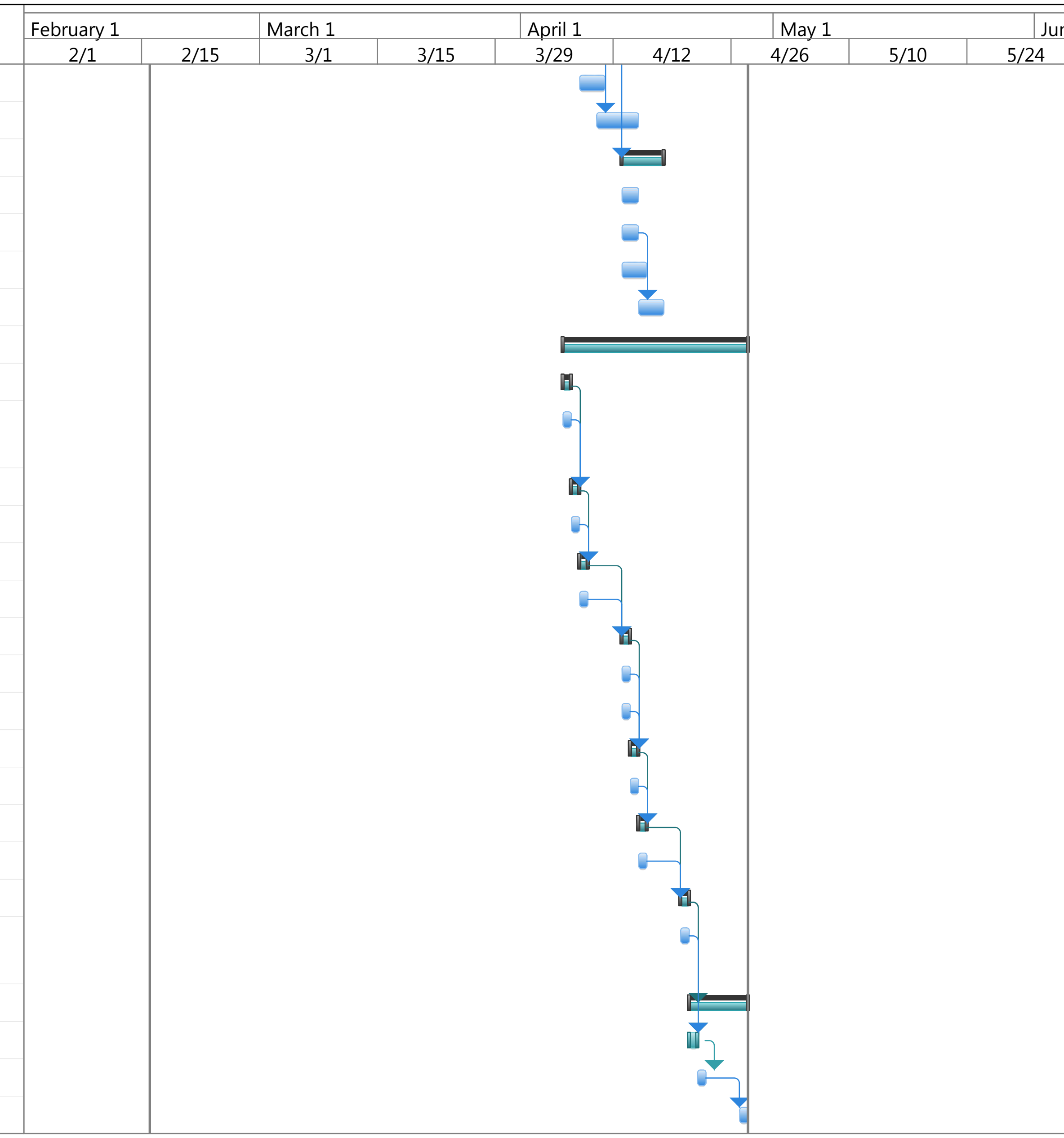
Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

Bajo Gavilan Aqueduct Design

Gantt Chart

Reasonable Engineering

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
102		Tank Construction	3 days	Wed 4/8/15	Fri 4/10/15	
103		Setting Time	3 days	Fri 4/10/15	Tue 4/14/15	101
104		**Pressure Break Tank Constuction, Waypoint #60**	**5 days**	**Mon 4/13/15**	**Fri 4/17/15**	**87**
105		Material Transportation to site	2 days	Mon 4/13/15	Tue 4/14/15	
106		Mixing Cement, Mortar, and cutting Rebar and PVC	2 days	Mon 4/13/15	Tue 4/14/15	
107		Tank Construction	3 days	Mon 4/13/15	Wed 4/15/15	
108		Setting Time	3 days	Wed 4/15/15	Fri 4/17/15	106
109		**Constructing and Burying PVC Pipeline**	**16 days**	**Mon 4/6/15**	**Mon 4/27/15**	
110		**From Waypoint #1 to #13**	**1 day**	**Mon 4/6/15**	**Mon 4/6/15**	
111		Add Air Release Valve and Protective Box at Waypoint #11	1 day	Mon 4/6/15	Mon 4/6/15	
112		**From Waypoint #13 to #32**	**1 day**	**Tue 4/7/15**	**Tue 4/7/15**	**110,111**
113		Connect to Break Pressure Tank at Waypoint #32	1 day	Tue 4/7/15	Tue 4/7/15	
114		**From Waypoint #32 to #39**	**1 day**	**Wed 4/8/15**	**Wed 4/8/15**	**113,112**
115		Connect to Break Pressure Tank at Waypoint #39	1 day	Wed 4/8/15	Wed 4/8/15	
116		**From Waypoint #39 to #56**	**1 day**	**Mon 4/13/15**	**Mon 4/13/15**	**115,114**
117		Connect to Stream Crossing at Waypoint #48	1 day	Mon 4/13/15	Mon 4/13/15	
118		Connect to Break Pressure Tank at Waypoint #56	1 day	Mon 4/13/15	Mon 4/13/15	
119		**From Waypoint #56 to #65**	**1 day**	**Tue 4/14/15**	**Tue 4/14/15**	**117,118,116**
120		Connect to Break Pressure Tank at Waypoint #60	1 day	Tue 4/14/15	Tue 4/14/15	
121		**From Waypoint #65 to #75**	**1 day**	**Wed 4/15/15**	**Wed 4/15/15**	**119,120**
122		Connect to Stream Crossing at Waypoint #71	1 day	Wed 4/15/15	Wed 4/15/15	
123		**From Waypoint #75 to #80**	**1 day**	**Mon 4/20/15**	**Mon 4/20/15**	**121,122**
124		Connect Pipeline to Break Pressure Tank, Storage Tank, and In-Line Chlorinator	1 day	Mon 4/20/15	Mon 4/20/15	
125		**Community Pipeline and Tapstand Construction**	**5 days**	**Tue 4/21/15**	**Mon 4/27/15**	**123**
126		From Waypoint #80 to #92	1 day	Tue 4/21/15	Tue 4/21/15	124,123
127		From Waypoint #94 to #105	1 day	Wed 4/22/15	Wed 4/22/15	126
128		From Waypoint #105 to #118	1 day	Mon 4/27/15	Mon 4/27/15	127



Project: Bajo Gavilan
Date: Wed 12/10/14

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	

Appendix L: User manual

Appendix L: Construction and Maintenance Manual

1.0 Introduction

This document is intended to provide the PCV in Bajo Gavilan with general construction guidance for the components designed in this project. It is important to note that these are guidelines and not rules. Steps for construction should be carefully reviewed, revised, developed, and discussed with community members prior to the commencement of work.

Visual representations of all components are located in Appendix M and N. Illustrations for each component can be found in Appendix M; constructions drawings are found in Appendix N.

2.0 Spring Box

Construction
The following steps are adapted from Jones, 2014 (Available on CD). Consult Jones, 2014 for more information on low-profile spring boxes.

- The first step in construction is the development the capture zone. This concept is new to the community, so proper planning by prior to beginning the project will be important.
- Material must be removed from the flow path of the spring. The main goal is to remove the soft soil above the impermeable rock layer, exposing the spring.
- Once this soil layer is excavated, the area should be filled first with a base layer of large rocks, likely collected during the initial excavation process, followed by a layer of small rocks, and finally a layer of purchased gravel. This entire capture zone is capped with mortar.
- The spring box must be constructed at the base of the spring capture system, with dimensions that suit the location the best. The design can be based on the two other spring boxes the community has built previously, but the cap over the capture zone must extend fully through the capture zone for a complete seal.
- Screened ventilation tubes (also present in existing spring boxes in the community) should be installed to allow air to escape and promote water flow.

Maintenance
- The spring box should be inspected monthly or when a problem arises
- Inspections should include checking for sediment build-up
- If sediment exists, access the box through the clean-out pipe and remove the sediment

3.0 Aqueduct Line

Construction
- The aqueduct route should be cleared prior to trenching
- Locations of all system components should be marked
- All pipe is to be buried at least 1.5’ below the ground surface

    - Trenching and construction methods used in the existing aqueduct should be followed

Maintenance

- The aqueduct line should be inspected annually or when a problem arises
- Inspections should include walking along the line to check for any issues or potential issues.

3.1 Geoflow Air Release Valve

Construction

- One air release valve shall be installed at Waypoint 11
- Installation should be quick and easy; follow the directions provided with the valve
- An air vent box will be placed over the buried air release valve to protect it from being stepped on. The top of the box will be flush with the ground and will have a green top for visibility.

Maintenance

- The twist off cap on the valve should be removed every 3 months for cleaning. If there is no debris after 3 months of operation, cleaning can occur less frequently
- The replacement valve can be installed if the first valve is damaged or fails
- If both valves do not work at all, alternatives include: (1) creating a DIY air release valve (Section 6.0) and (2) drill or punch holes through the PVC at this location.

3.2 Stream Crossings

Construction

- Construction will involve the creation of two concrete anchors which will be placed 10’ from each bank of the stream.
    - These anchors should be level in relation to each other across the stream bed, as the pipe will extend from one anchor to the other.
    - The anchors will be 2’ wide, 2’ high, and 1’ deep
    - Rebar U-shaped loops will be inserted at a depth of at least 4”. The loops should be placed 2” away from each other to allow the galvanized pipe to be dropped between the loops (not threaded through).
    - When the pipe is placed between the rebar loops, the pipe should be tied down with wire or other material suitable to keep the galvanized pipe down.
- Next, the pipe will need to be assembled on land in sections to prepare for installation.
- Excavation of a trench across the stream perpendicular to stream flow will be required to bury the pipe.
    - The trench will likely be able to be dug across the stream without diverting the flow of the stream.
- However, a dam may be required to divert water away from the construction zone to improve working conditions.

    - In this case, it is recommended that crossings are constructed in the dry season when stream flows are low.
- Finally, the pipe shall be placed into the trench and appropriately connected to the anchors.
- The trench will be filled (from bottom to top) with well graded boulders, rocks, gravel, and stream sediments.

Maintenance

- Stream crossings should be checked for scouring and/or movement during the annual aqueduct inspection.

<u>3.4 Break Pressure Tanks</u>

For more details on construction, please consult pages 69-83 in Niskanen, 2003 (available on CD). While the description in Niskanen is for a storage tank, he used the same procedure to construct break pressure tanks at a rural community in the Dominican Republic.

Construction

- Wooden forms will need to be assembled for the perimeter of the base of each of the break pressure tanks, and the area around each tank location will need to be cleared, marked, and excavated.
- The tank should be constructed on a flat area of ground. If this is not available near the waypoint location, the concrete footing will need to be adjusted accordingly.
- Before the pouring of the concrete pad, install a line of No. 3 rebar stands vertically. The rebar stands will later be threaded through the cinder block cavities to give the structure more strength. Although measurements are given in the engineering drawings, this may need to be adjusted for local cinderblock.
- Once the rebar has been placed around the perimeter of the break pressure tank, the concrete may be mixed and poured, and the foundation may be allowed to set with vertical rebar.
- Next, the cinder blocks should be laid and stacked, threading the No. 3 rebar through the cinder block cavities.
- All cavities should be filled with a concrete mix and allowed to set
- All pipes (inflow, outflow, clean-out, and overflow) will need to be cut and installed; this may be done during the stacking of cinder blocks
- Wooden forms and placed curved rebar will also be needed to construct the break pressure tank lids. This can be done in the village at transported to the site. Once cut to dimensions and nailed together, the forms may be reused for multiple lids. The curved rebar will be place approximately 5 inches from the edge of the lid, placed vertically for use as a handle, then the concrete may be poured and allowed time to set.
- The overflow pipe should be directed a safe distance away from the tank to eliminate the possibility of erosion near the components. The outflow from this pipe should be directed onto riprap to reduce erosion.

Maintenance

- Three concrete covers on the top of the break pressure tank offer community members various configurations on how to remove the roof and inspect the tank
- Tanks should be visually inspected every 3 months to track the build-up of sediment in the tank
- When sediment builds up, the tank should be cleaned out via the clean-out pipe on the inlet side of the tank, allowing inflow to flush the tank of sediment

4.0 Waypoint 80

4.1 Concrete Pad

Construction

- The area of the concrete pad will be cleared and staked to the proper dimensions, and then excavated for concrete.
- Lay edge boards to form the perimeter of the pad wall. Arrange ⅜” diameter rebar in grid pattern to form 12” x 12” mesh, suspended 4” above the ground.
- Through mesh, fill pad area with 6” of concrete using a mix of ½ gravel, ⅓ sand, and ⅙ cement by volume. Allow slab to cure for 7 days before removing molds.

4.2 In-line chlorinator

See Appendix I and Yoakum, 2013 (Available on CD) for construction and maintenance instructions.

4.3 Storage Tank

Construction

- In the existing aqueduct, one of the 4,200 liter storage tanks is not being used. This tank should be transported from its current position to the concrete pad at waypoint 80.
- The community can use the same method they used to move the tank to its current location to move it to the concrete pad at waypoint 80.
    - The tank is large and fragile; workers should move slow and deliberately.
- The overflow pipe should be directed a safe distance away from the concrete pad to eliminate the possibility of erosion near the components of waypoint 80. The outflow from this pipe should be directed onto riprap to reduce erosion.

Maintenance

- The tank should be visually inspected routinely to gauge the necessity of maintenance tasks for the tank. Suggested inspection intervals:
    - Every 3 months for the first year
    - Every 6 months after that
- During inspection, look for sediment build up (there should not be enough to cause problems), leaks, and any other causes for concern

- Should the tank need maintenance of any kind, water should be routed through the break pressure tank to allow the storage tank to be worked on without disrupting the water supply to the community.

4.4 Break Pressure Tank

Same as section 3.4, but the tank will be built on the concrete pad.

5.0 House access

5.1 Tapstands

Construction
The construction of tapstands at the proposed aqueduct should be similar, if not identical, to tapstand construction at the existing aqueduct.

- The branching PVC pipe should also be buried
- Order of installation:
    - Install a wooden post (a 2x4 or similar size) at desired location
    - Install a tee at the main line, which reduces the pipe diameter to 0.5" SDR 13.5 PVC
    - Install a shut-off valve between the tee and the faucet
    - Install the faucet at a convenient height
    - A small piece of fabric may be placed at the end of the faucet to filter any coarse materials prior to use

6.0 Other

6.1 DIY Air release valve

In the instance that the air release valves suggested have failed and there are no available replacements, follow the directions below to make an air release valve from likely available materials.

Materials:

- ¾" male PVC slip adapter (2), preferably with a small ledge on the inside that the o-ring can set
- ¾" PVC tubing
- ¾" acrylic ball
- Rubber O-ring
- Nail
- PVC cement

Construction

1. On the PVC tubing, mark ⅝ inch from the base and drill a small hole all the way through the pipe. Put the nail through the hole and secure both sides of the nail to the PVC pipe, making sure that excess metal is removed from the nail and it is flush on both sides.
2. Prime the adapter with PVC cement and place the o-ring and adapter.
3. Prime the PVC tubing from the previous step with cement and place it into the adapter. On the other side add the other adapter piece with cement and secure both ends. allowing for cement to cure.
4. Be sure to test the air-release valve before it is placed in the line to ensure a tight seal when water is in the line.

7.0 References

Jones, E.K. 2014. Improvements in Sustainability of Gravity-Fed Water Systems in the Comarca Ngäbe-Buglé, Panama: Spring Captures and Circuit Rider Model, a master's report. Michigan Technological University, Houghton, MI. Link: http://www.mtu.edu/peacecorps/programs/civil/pdfs/JONESE_MSReport.pdf. Available on CD.

Niskanen, R.W. 2003. The Design, Construction, And Maintenance of a Gravity-Fed Water System In The Dominican Republic, a thesis report. Michigan Technological University, Houghton, MI. Link: http://www.mtu.edu/peacecorps/programs/civil/pdfs/matt-niskanen-thesis-final.pdf. Also available on CD.

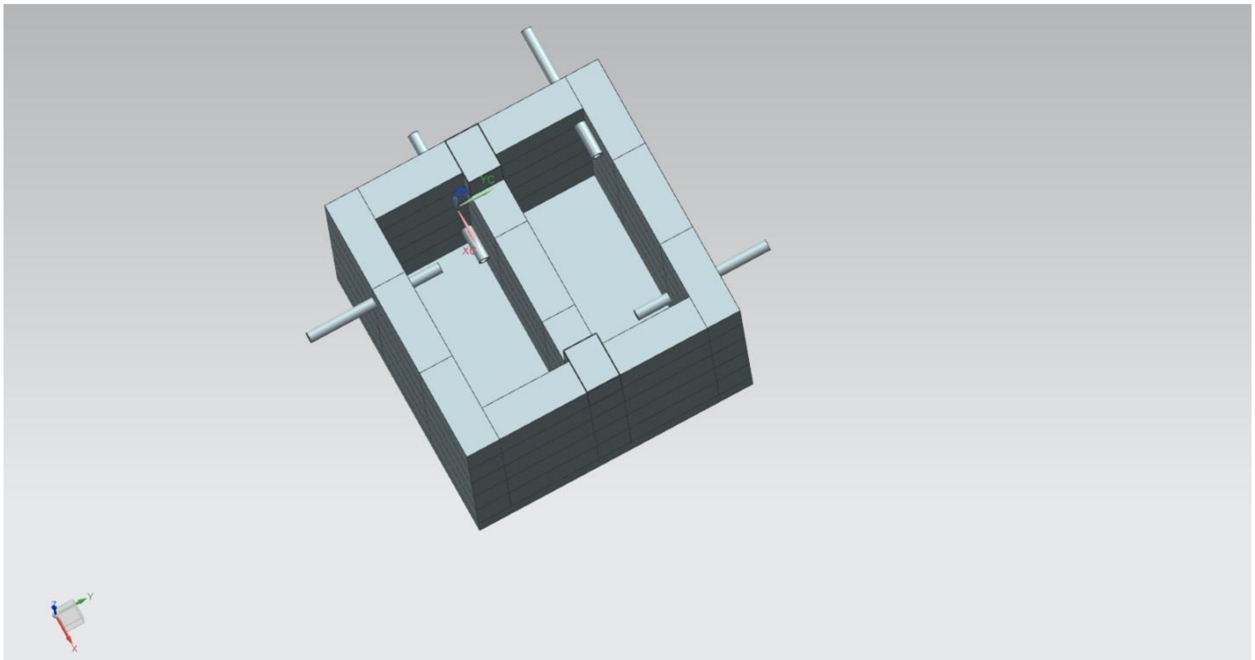
Yoakum, B. 2013. User Field Guide for MINSA's In-Line Chlorinator. Link: http://usfmi.weebly.com/uploads/5/3/9/2/5392099/users_manual_for_minsa_in-line_chlorinator.pdf. Also available on CD.

Appendix M: Illustrations of components

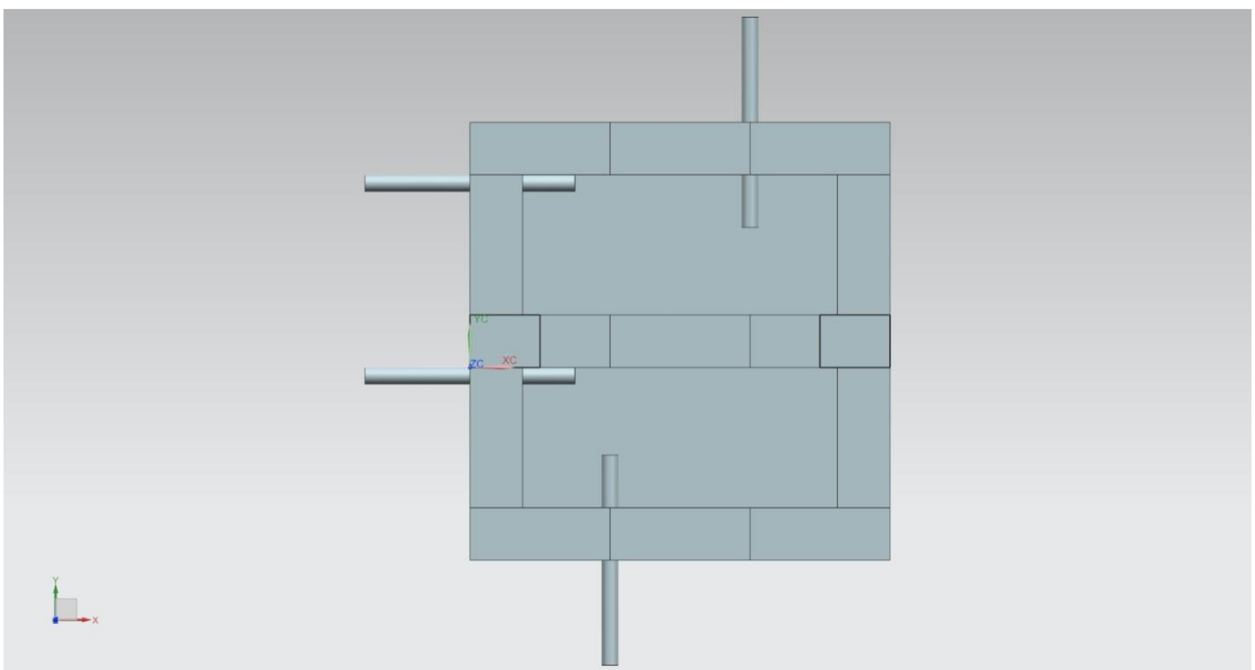
Appendix M: Illustrations of components

Break Pressure tanks

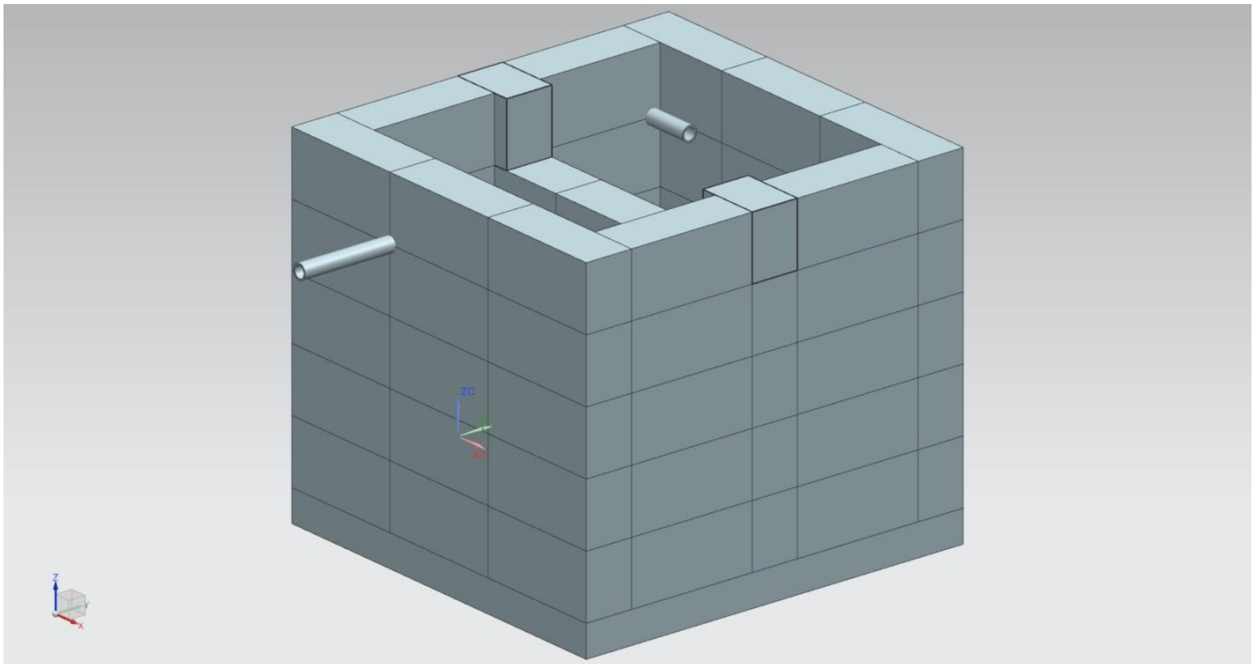
Overview:



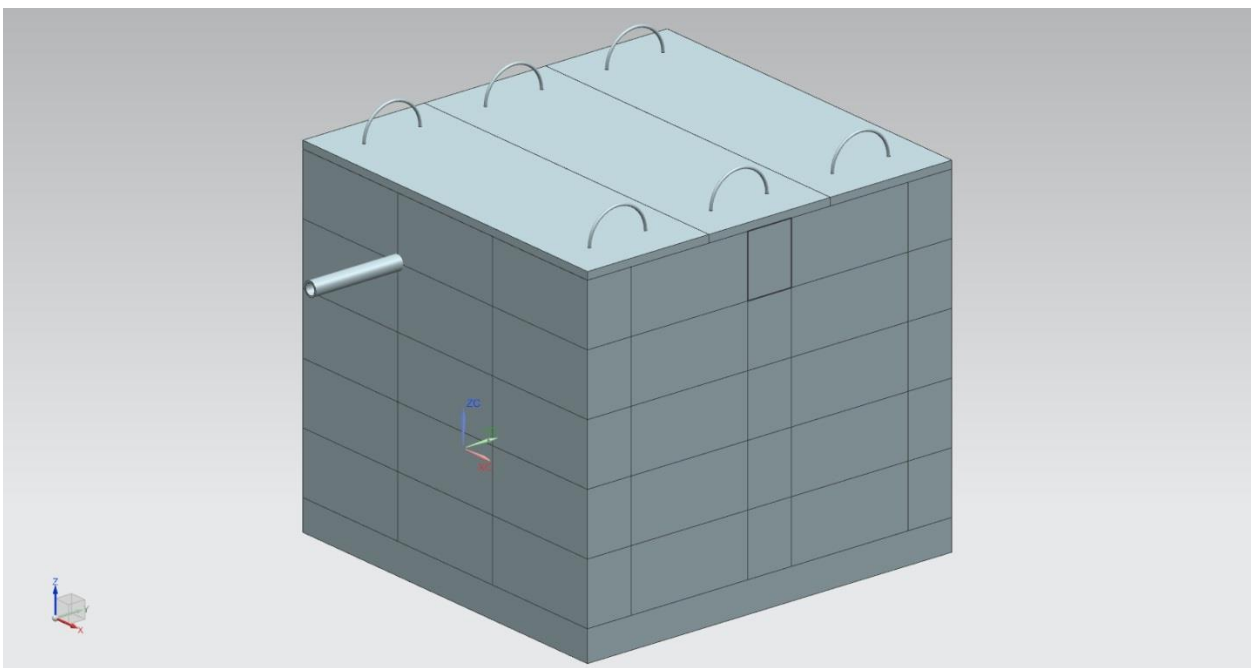
Top:



Isometric (without cover):

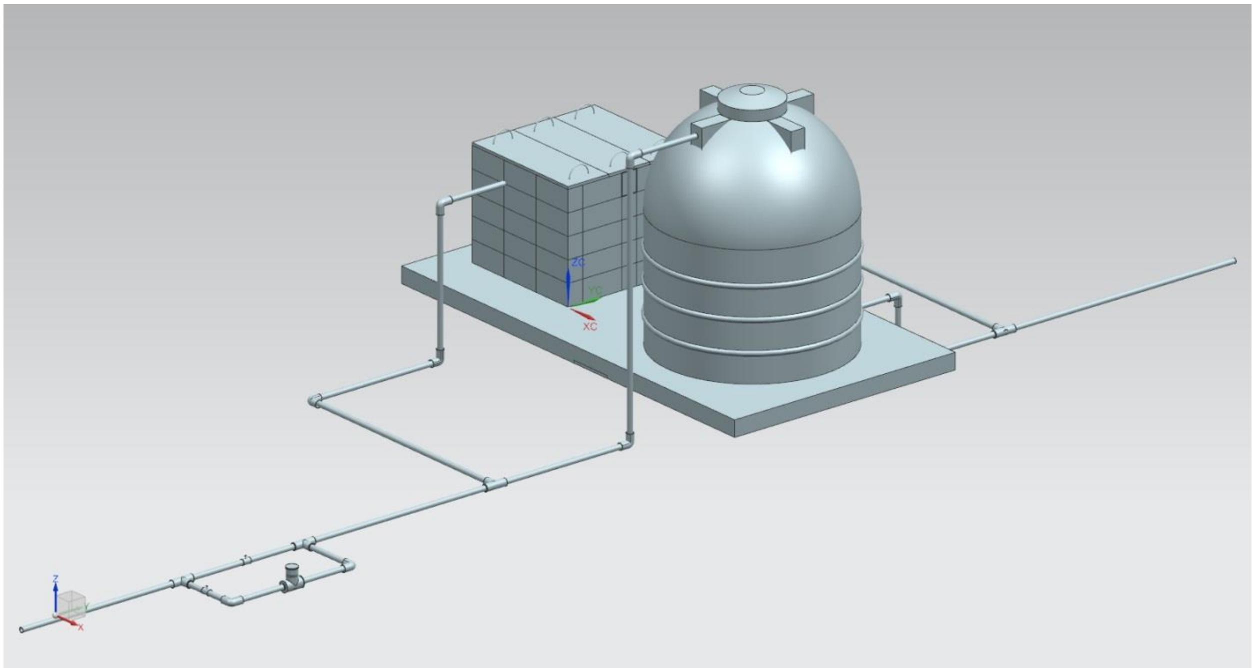


Isometric (with covers):

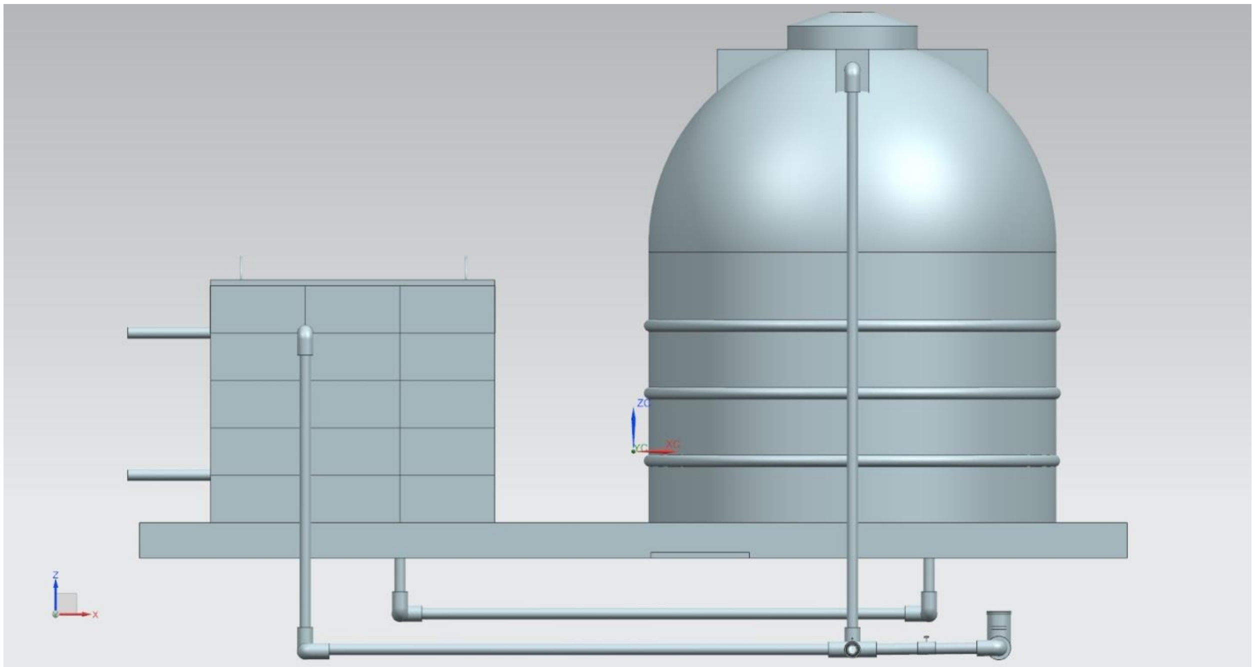


Waypoint 80:

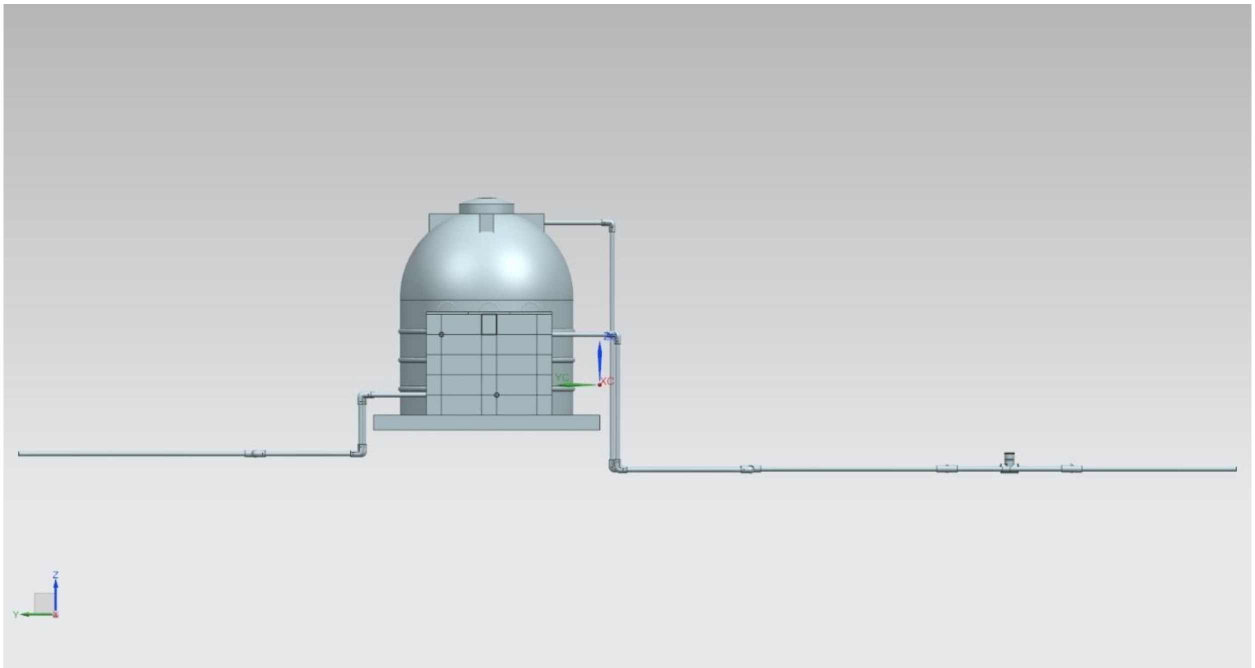
Isometric:



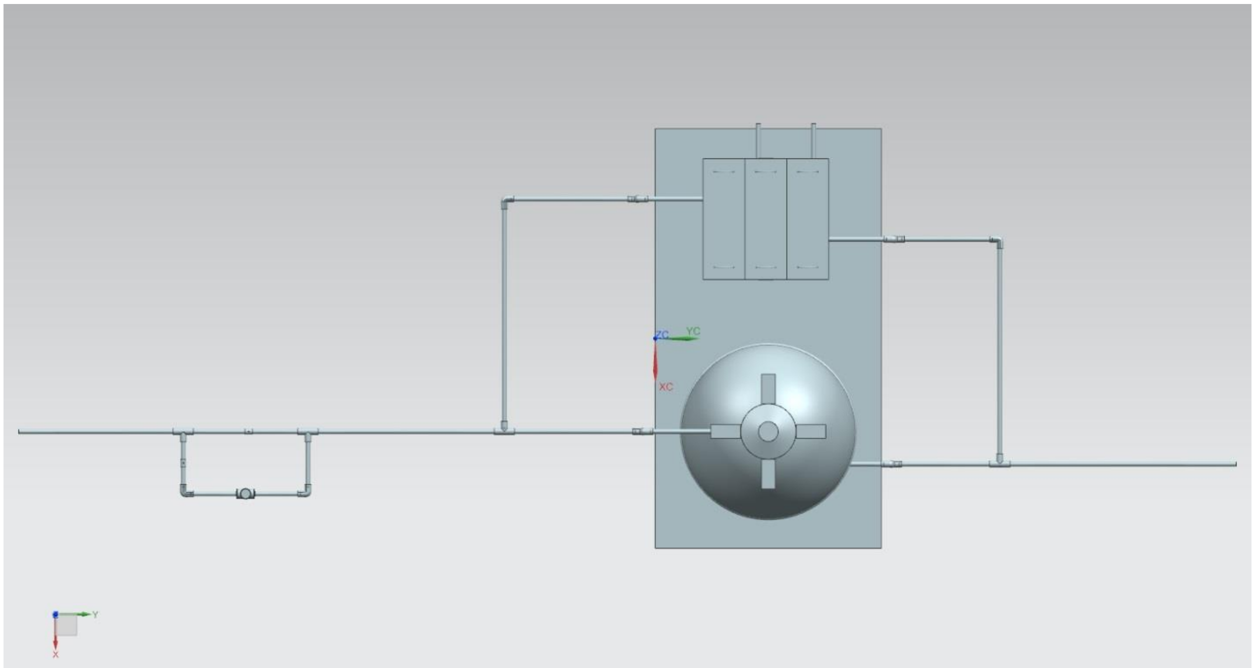
Front:



Side:

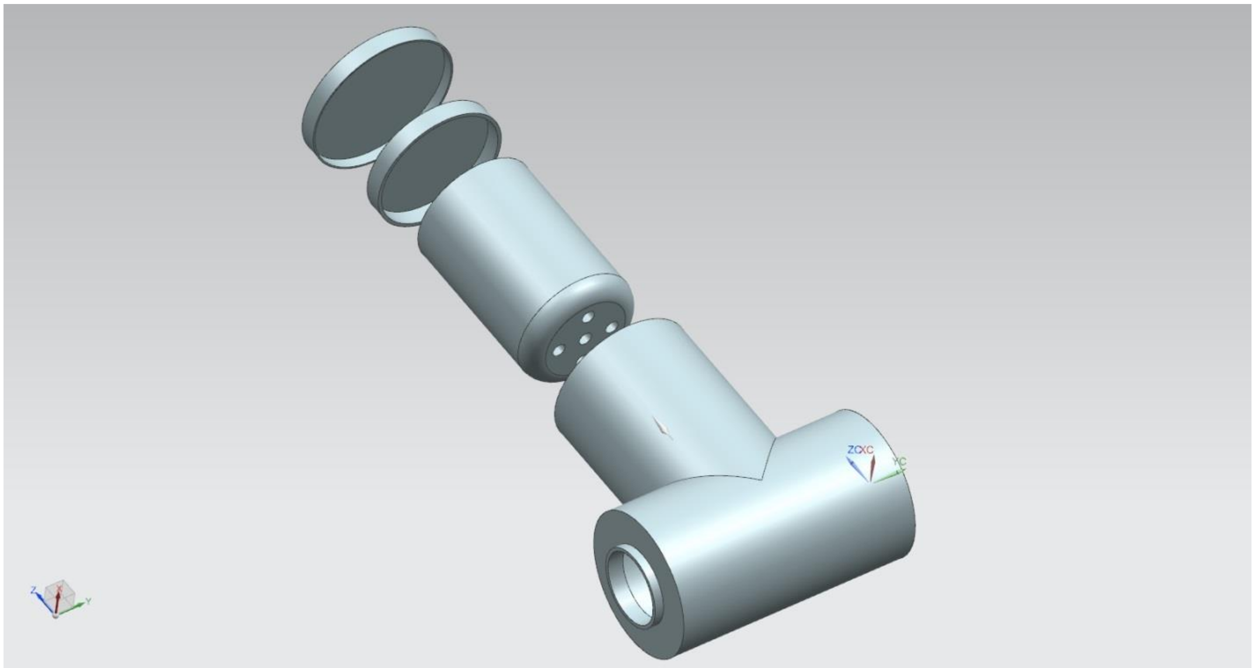


Top:

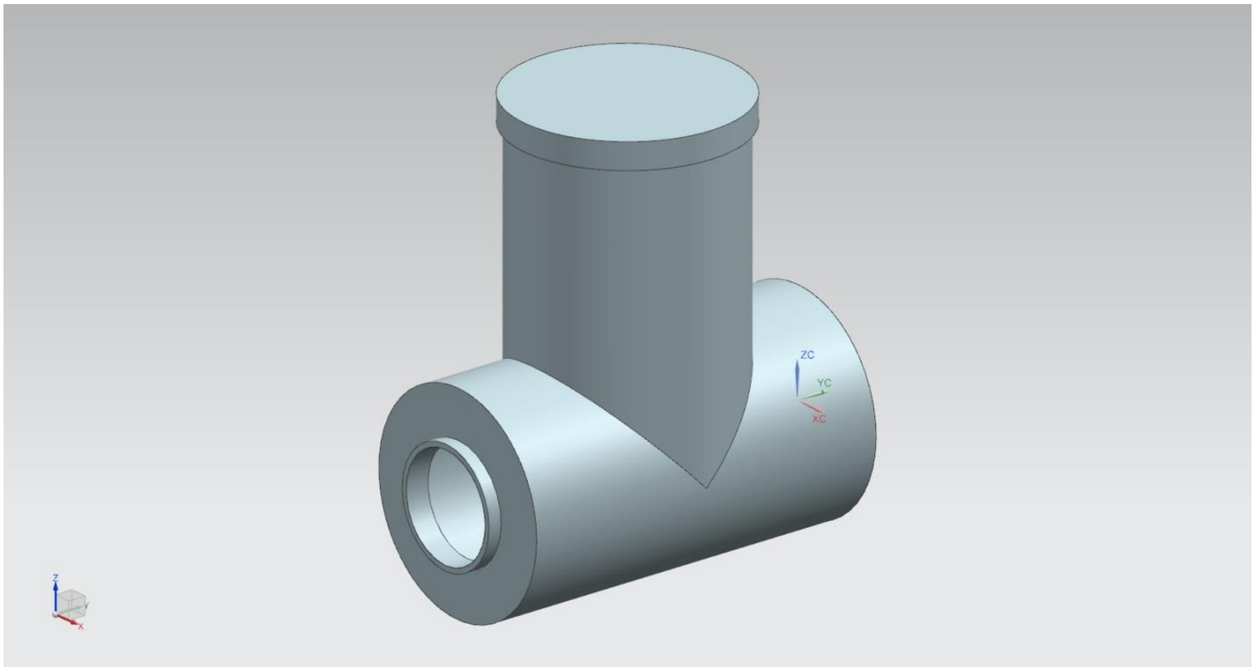


Chlorinator

Exploded:

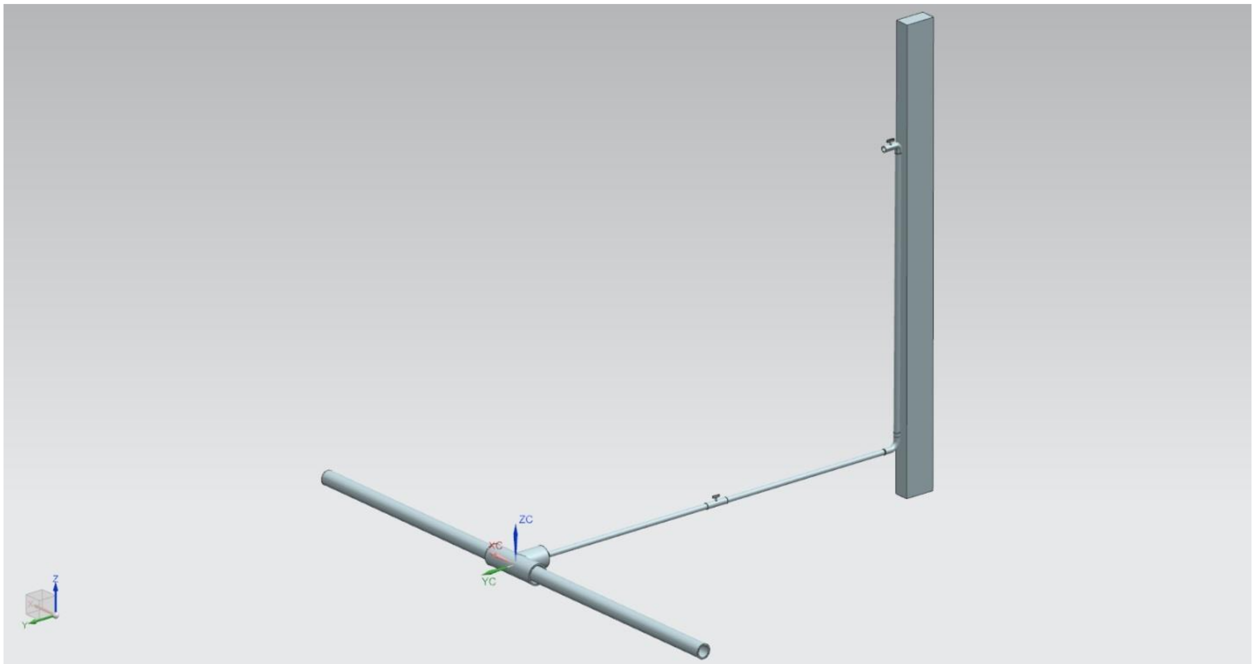


Isometric:



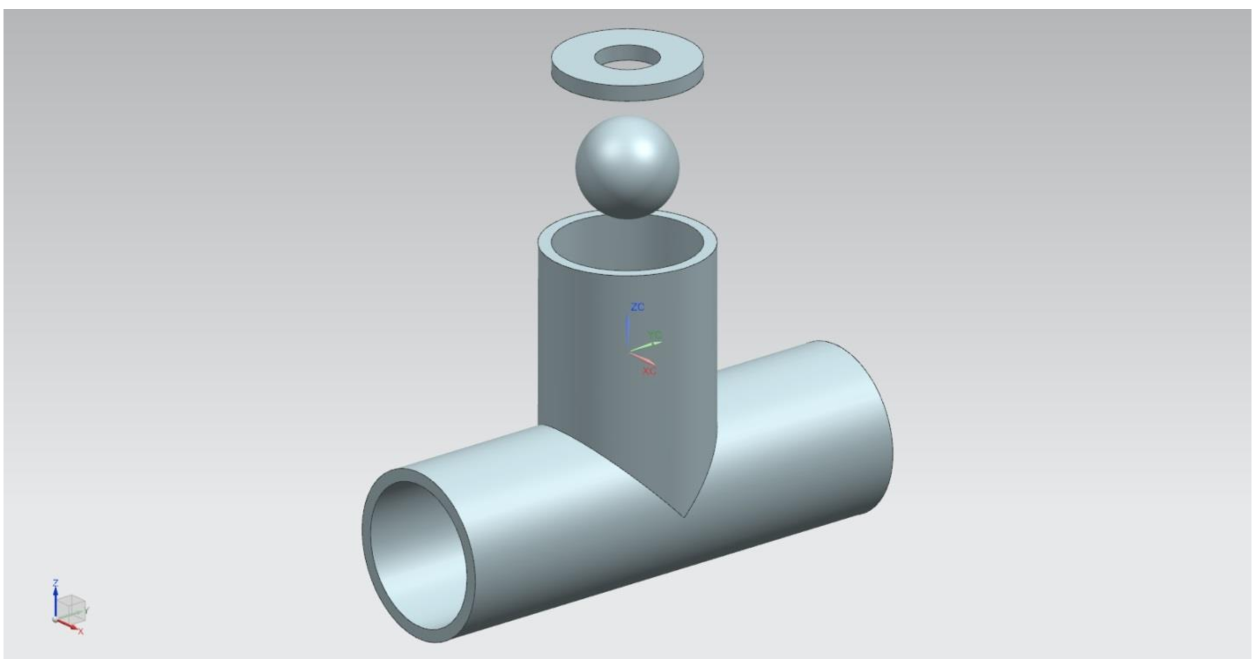
Tapstands

Isometric:

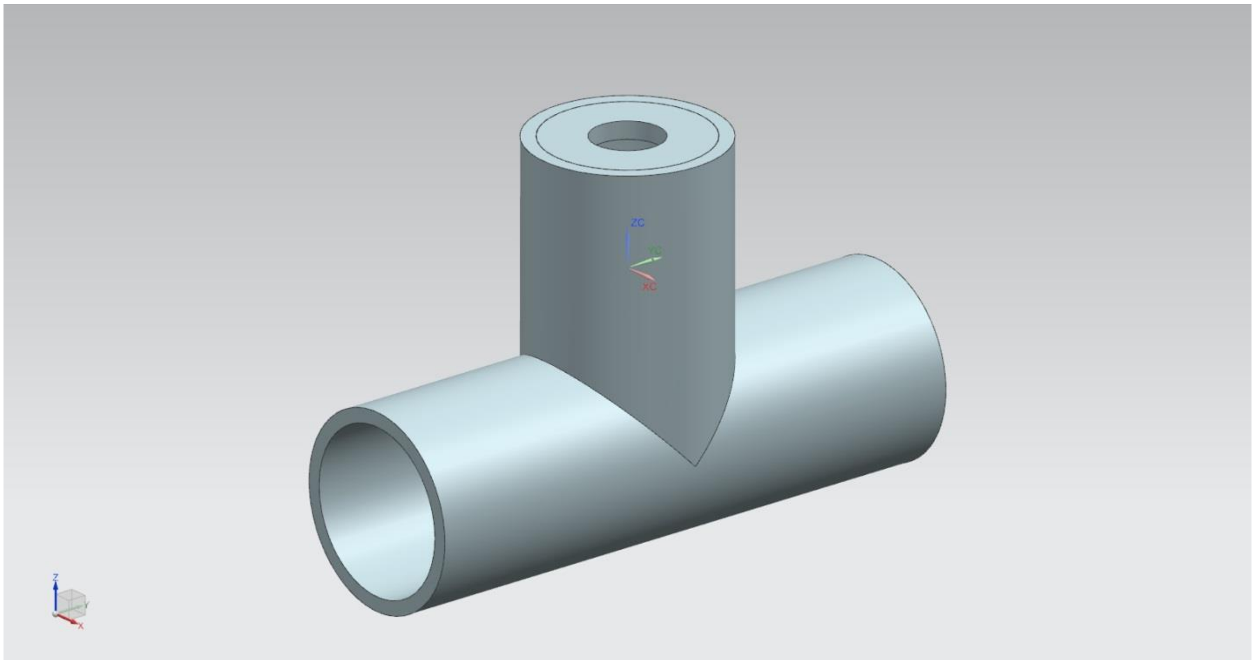


DIY Air release valve

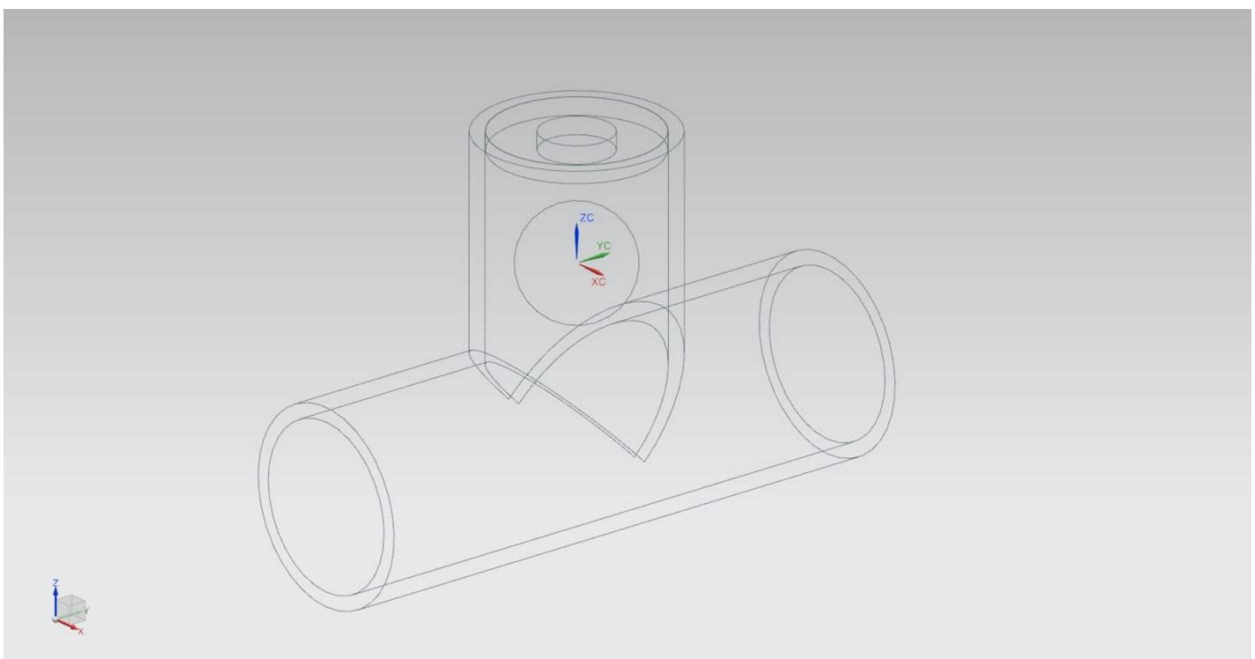
Exploded:



Isometric:

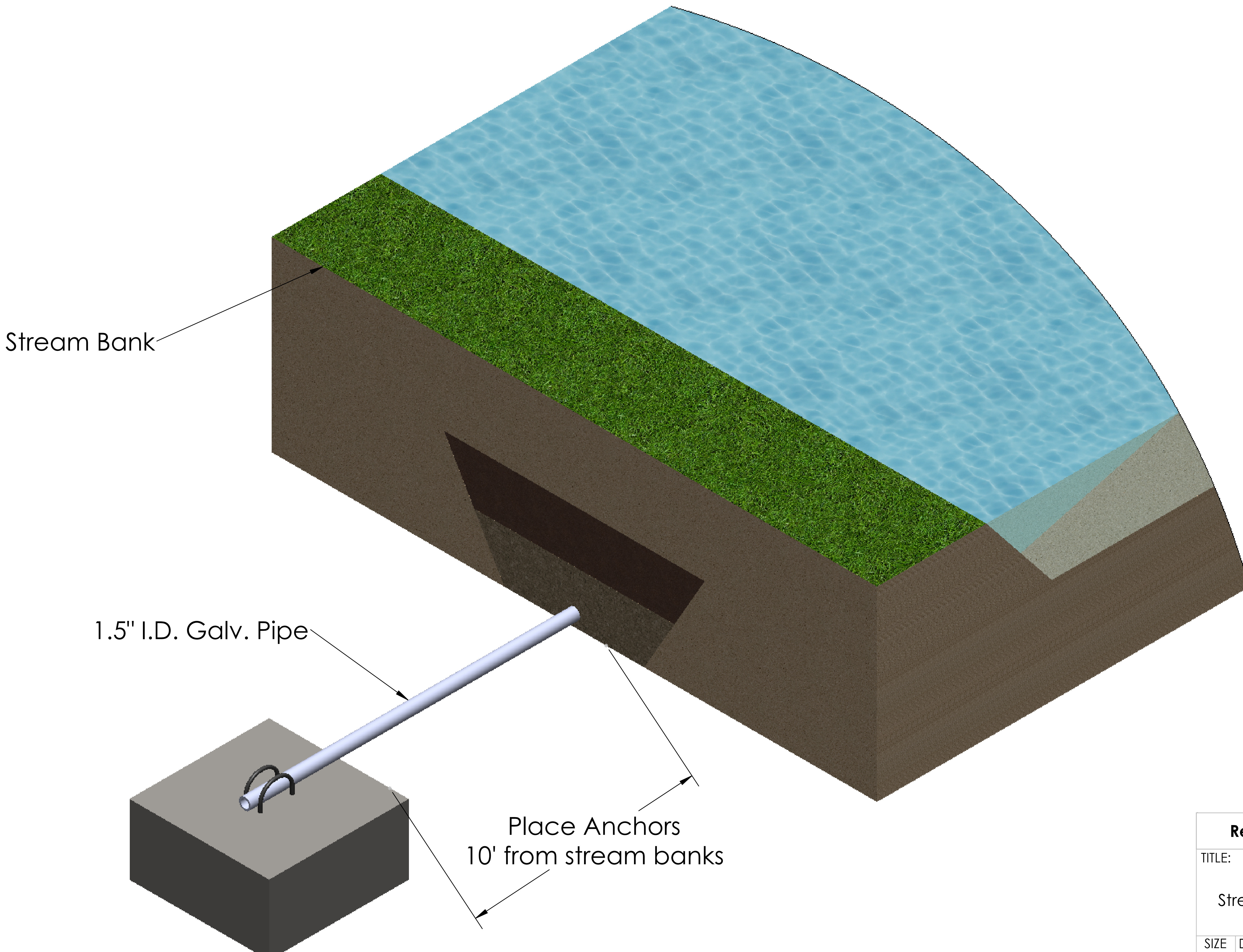


Wire:



Appendix N: Engineering Drawings

<u>Sheet Index</u>



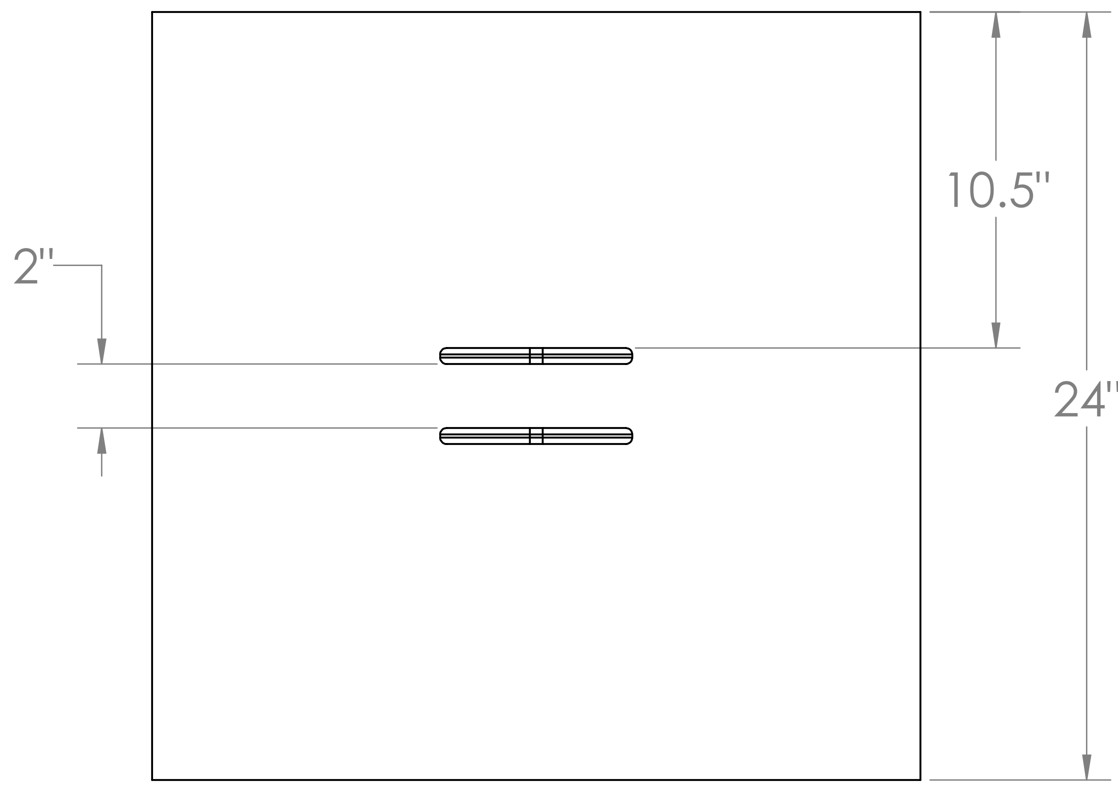
Reasonable Engineering

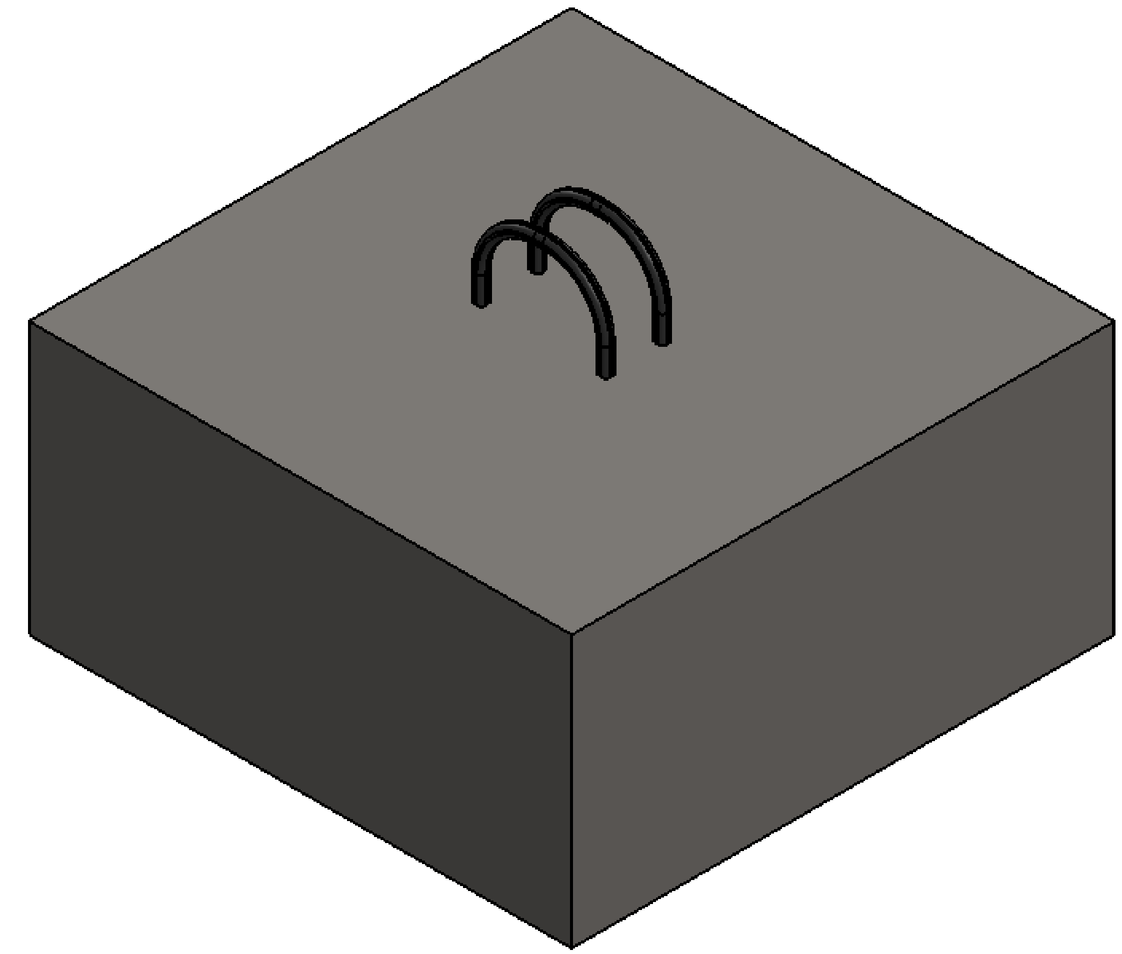
TITLE:

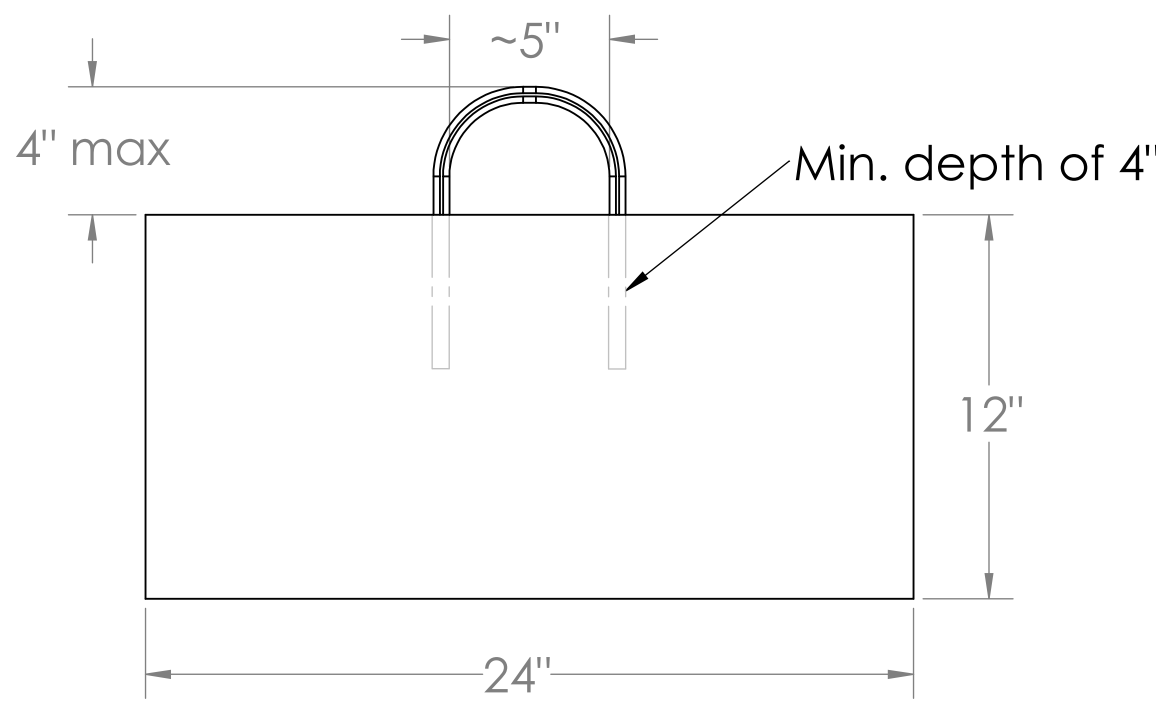
Stream Crossing: Overall View

SIZE	DWG. NO.	REV
B		

SHEET 1 OF 9







Construction Notes:

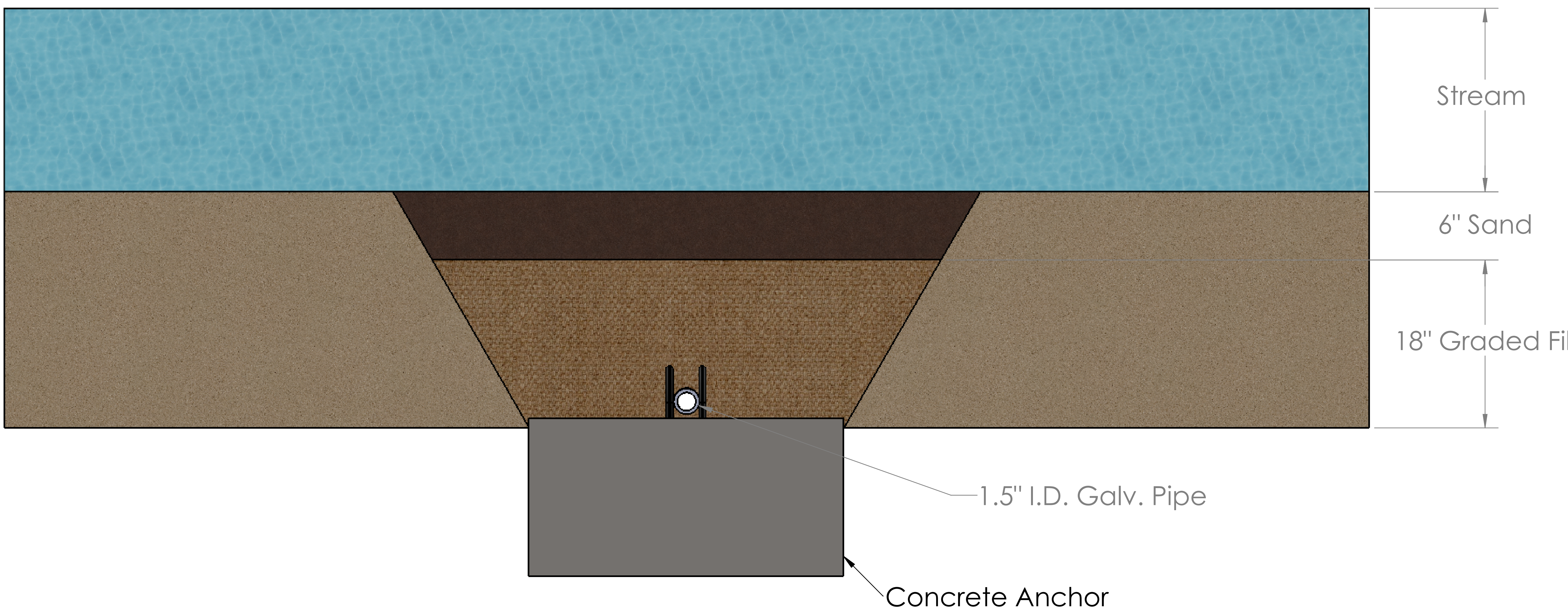
-Use 0.5" Rebar

-Secure pipe between both loops using wire or a weatherproof equivalent

-Ensure each end of the rebar is embedded in at least 4" of concrete

-One anchor will be required at each end of the stream

Reasonable Engineering		
TITLE: Stream Crossing: Concrete Anchor		
SIZE B	DWG. NO.	REV
Scale: 1:6		SHEET 2 OF 9



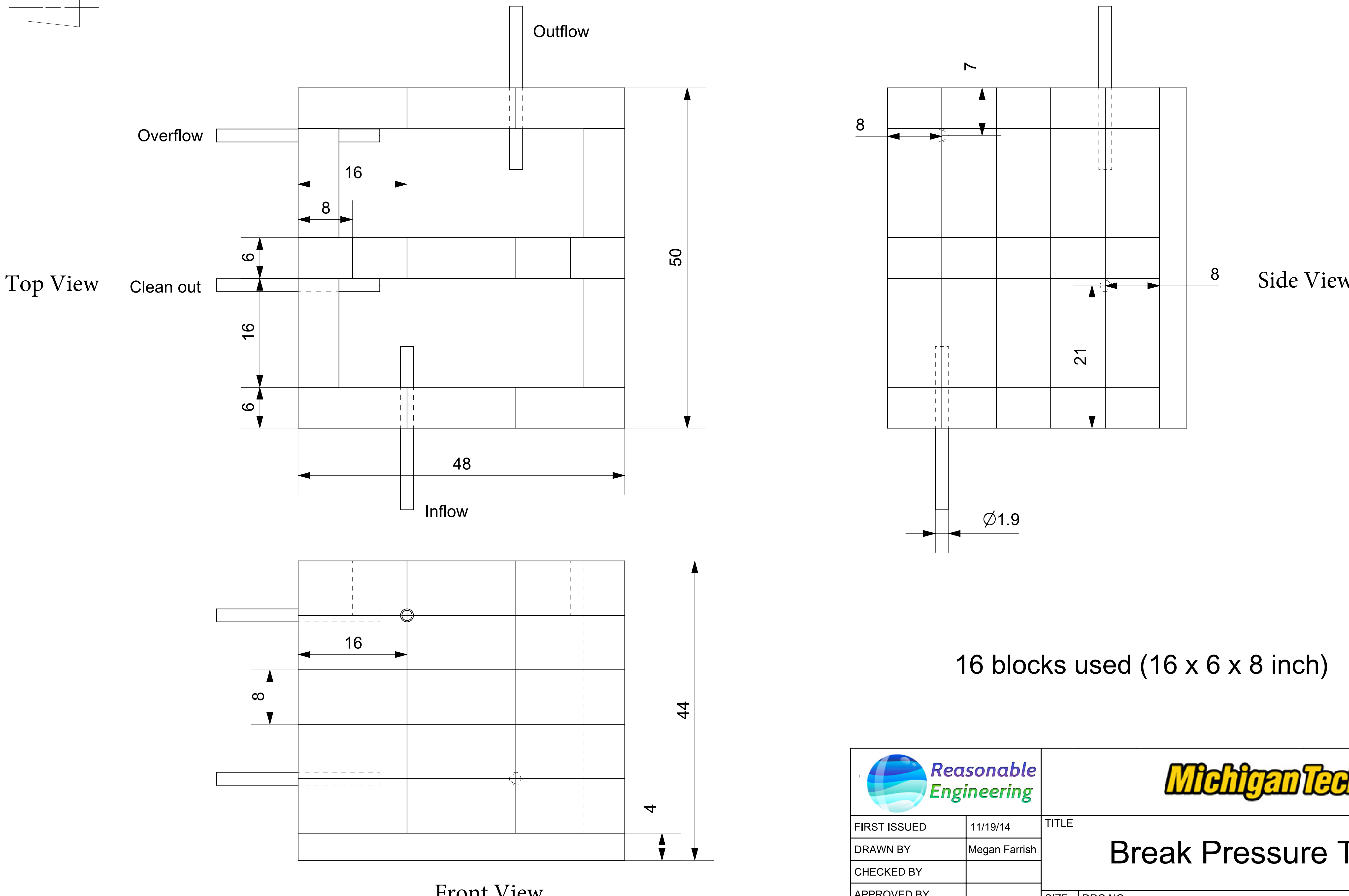
Reasonable Engineering

TITLE:

Stream Corssing:
Ground Section View

SIZE	DWG. NO.	REV
B		

SHEET 3 OF 9

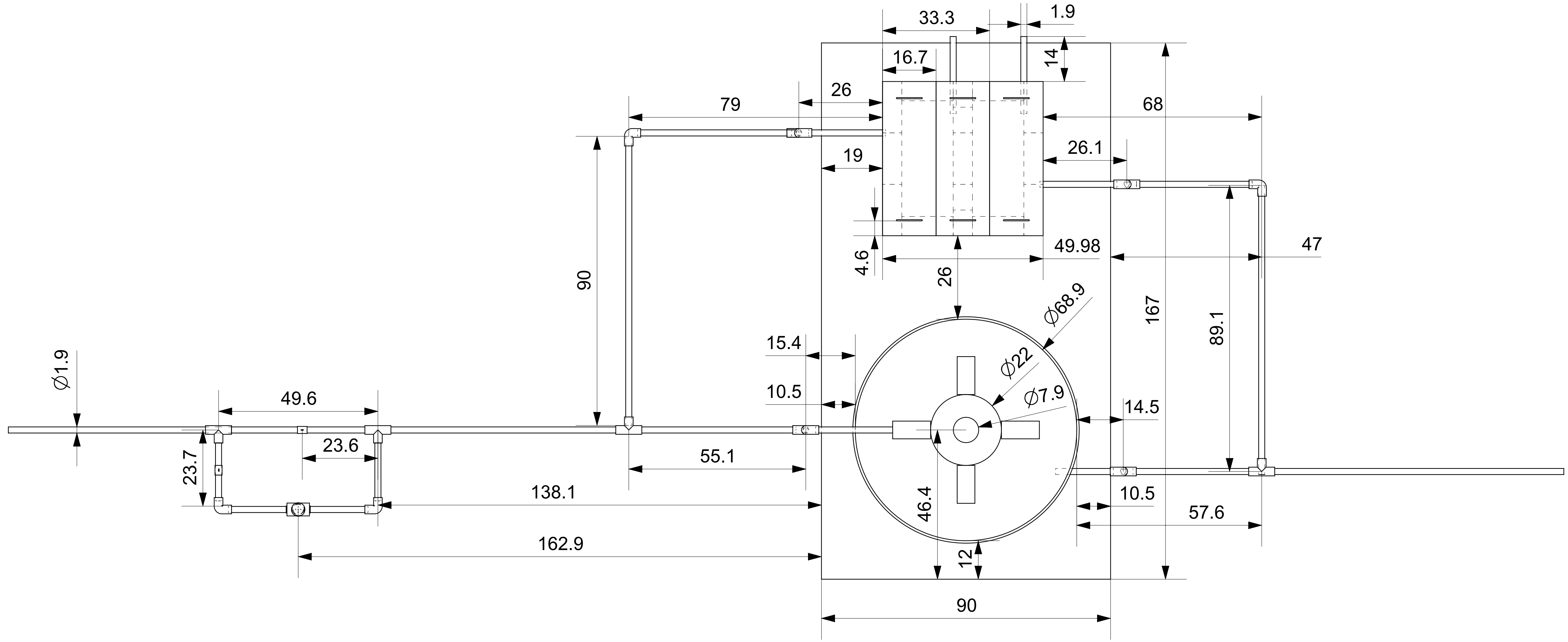


ALL DIMENSIONS IN INCHES

Reasonable Engineering	Michigan Tech
FIRST ISSUED	11/19/14
DRAWN BY	Megan Farrish
CHECKED BY	
APPROVED BY	

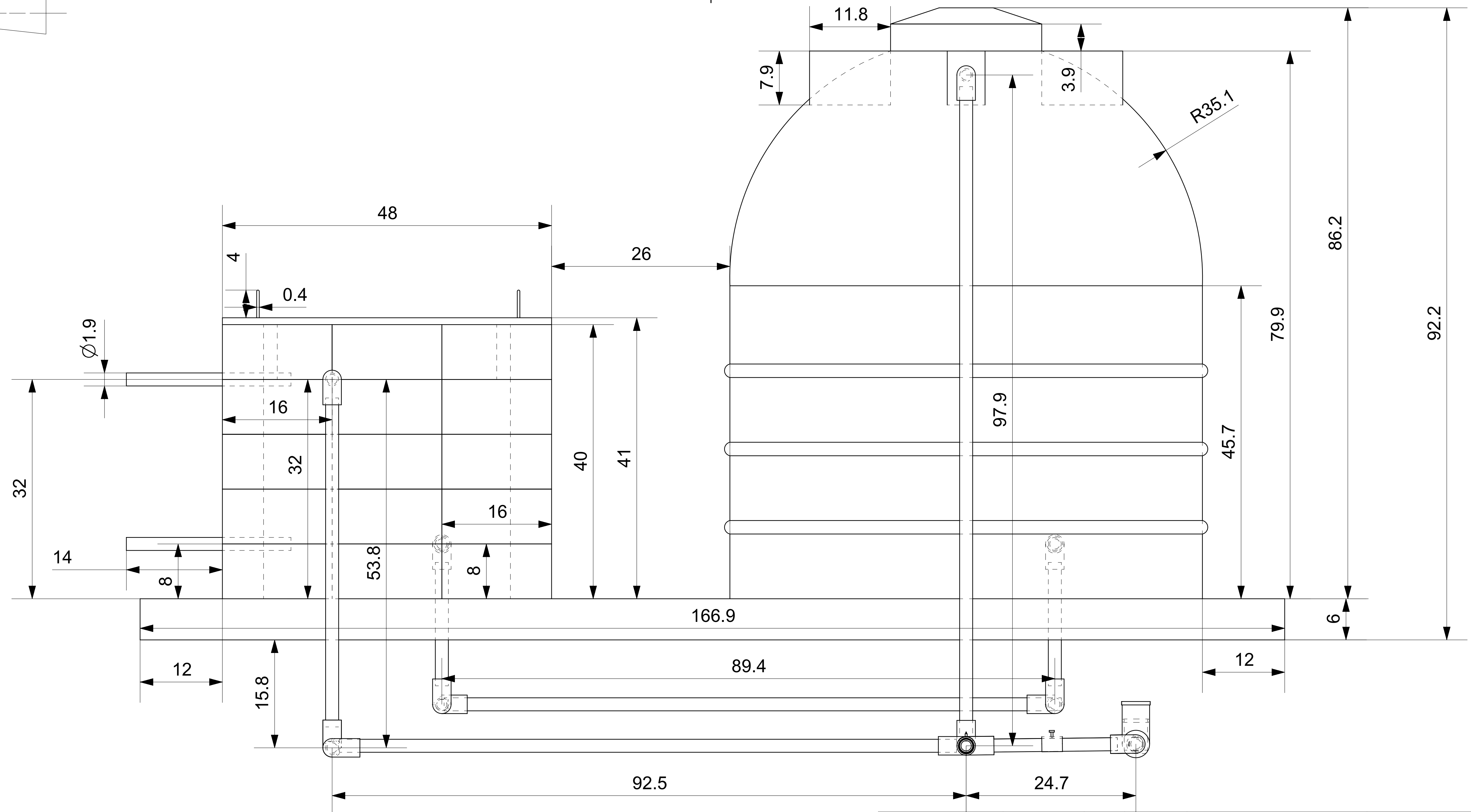
TITLE: Break Pressure Tank

SIZE	DRG NO.	SHEET REV
B		A
SCALE 1:1		SHEET 4 OF 9



ALL DIMENSIONS IN INCHES

Reasonable Engineering		Michigan Tech		
FIRST ISSUED	11/19/14	TITLE		
DRAWN BY	Megan Farrish	Waypoint 80: Top View		
CHECKED BY				
APPROVED BY		SIZE B	DRG NO.	SHEET REV A
		SCALE 1:1		SHEET 5 OF 9

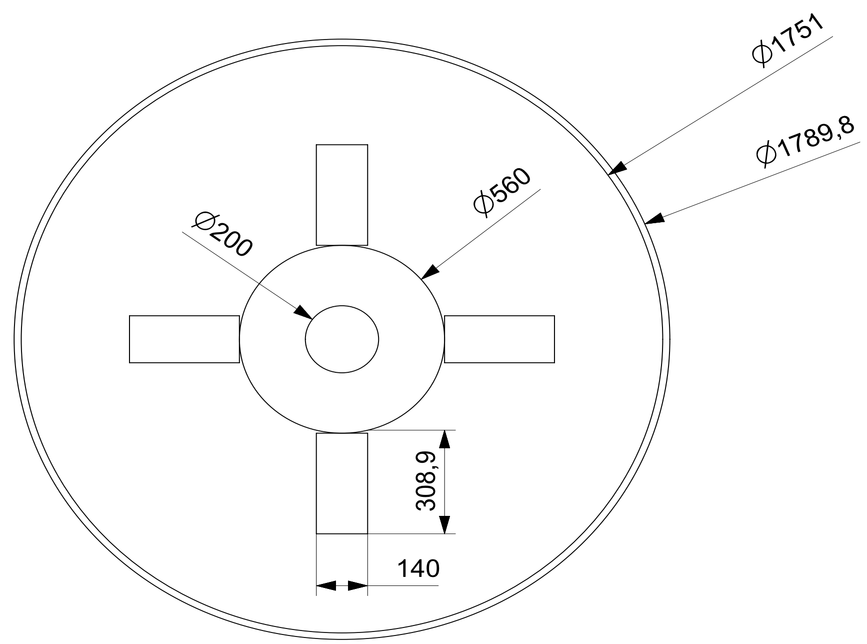


ALL DIMENSIONS IN INCHES

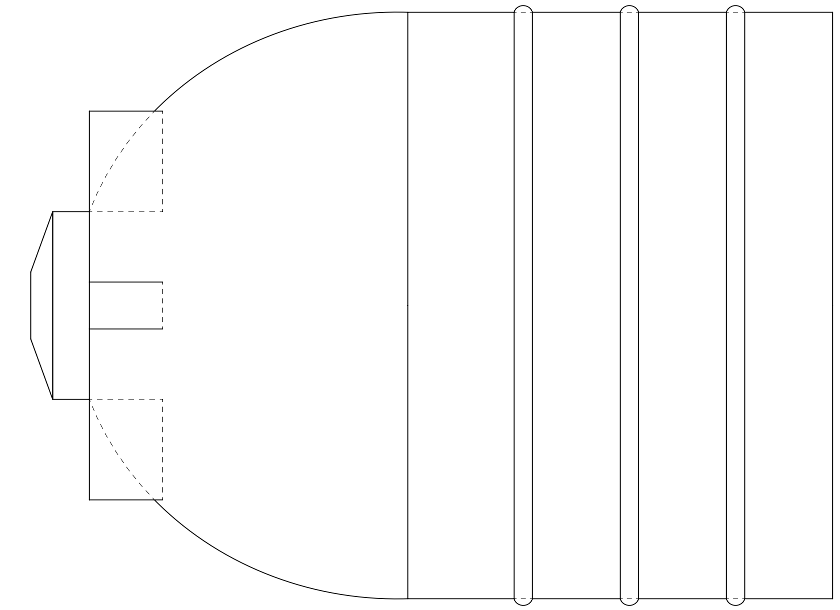
Reasonable Engineering

Michigan Tech

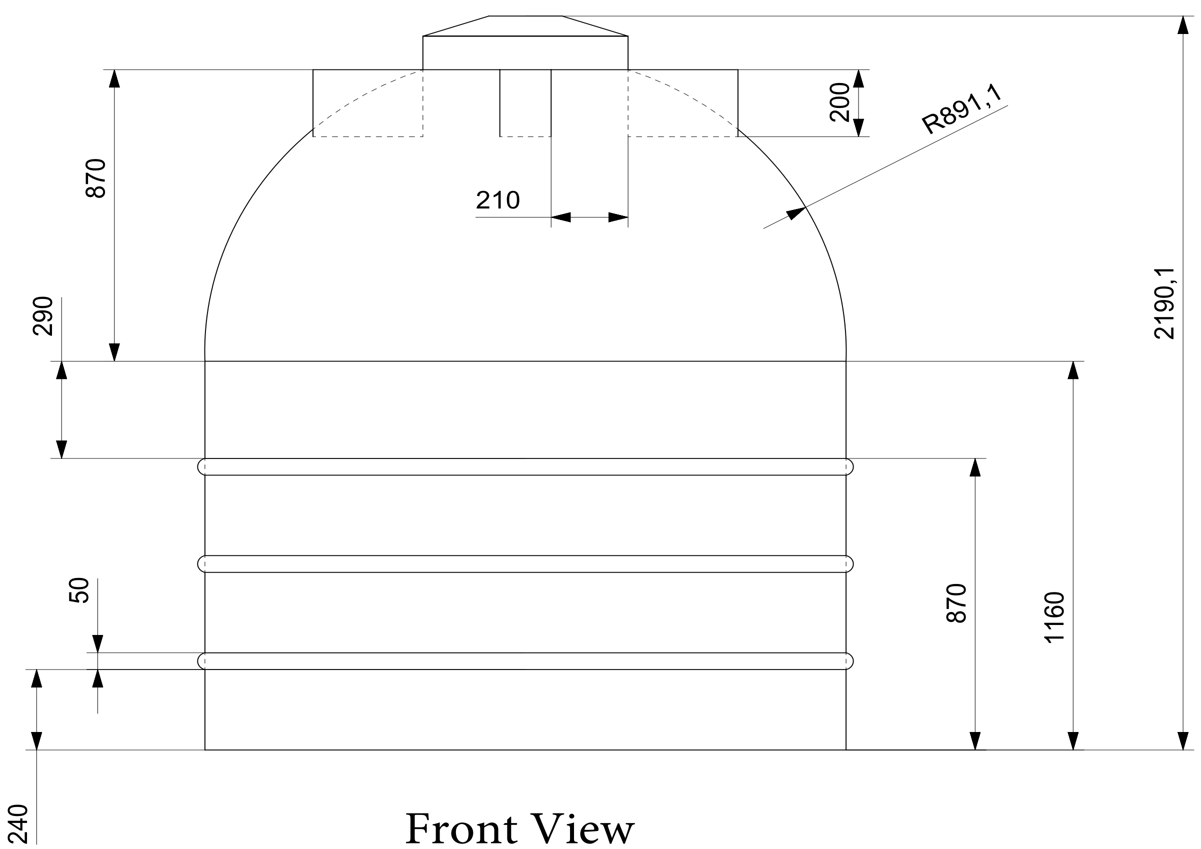
FIRST ISSUED	11/20/14	TITLE	
DRAWN BY	Megan Farrish	Waypoint 80: Front View	
CHECKED BY			
APPROVED BY			
		SIZE B	DRG NO.	SHEET REV A
		SCALE 1:1	SHEET 6 OF 9



Top View



Side View



Front View

ALL DIMENSIONS IN MM

Reasonable Engineering

Michigan Tech

FIRST ISSUED	11/14/14
DRAWN BY	Megan Farrish
CHECKED BY	
APPROVED BY	

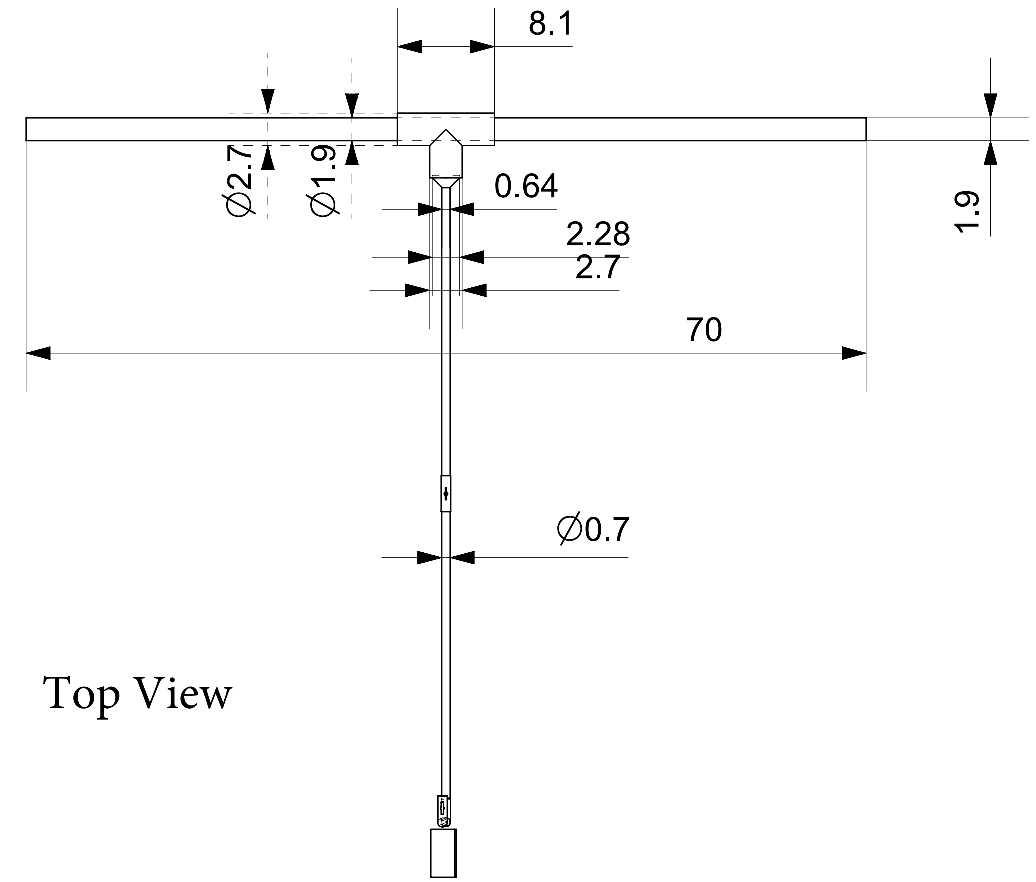
TITLE

Waypoint 80: Storage Tank

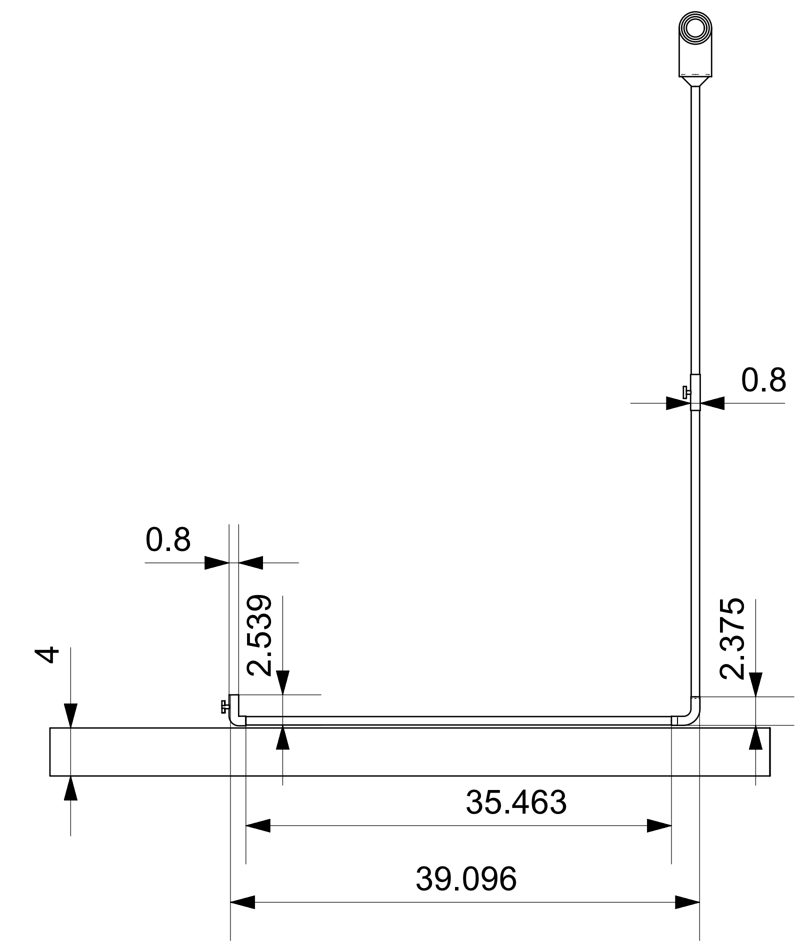
SIZE	DRG NO.	SHEET REV
A2		A

SCALE 1:1

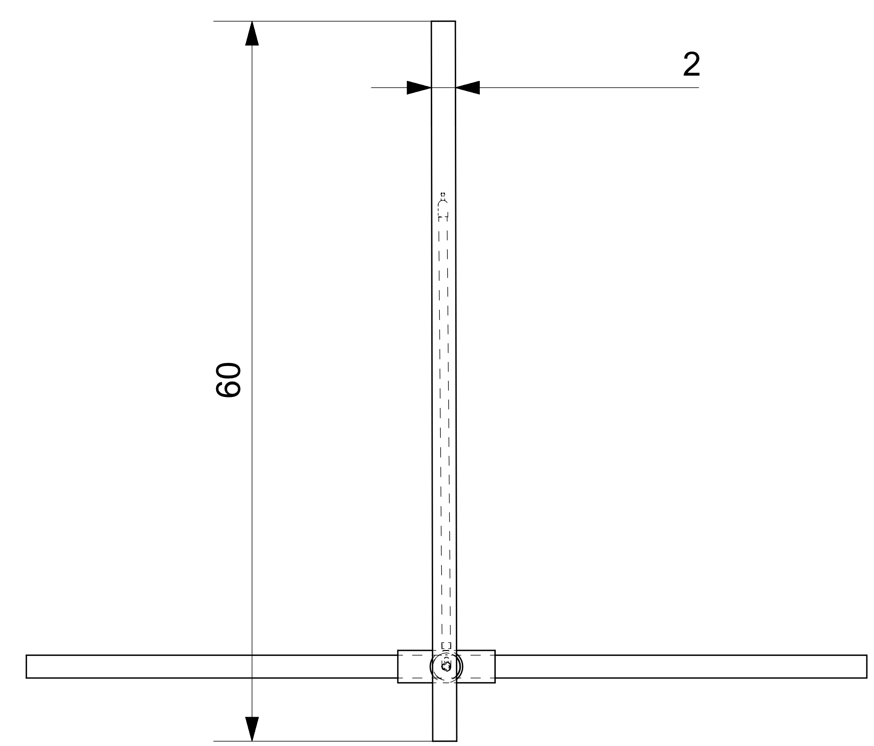
SHEET 7 OF 9



Top View



Side View



Front View

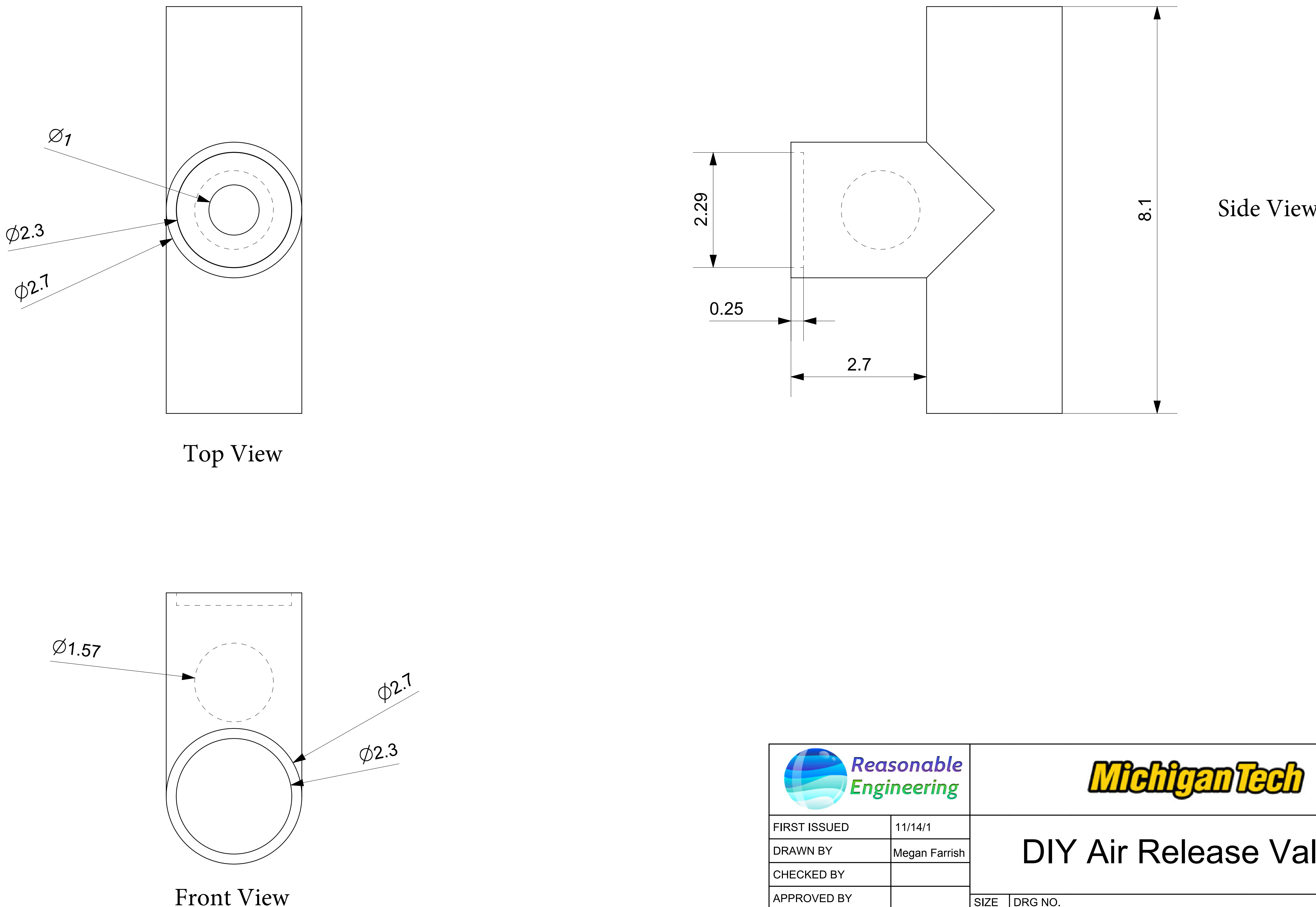
ALL DIMENSIONS IN INCHES

Reasonable Engineering

Michigan Tech

FIRST ISSUED	11/14/14	TITLE: Tapstand
DRAWN BY	Megan Farrish	
CHECKED BY		
APPROVED BY		

SIZE	DRG NO.	SHEET REV
B		A
SCALE 1:1		SHEET 8 OF 9



ALL DIMENSIONS IN INCHES

Reasonable Engineering		Michigan Tech
FIRST ISSUED	11/14/1	DIY Air Release Valve
DRAWN BY	Megan Farrish	
CHECKED BY		
APPROVED BY		SIZE B / DRG NO. / SHEET REV A
		SCALE 1:1 / SHEET 9 OF 9