Valle Risco Water System Improvements

International Senior Design Project

Michigan Technological University

CEE 4916 Fall 2019

Advisors:

Michael Drewyor P.E., P.S.

David Watkins PhD., P.E.

Prepared by:

Camille Carlson

Ceily Fessel Doan

Sam Kiluk

Letter of Transmittal

Date: December 13, 2019
To: Tristan Odekirk
From: Sultan Consultants
CC: Dr. David Watkins and Mike Drewyor
Re: Final Report

Dear Tristan,

Sultan Consultants has assembled this report detailing recommended design improvements for the existing Mono Congo water distribution system. The proposed design system will include (1) a Water Storage Tank, (2) Filtration System, (3) Distribution Pipeline, and (4) Recommendations for system success. Detailed drawings and further explanation can be found in the sections to follow.

This system is intended to be built in the next year with financial support from the Panamanian government and/or Peace Corps, Panama. Construction of the distribution network is estimated to take between 3 and 6 months. The total cost, based on local Almirante prices, is estimated to be $11,300.

We would like to thank you for the opportunity to work with you and the community of Valle Risco to enhance our skills and contribute to the global society we are a part of. Please contact Sultan Consultants if you have any questions or concerns, or if you would like information beyond what has been incorporated in this report.

Sincerely,

Sultan Consultants:
Camille Carlson, Ceily Fessel Doan and Samantha Kiluk

Disclaimer:
This report titled "Valle Risco Water Improvements" represents the efforts of undergraduate students in the Civil and Environmental Engineering programs at Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report should not be considered professional engineering.

Table of Contents

List of Figures

List of Tables

Executive Summary

Sultan Consultants is an engineering consulting firm, created by a Senior Design group in CEE 4915/4916. This consulting firm specializes in design work for water distribution systems. The firm's mission statement is "*We strive to provide access to safe and reliable drinking water for our clients through excellence in engineering and communication.*"

Sultan Consultants is acting as an engineering specialist to Peace Corps Volunteer, Tristan Odekirk. In August 2019, Sultan Consultants traveled to Tristan's community in Valle Risco, Panama. While in Valle Risco, the team evaluated the current water system by testing water quality and surveying. The water quality tests showed coliforms and E. coli present and the surveying resulted in an elevation profile which aided in modeling the system. Tristan tasked Sultan Consultants with providing multiple design recommendations at different price points.

Sultan Consultants has three proposed designs. The optimal and most expensive design is recommended. This proposed design includes: a storage tank, sedimentation tank, sand filter, chlorine disinfection, new PVC pipes and valves. The storage tank is a component strongly desired by the community of Valle Risco in order to aid in times of drought. There is no water treatment system currently in place, so having the sedimentation tank, sand filter and chlorine disinfection should result in better water quality and deactivate coliforms and E. coli present.

A construction schedule outlines the timeline of the work. The schedule is based on a 5 day work week and is expected to be built in 3-6 months. Required construction for this design has resulted in an estimated material cost of $11,300.

The goal of this design is to satisfy the needs of the community while considering maintenance capabilities. Successful implementation of this project will be dependent on the consistent monitoring and maintenance of each component. Overall, the proposed design aims to improve the existing water systems and provide a clean, reliable water supply for years to come.

1.0 Introduction

Sultan Consultants traveled to Valle Risco, Panama in summer 2019 with Michigan Technological University's International Senior Design program, iDesign. The team's objective was to evaluate and collect data on the current water distribution system with the intent of giving design recommendations for improvement. The team traveled to Valle Risco to work with Tristan Odekirk, a Peace Corps Volunteer stationed there, who requested assistance in evaluating and improving his community's water system. Tristan is a Water, Sanitation, and Hygiene (WASH) Facilitator that works hand in hand with the established Water Committee in Valle Risco. Tristan helped the team connect with the community while in country and will act as the advocate for implementing the proposed design.

The Water Committee is made up of four community members who are passionate about providing reliable access to clean water for their community. The Water Committee takes it upon themselves to maintain the system and collect payment from each household receiving water. The Water Committee worked closely with Sultan Consultants while in the community and gave insight to the needs that the community prioritizes.

Currently there are no guaranteed funds in order to make improvements to the water system, so Tristan has requested multiple designs at different price points. Outlined in this report are three design options: a basic, mid-range, and optimum design scheme. The optimum design is discussed in detail as it is the recommended option by Sultan Consultants.

Along with the three design options, the report will include a thorough background, an overview of data collected and an operations and maintenance manual.

2.0 Background

2.1 Site Location

The village of Valle Risco is located in northwestern Panama, in the Bocas Del Toro province. Valle Risco is a small community comprised of about 500 people. The closest urban area is Almirante, with about 12,000 inhabitants, approximately 20 miles away. A map of Panama, along with the location of Valle Risco, is shown in Figure 1.

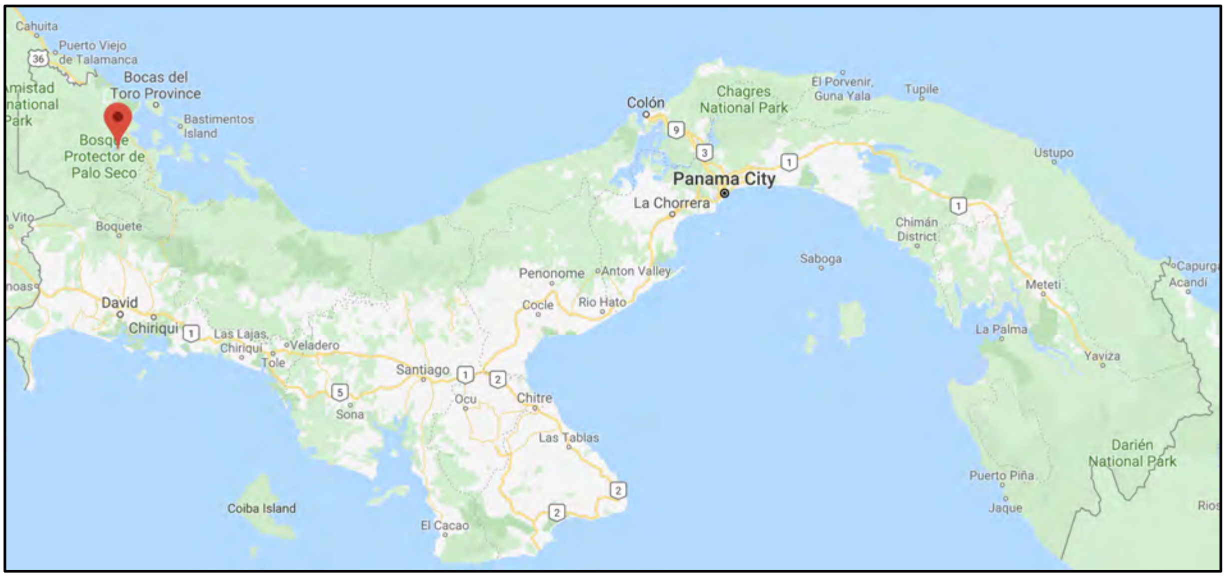

Figure 1: Map of Panama and Valle Risco

2.2 Community Background

Currently there are about 500 people and 70 households in Valle Risco. Households average 7 persons, and it is common for multiple generations to live together. Homes are generally two stories high and made of concrete and wood. Most have running water, flush toilets or latrines, electricity, and some even have cable TV. Although the community seems well off with running water and electricity, neither system is reliable; there are frequent power outages and times of no water.

The Ngäbe indigenous group makes up the majority of community members in Valle Risco. The Ngäbe people are the largest indigenous group in Panama, most living in the Ngäbe-Buglé Comarca in western Panama. They speak Spanish as well as their native dialect, Ngäbere. Most of their cuisine is centered around rice and meat, pairing it with whatever they produce locally, such as plantains and taro root. Many of the families own farms, or *fincas*, where the men harvest different crops, from oranges to cacao. The women mostly focus on raising children but also make handicrafts like *kras*, hand woven bags, and *naguas*, bright hand sewn dresses.

Figure 2 shows *naguas*, and Figure 3 shows examples of *kras*. Tradition is important to them, and they practice the traditional dances and customs.

Figure 2: Camille and Ceily Wearing *Naguas*

Figure 3: *Kras* Made by Women in Valle Risco

2.3 Problem Description

The current water distribution system in Valle Risco is made up of PVC pipe. Half of the community is supplied by the San Francisco system, while the other is supplied by the Mono Congo. The San Francisco system was built primarily by a past Peace Corps volunteer along with community members and serves the east side of the community. The system consists of spring boxes at the sources of the system, and a tank located approximately halfway between the community and the sources. The Mono Congo system is supplied by two rivers, the Mono Congo and Armadillo, and serves the west side of the community. The water system is fed by two creeks located up in the mountains, 4,000 feet away from the village. The Mono Congo system is in need of updating and is the system being analyzed in this report.

The system currently does not have any storage or filtration implemented. At times, the village does not have water in their taps, from either heavy use downstream or low pressure upstream. Sultan Consultants traveled during the wet season, and still experienced days of no water. The main problem facing the community is water security.

Figure 4: Mono Congo Source Intake Structure

The Water Committee stressed their main priority is a storage tank for the Mono Congo system. They identified an area suitable for a tank, on a hill overlooking the cemetery. Besides lack of storage, other concerns observed while visiting the system include frequent pipe diameter changes, leaks in the pipes, and lack of water treatment. Many leaks in the pipes are attributed to man-made air release holes, aimed at allowing air trapped in the pipe to escape.

2.4 Project Objectives

The objectives of this project are to analyze the existing system, propose a design, and provide recommendations for future use. The design will tackle major issues such as water storage and water quality. The design will include tank dimensions, details and locations of system components, a cost estimate and construction schedule.

3.0 Data Collection and Analysis

3.1 Surveying

During Sultan Consultants' time in Valle Risco, the majority of the Mono Congo water system was surveyed. The team used a handheld Rangefinder, GPS, compass and visual target. The team first surveyed from the Armadillo and Mono Congo sources to the proposed tank location. Next, the team surveyed from the proposed tank location to the village, and then followed the main pipelines through the community. Finally, the team surveyed the road in order to understand the overall elevation difference through the community. Figure 5 shows the proposed tank location.

Figure 5: Proposed Tank Site

The surveying data was input into a spreadsheet in order to visualize the data. The system stretches a total of 7,250 feet and has a total elevation change of approximately 400 feet. From the surveying data, elevation profiles were constructed. Each graph shows the horizontal distance in relation to the elevation change.

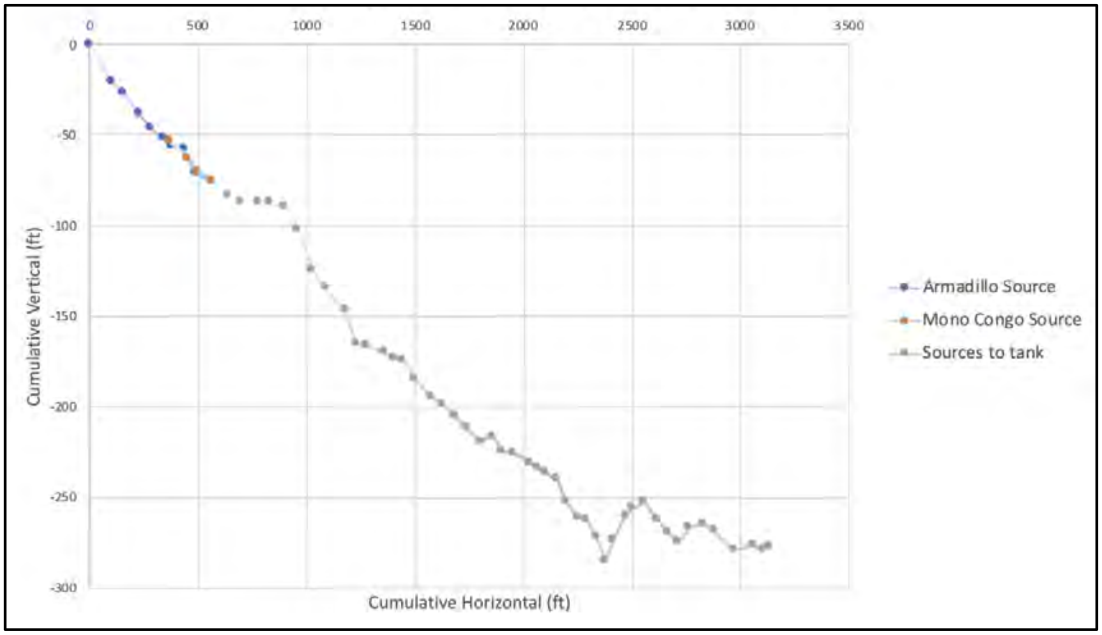

Figure 6: Elevation Profile from Sources to Proposed Tank Location

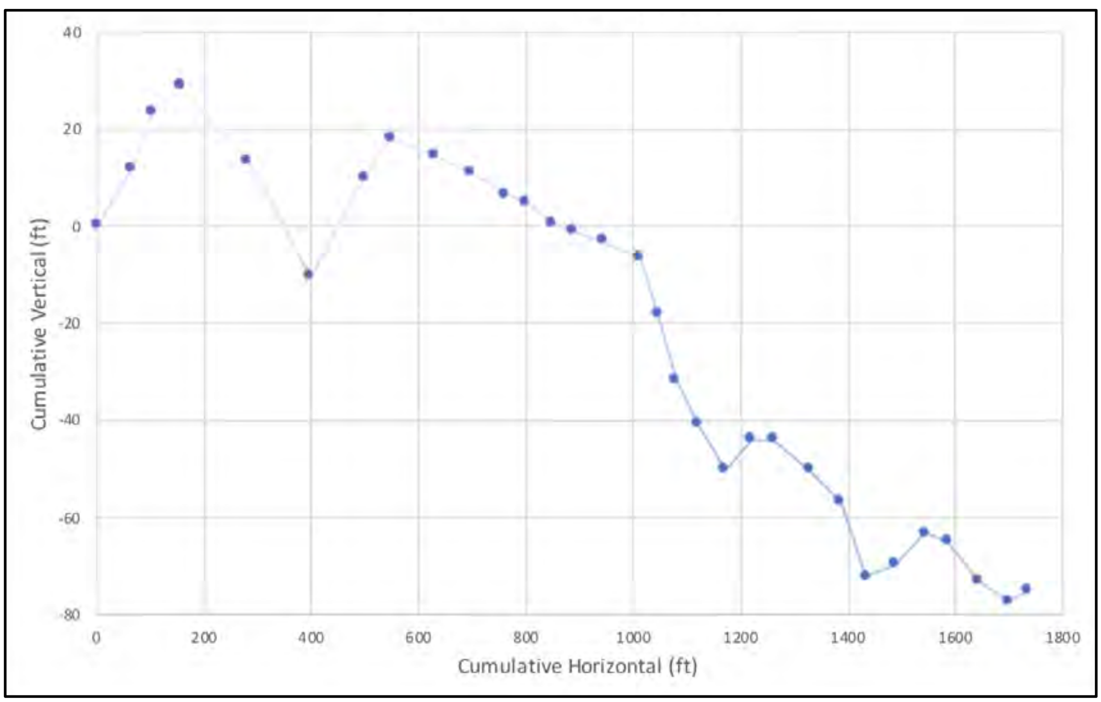

Figure 7: Elevation Profile from Proposed Tank Location through Community

The GPS points collected were imported onto a Bing map of Valle Risco, shown in Figure 8. The two sources are outlined in the top right corner. The upper dot represents the Armadillo source, and the lower dot represents the Mono Congo source. The red dot is the tank location proposed by the Water Committee.

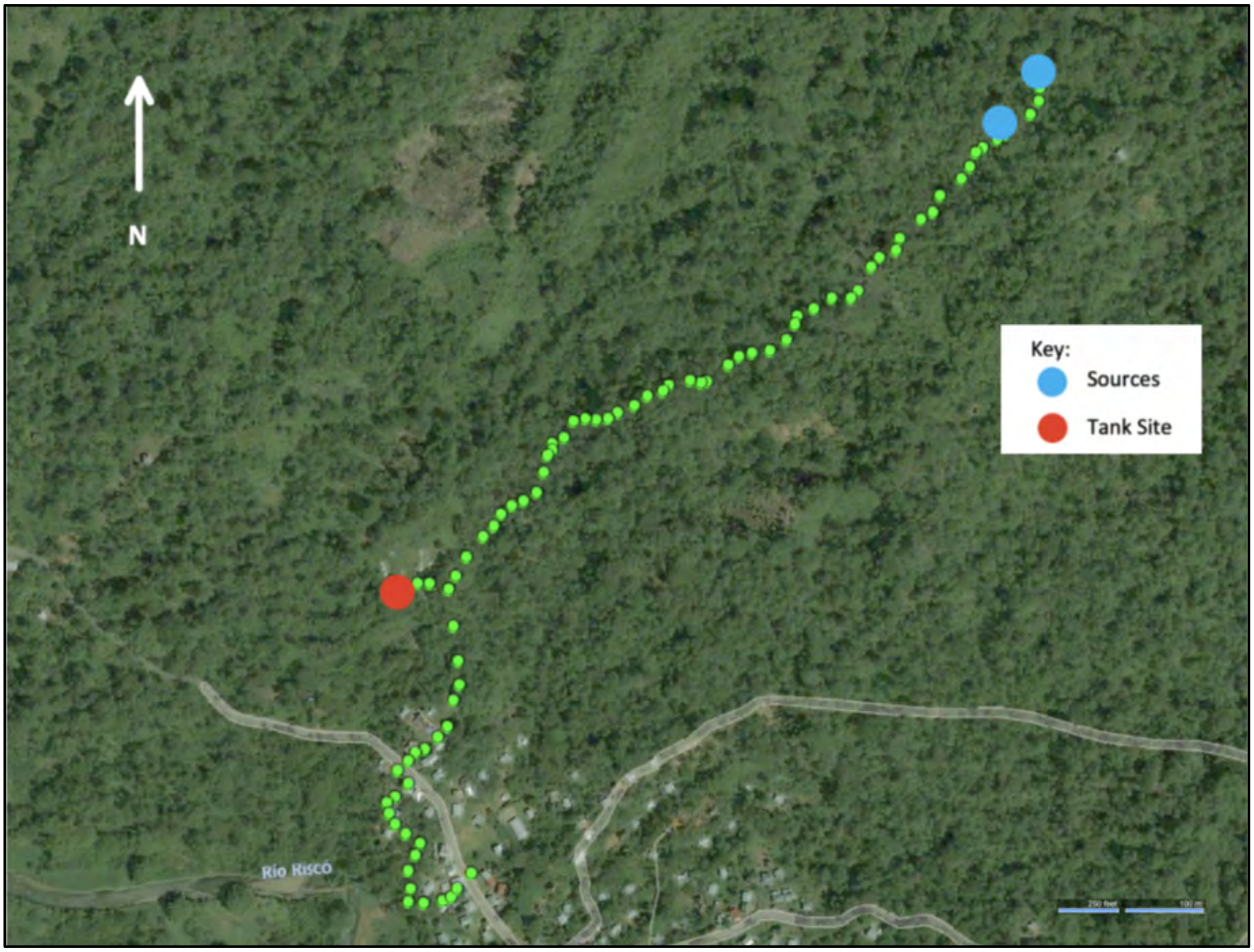

Figure 8: Aerial View of Current Trunk Lines in Valle Risco [2]

3.2 Water Quality

The water quality of both sources and the tap water at a community member's house was tested. Three 3M Coliform/E. Coli Petrifilms [1] were used to test water quality at each location. The petrifilms were incubated in open air for 48 hours before they were analyzed. For each petrifilm, the pink and blue dots were counted with and without bubbles beside them. The smaller pink dots represent coliform forming units (CFUs), or organisms present in the environment and in the feces of all warm-blooded animals. CFUs present in water may not cause illness but indicate that disease-causing organisms (pathogens) may be present. The larger blue dots represent Escherichia coli, better known as E. coli, a more harmful bacteria that comes from feces. Various strains of E. coli can cause many different illnesses, including stomach cramps, severe diarrhea, and fever [4]. The bubbles found next to, or near, a dot indicate that the colony is respirating.

An example of an incubated petrifilm can be seen in Figure 9 below. The Armadillo source had an average of 147 CFUs and 1 E. coli colony per mL, while the Mono Congo source had an average CFUs of 513 and 3 E. coli colonies per mL. The tap water tested had 153 CFUs on average and 15 E. coli colonies per mL. The increased number of both types of bacteria from sources to tap was shocking. The team believes that this increase in bacteria is due to a buildup of bacteria throughout the pipeline. Another possible cause is the in-house filtration currently used by many of the community members, which is a rag tied around the faucet. This rag can act as a generation site for bacteria. Images of all petrifilms, along with a data collection summary from each sample, can be found in Appendix B.

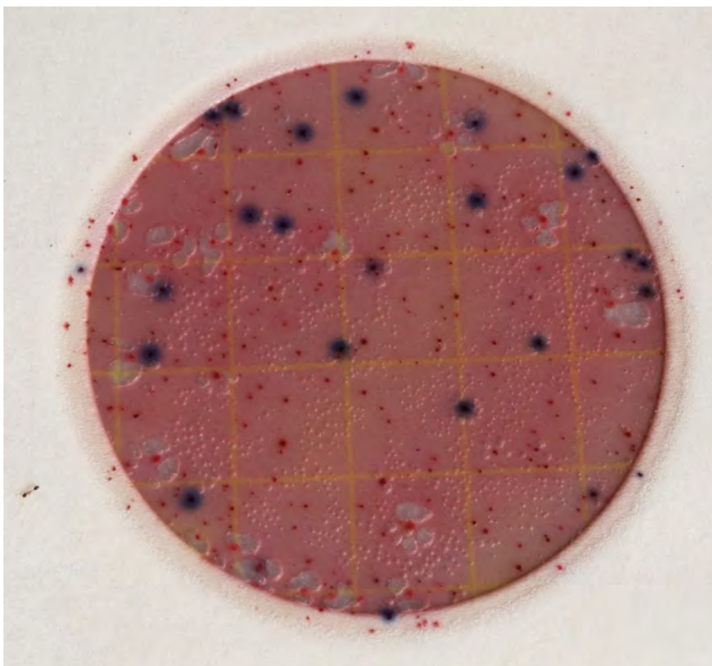

Figure 9: Petrifilm Results from Tap

4.0 Design Alternatives

After careful consideration of the current water system, several design options were created. The following section will describe Sultan Consultants' critical thinking process in selecting design components for the ideal water distribution system in Valle Risco.

Design considerations include the size of the storage tank, water treatment mechanisms, system improvements, cost, construction schedule and more. Water treatment options include a sedimentation tank, sand filter, carbon or granular activated carbon (GAC) filter cartridges, chlorine or iodine. Location is also a consideration when deciding where to implement a treatment system. For large scale filtration systems, they should be placed where land is level, clear, and in close proximity to the community. Past volunteers have suggested that sand filtration is the best filtration option for rural and remote places. Although construction of sedimentation and sand filtration tanks is costly, the longevity and security of the system outweigh other options.

Considering disinfection, it is important to note the differences between in-line and at-home disinfection options. One option for disinfection is in-house treatment, which leaves the responsibility of treating the water to the individual and could result in no water treatment. The other option is to have disinfection implemented before the taps, to ensure water quality before it reaches homes. Regardless of the treatment option, Sultan Consultants recommends educating the community on water quality and security in order to elevate a sense of awareness and accountability.

Sultan Consultants has assembled three design schemes at different price levels: optimum, mid-range and basic. The optimum design would include a storage tank built for a 20 year population's single day's use. Accompanying the tank would be all new PVC pipes to be buried, screens at the intake, and a water treatment system. The treatment system would include a sedimentation tank, sand filter and chlorine disinfection. This design is estimated to cost $11,300.

The mid-range design includes a storage tank built for a 10 year population's single day's use. The treatment system would have screens at the intake and chlorine disinfection at the tank, but will not include large scale filtration. PVC pipes that have leaks would be replaced and air release valves would be implemented throughout the system, so holes will no longer need to be punctured. The estimated cost of this mid-range system is $2,000.

The basic design would have new PVC pipes where there are current leaks and implement air release valves, similar to the mid-range design. The treatment for this design would be in-home treatment. Recommended treatments include boiling the water before drinking or by solar disinfection, placing water bottles in direct sunlight for at least 6 hours. The estimated cost of the basic design is $800. A cost estimate for each design scheme can be found in Appendix H.

Sultan Consultants recommends that the optimum design be implemented because it contains the most thorough treatment system and a water storage tank that will last Valle Risco for many years to come. The following section outlines the recommended design in more detail.

5.0 Proposed Design

Water availability and water quality are the main motivators when designing improvements for this water distribution system. The main goal of this design is to supply clean, reliable water for the community and it's future generations. In the following sections, the proposed design will be described in detail. The aerial map in Figure 10 shows the current pipeline along with the desired design components at their relative locations.

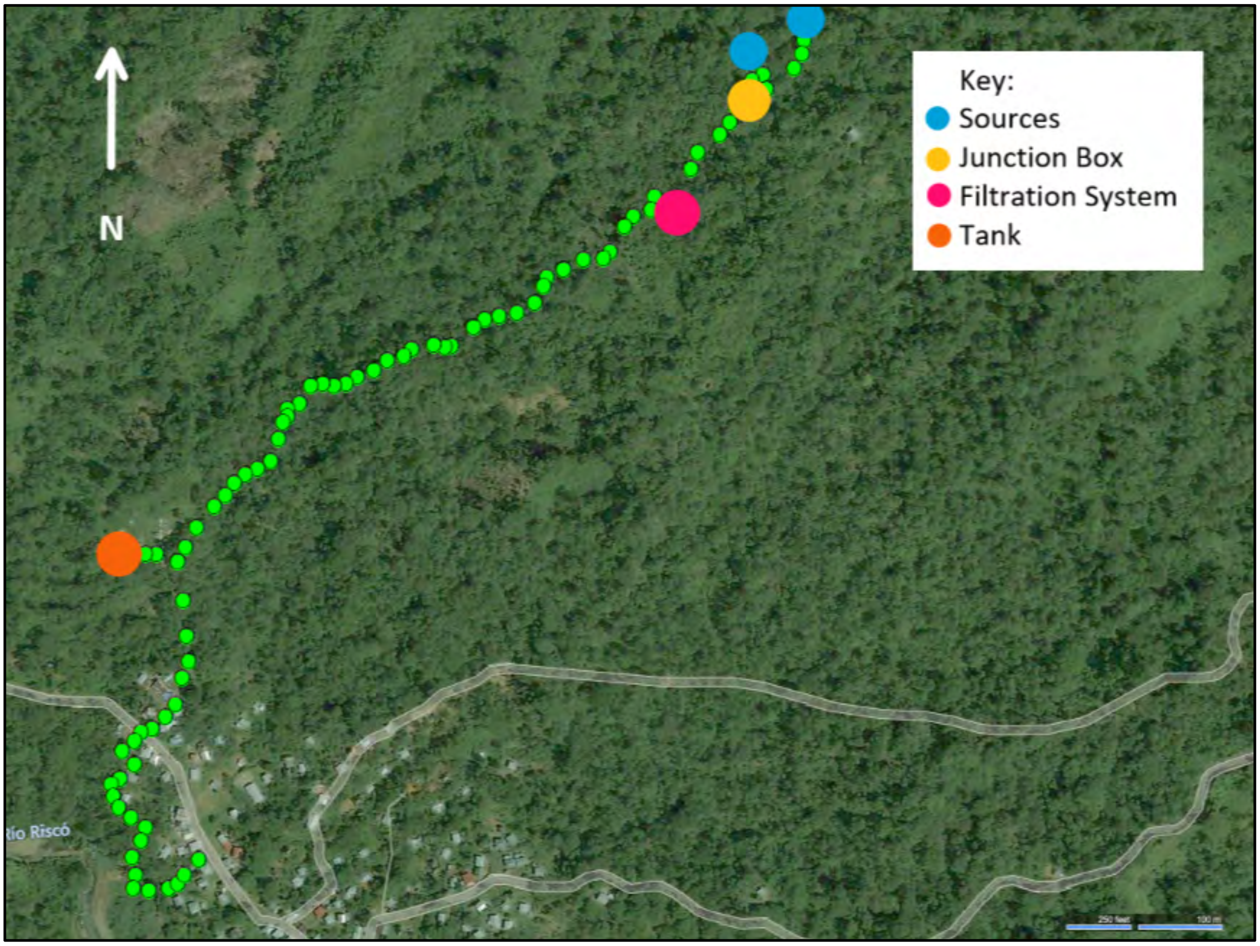

Figure 10: Valle Risco Map with Design Element Locations [2]

5.1 Water Distribution System Model

The data collected during surveying was used to create a water distribution system model for the proposed design. The system was modeled using a water distribution software from the U.S. Environmental Protection Agency (EPA), called EPANET 2.2 [5]. The model was based primarily on elevation change and horizontal distance between each survey point collected. The storage tank, treatment system, junction box, and supply lines to houses were also modeled in the software. Figure 11 is a screen capture of the model.

The distribution line downstream of the tank was modeled to follow the current pipeline with additional supply branches to potential future homes. The nodes represent clusters of homes while the lines represent pipeline. Each node is assigned a water demand value for the future population's consumption. This water demand values is distributed over a designated demand pattern for a single day. The demand pattern was chosen based on the average resident's water consumption. The EPANET model outputs parameters such as flow rates and pressure levels throughout the system. The pipe diameters were adjusted as necessary to obtain an appropriate design flow rate of 10 gallons per minute. This comprehensive model is used in design to estimate pipe diameters for the entire system.

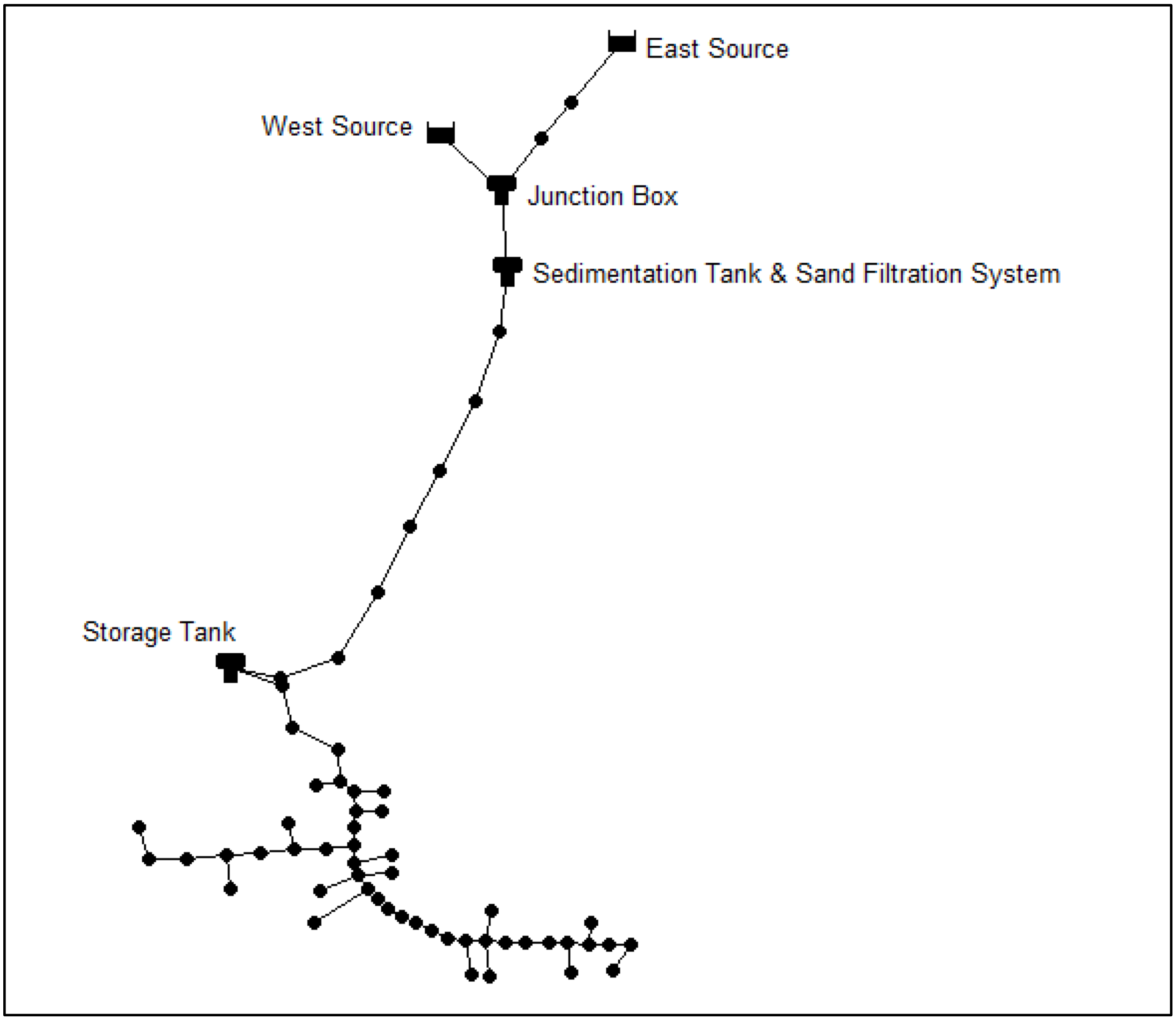

Figure 11: Proposed EPANET Model (schematic not to scale)

5.2 Pipe Network

Sultan Consultants recommends new PVC pipes be bought for the entire system, approximately 5,400 feet. It is recommended that pipe should be buried 2 feet below the surface, to avoid breakage. The pipes from sources to junction box should be 1 inch in diameter. The pipes between the junction box and filtration system is designed to be 0.75 inches and is roughly 500 feet long. The pipe diameter is smaller between the junction box and treatment system to maintain the design flow rate of 10 gallons per minute. The length of pipe from the treatment system to the storage tank is 2,500 feet of 2 inch diameter pipe. Piping from the storage tank to the trunk lines is 1,600 feet of 1.5 inch diameter pipe. The pipes from the trunk lines to the houses should be 1 inch diameter and 0.5 inches diameter from the base of the house to the tap.

5.3 Junction Box

Due to the Armadillo source being 50 feet higher in elevation than the Mono Congo source, a junction box needs to be implemented. This large difference in elevation could cause water flow from the Armadillo source to travel up the pipes to the Mono Congo source instead of down to the storage tank. To prevent this, a junction box is designed at the location where the two pipes meet. The junction box will be made of poured concrete and will have a 4 foot width and length and a 2 foot height, see Figure 12. Although screens will be built at the intake structures, sediment may arrive at the junction box. To aid in junction box cleaning, a clean out port is located at the bottom. There should be shut off valves on the inlets to allow the box to be emptied for weekly cleaning.

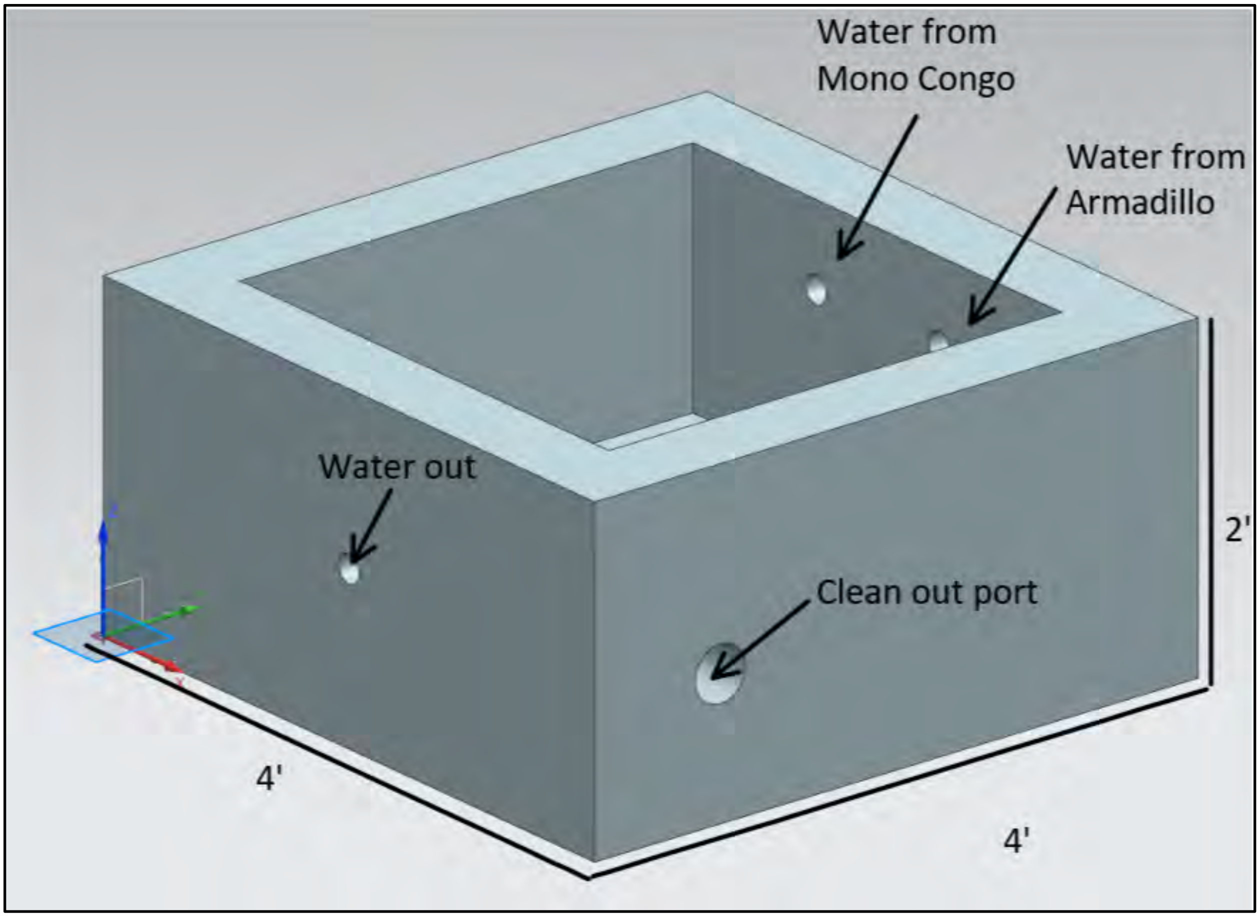

Figure 12: Junction Box Drawing

5.4 Sedimentation Tank

A sedimentation tank and a slow sand filtration system will be implemented in addition to the screening at the sources. These structures will be placed closer to the sources near a newly constructed farm house (at 9.2389°N, 82.4279°W). The sedimentation tank will remove large suspended particles in the water ($> 10\mu m$). The sedimentation tank is designed to be 33 feet long, 9 feet wide, and 7 feet high, as shown in Figure 13. See Appendix E for more information on the sedimentation tank and detailed design drawings.

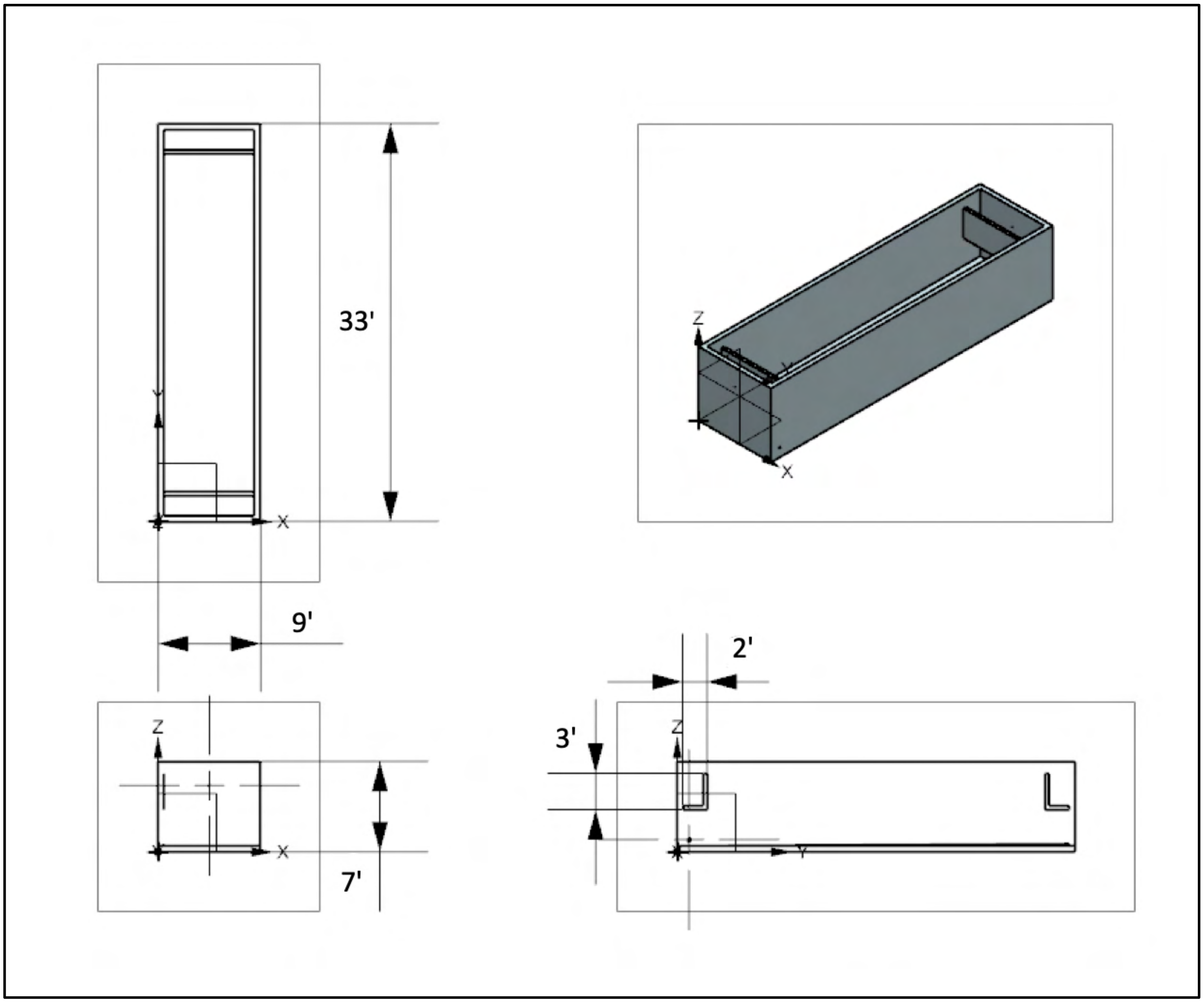

Figure 13: Sedimentation Tank Design

The sedimentation tank will be above ground and composed of reinforced concrete walls, particle settling ramp, velocity control weirs, and sludge clean out ports. The inlet and outlet weirs are to slow the velocity of the incoming and outgoing water flow, as well as distribute the water evenly across the width of the tank. The particle settling ramp will allow solids to roll down towards the sludge port. However, sediment collected on the bottom of the ramp will need to be manually raked to the sludge ports, and disposed of. The sedimentation tank serves as the preliminary treatment for the system, preparing the water for sand filtration.

5.5 Slow Sand Filter

Following the sedimentation tank, a slow sand filter will be constructed. The main goal of the sand filter is to remove dissolved particles (0.001 to 0.01 mm) by physical straining and bacteria with size via biological uptake. Design components include a dual basin tank, with reinforced concrete walls, overflow weirs, clean out ports, and mixed filter media. Dual basins will allow for one basin to be cleaned while the other remains in full operation. The mixed filter media is composed of different grain sizes, from large gravel to fine sand. Sand particle diameters range between 0.5 mm and 0.35 mm. Gravel size ranges from 3 mm to 75 mm. The top layer of the sand filter is a biofilm, made up of organisms that can help consume other pathogenic organisms through biological uptake. The slow sand filtration tank is designed to be 12 feet long, 12 feet wide, and 8 feet high. A sketch of the sand filtration tank is shown in Figure 14. For more information on sand filtration dimensions, composition, and design drawings, see Appendix F.

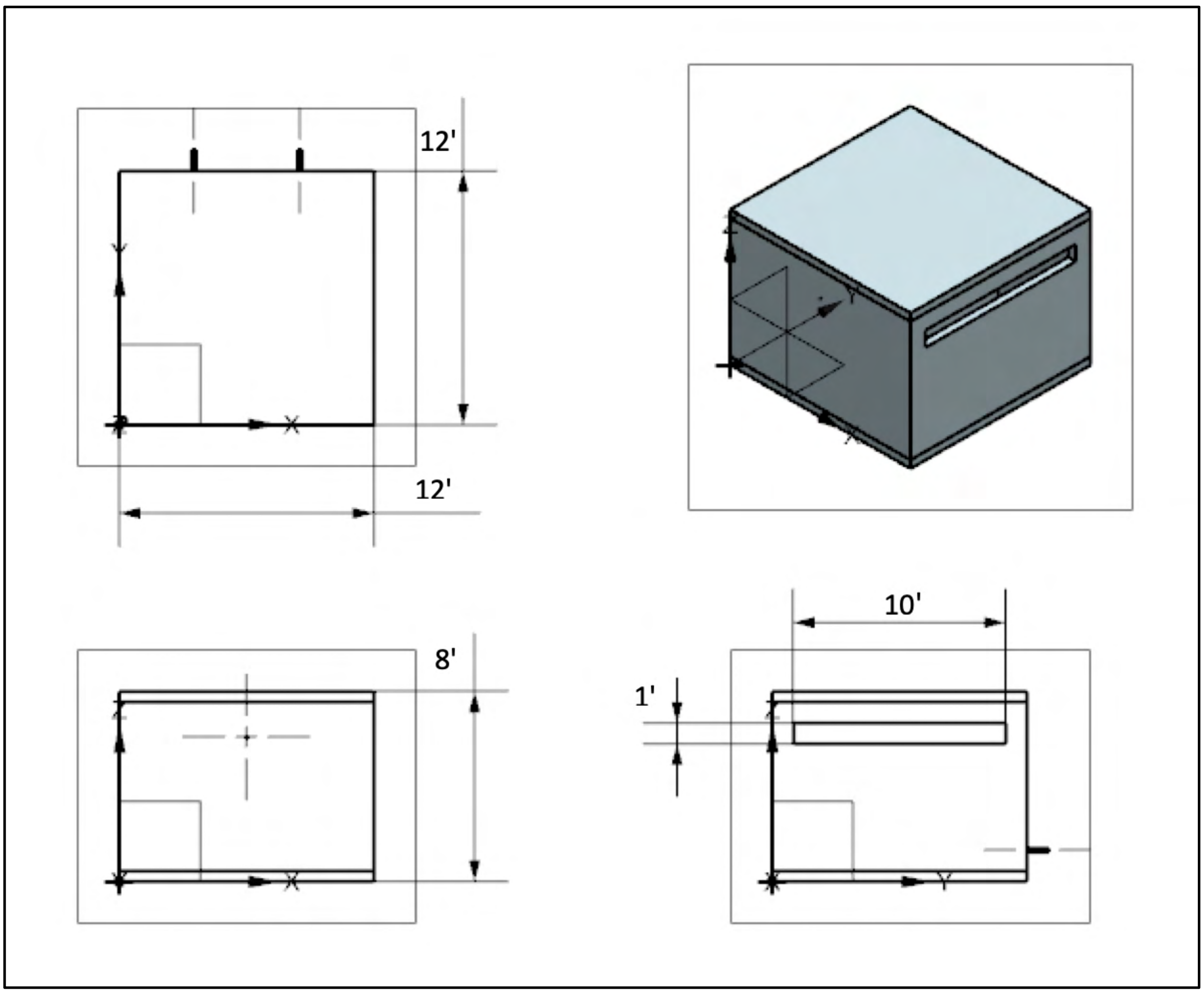

Figure 14: Sand Filter Design

Maintenance of the sand filter will require initial media cleaning, where pathogens are removed from the sand and gravel media. Since the influent water is expected to have wide ranges of quality, bi-weekly backwash cleaning of the filter is recommended. The backwash process requires piping and valves that allow for water to flow in from the clean out ports. Water will flow upward through the filter media and over the weirs. This backwashing will remove excess particles from the media, so the sand and gravel can be reused for further cleaning. This backwash effluent needs to be drained and diverted away from the tank. Once backwash is complete and the media is free of unwanted particles, water flow stops. Then the filter media settles back into place, allowing for further filtration.

5.6 Chlorination Disinfection

Although sedimentation and sand filtration tanks excel at removing particles from water they do not have the capacity to remove all pathogens. These pathogens can be deactivated through the process of disinfection. The recommended disinfection treatment is by chlorine. Chlorine pucks will be implemented following the filtration tanks, prior to storage. Chlorine pucks will continually need to be replenished, most likely every week. The in-line chlorinator is shown below in Figure 15.

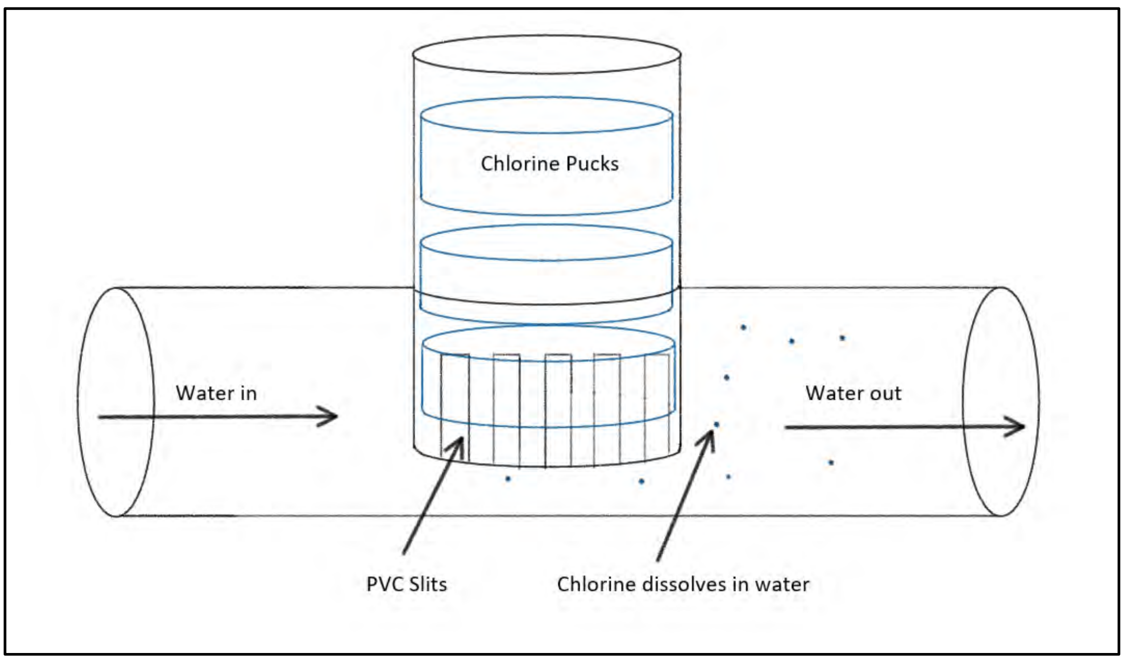

Figure 15: Chlorine Disinfection

5.7 Water Storage Tank

Following chlorination is a water storage tank. The water storage tank will be placed on a hill above the cemetery (at 9.2353°N, 82.4321°W), the desired location by the Water Committee. The location was found to be adequate by Sultan Consultants since it is higher in elevation than the village and is easily accessible. The designed volume of the tank is 14,000 gallons, which is the estimated daily use for the Valle Risco population in 20 years assuming that the growth rate is 3% and each person uses 30 gallons/day.

The tank area should be excavated and be at a uniform grade. After this, 8 inches of gravel should be placed before laying a reinforced concrete slab. The reinforced concrete slab should be 6 inches thick. This slab will have rebar placed in a grid design at 1.25 inches from the top of the slab. Number 4 bars should be spaced at 6 inches on center, along the 12 foot span and number 4 bars should be placed every 12 inches, along the 18 foot span. The walls will be constructed of concrete block, rebar, and filled with concrete. The tank will be 18 feet long, 12 feet wide and 8 feet tall. The concrete blocks available in community are nominally six inches thick, eight inches tall and 16 inches long. The concrete blocks will be placed with grout in between each one, and a number 4 rebar will be placed in the two cores of each block. The rebars will then be tied together to avoid slippage before the pouring of concrete which will fill the block's cores. After a wall is completed, grout will be used to smooth down the outside and inside of the walls to better bind the blocks together. The roof will be constructed using forms and will be poured, similar to the floor. The roof slab will have a total thickness of 6 inches with rebar placed 1.25 inches from the bottom. The rebar will be placed in a grid design exactly as the floor slab. The sedimentation tank and sand filter should be constructed similarly.

A sketch of the water storage tank is shown in Figure 16. For detailed design drawings and tank references, see Appendix D.

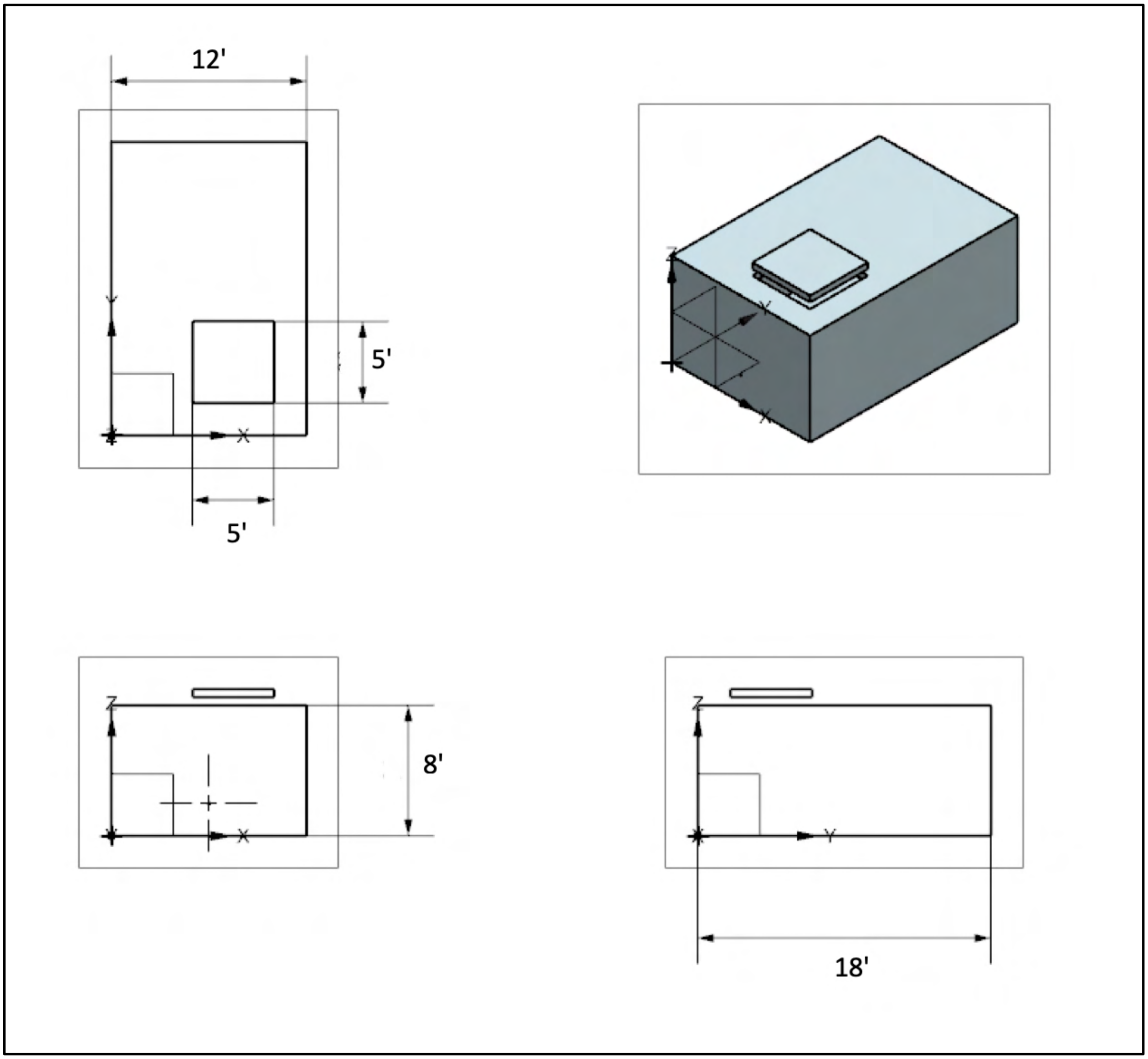

Figure 16: Storage Tank Design

5.8 Stream/Pipe Crossings

Four stream/pipe crossings exist in the Mono Congo water system. Stream/pipe crossings are sections of pipe that needs to be elevated like a bridge in order to cross streambeds. Each pipe bridge will consist of the 2 inch water pipe inside a 4 inch carrier pipe. A small tower will be built on each side of the streambed. The tower should be constructed of reinforced poured concrete standing about 4 feet tall. A cable will be drawn between the towers and will help carry the pipe across while controlling how much the pipe can sag. A saddle should be constructed on the top of each tower in order to hold the cable in place. The cable should be pulled taut to the ground and held in place by a poured concrete block. Smaller cables, referred to as stringers, will connect the large cable to the water pipeline. Design calculations and more information on stream/pipe crossings can be found in Appendix G. Figure 17 shows conceptually how a pipe crossing will be constructed.

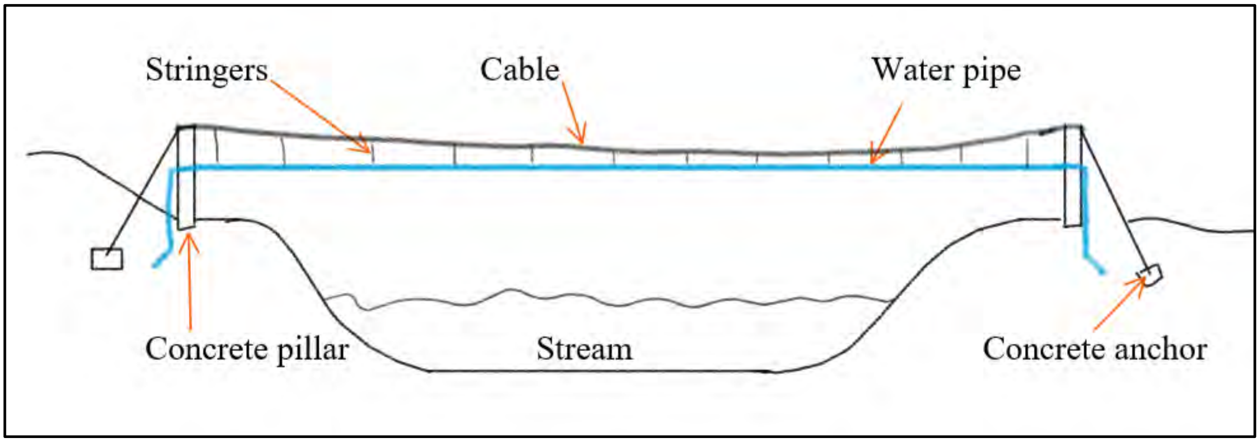

Figure 17: Example Stream/Pipe Crossing

5.9 Valves

Three types of valves will be implemented in the water system: air release, cleanout and shut off valves. Shut off valves will be placed at each tank and sporadically throughout the system. Shut off valves are most needed in the village so that if there is a break, one branch can be shut off while the rest of the system is still active. There will be six shut off valves spaced every 200 feet from the sources to the tank. There will also be 2 shut off valves at the junction box, 1 at the sedimentation tank, 1 at the sand filtration tank, and 1 at the water storage tank. Through the village, nine shut off valves will be placed every 200 feet and at major branches.

With expected sediments in the water, it is recommended that cleanout valves are implemented to allow sediment to collect in strategic places along the trunk line. Cleanout valves work by water flowing over a y-connection, where solids can settle in the clean out pipe. An estimated four clean out valves will be placed along the main trunkline at local low points. In Figure 18, a sketch of the cleanout valve and pipe can be seen.

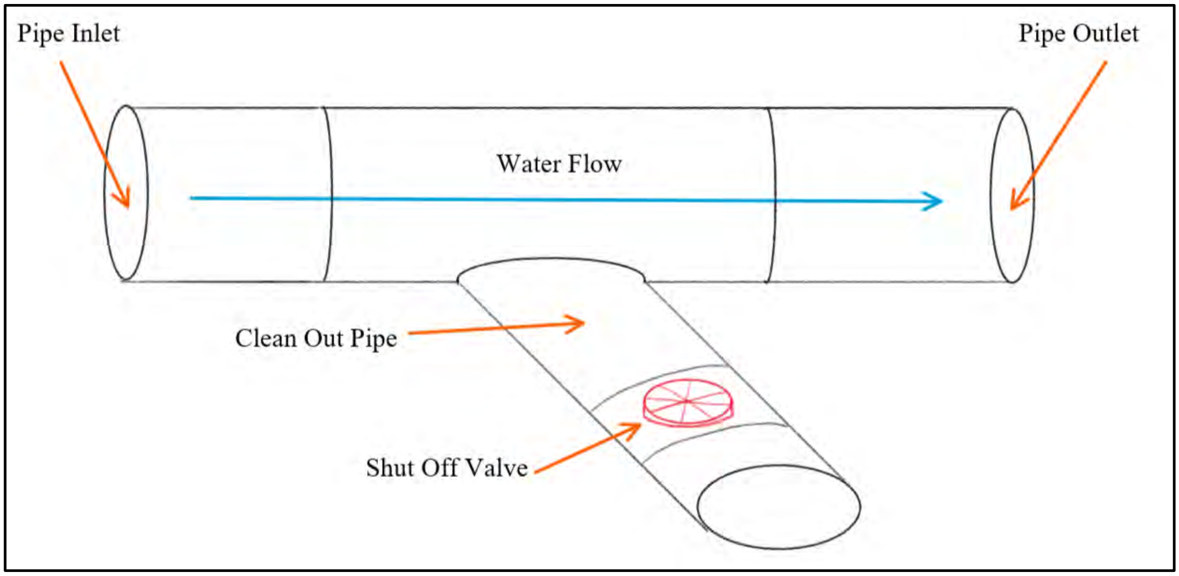

Figure 18: Cleanout Valve Sketch

Air release valves will be placed at local high points along the water system. Approximately four will be needed between the sources and the tank. Air release valves are aimed at allowing any trapped air to escape, avoiding punctures in the pipeline. All of the valve locations can be seen in Figure 19 below.

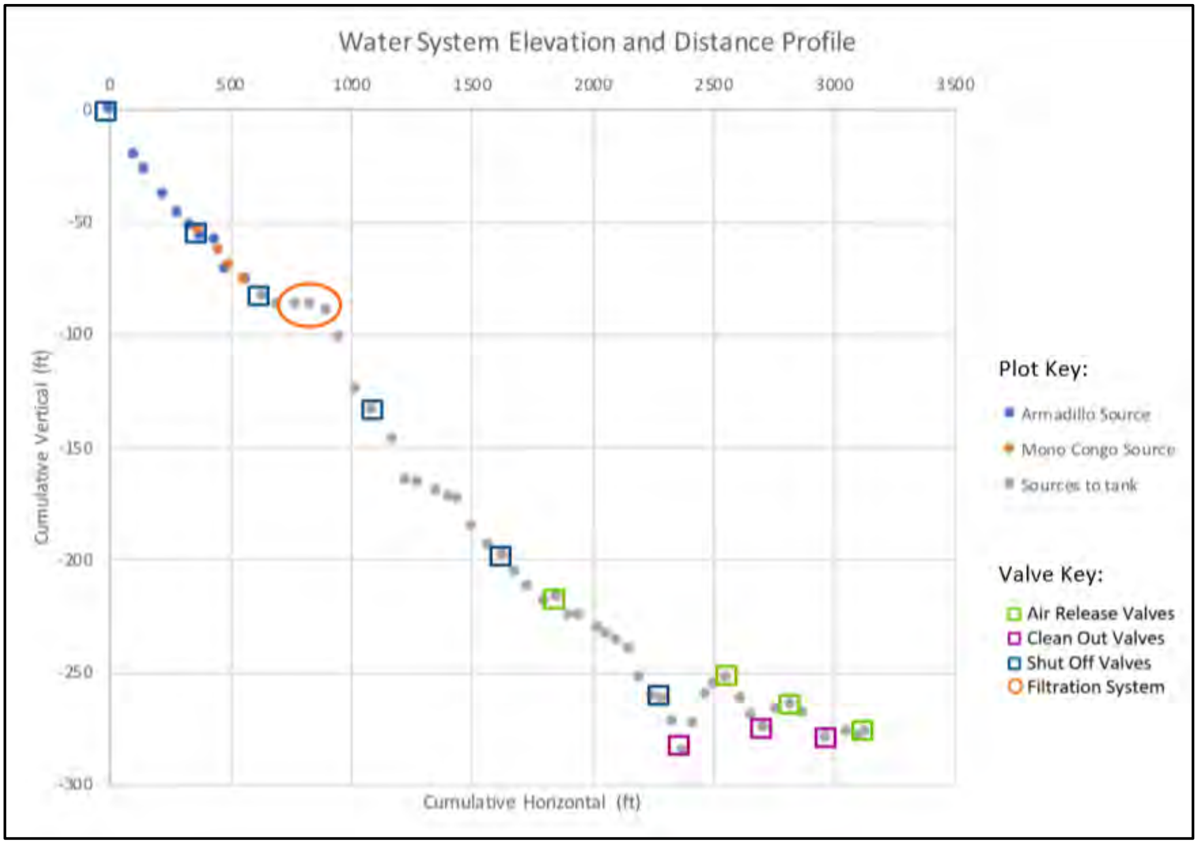

Figure 19: Locations of Valves

A valve box should be constructed whenever there is a valve placed in the pipeline. Valve boxes can be constructed using forms and hand mixed concrete with a gravel bottom. The boxes should be approximately one foot by one and a half feet. The purpose of these boxes is to protect the valves from being stepped on and tampered with, and they may include a lockable lid depending on the preferences of the Water Committee. Figure 20 shows the recommended valve box design.

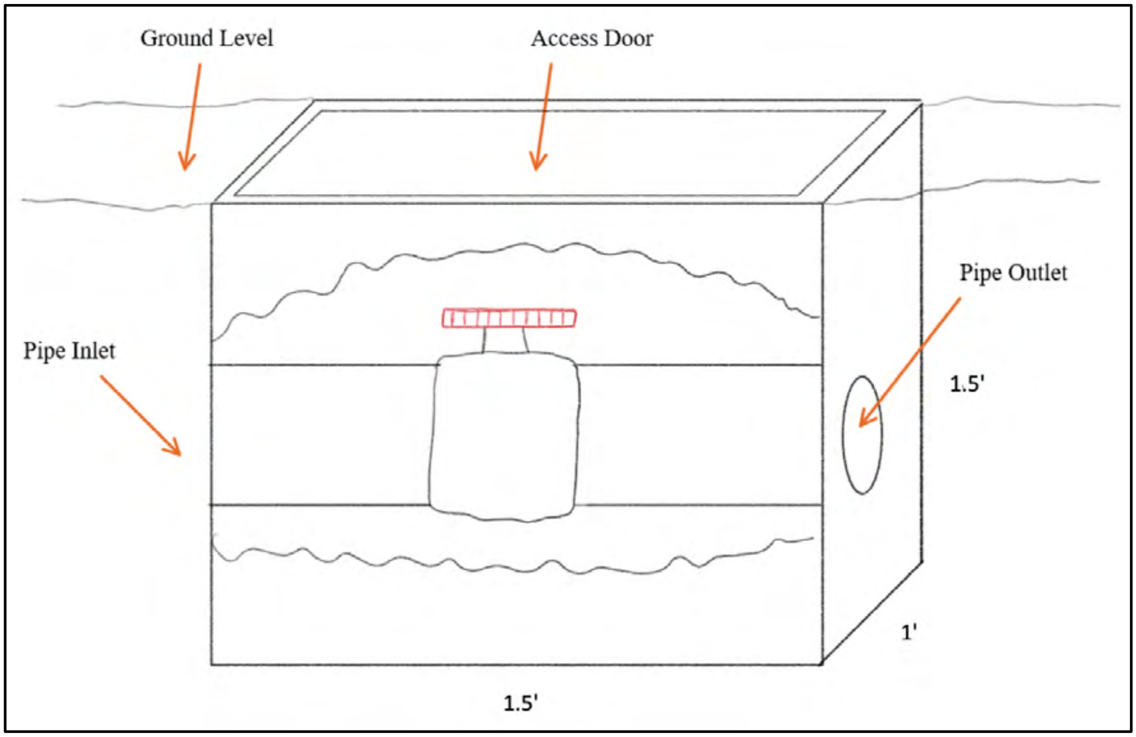

Figure 20: Valve Box Design

6.0 Cost Estimate and Construction Schedule

Based on local prices, a cost estimate was created. The cost estimate below is for the optimum design scheme described above. The estimated cost is $10,350 without contingency and $11,300 with 10% contingency. Some major cost contributors are the 5,000 feet of new PVC pipe and the concrete blocks needed to create the walls of all the tanks. Other notable contributors include rebar and materials needed for poured concrete. Chlorine pucks will need to be purchased continually, only the first 100 pucks are included in the cost estimate. Labor is assumed to be voluntary and is not included in the cost estimate. A simplified cost estimate can be seen below in Table 1. A more detailed breakdown of the cost estimate can be found in Appendix H.

Table 1: Cost Estimate

Item	Cost
Piping	$6,300
Valves	$100
Tank Materials	$3,800
Chlorine Pucks and Screens	$150
Total Cost	$10,350

The construction schedule was created based on estimated durations of the tasks required. The schedule provided assumes 5 day work weeks, with enough workers present to complete each task. It is also assumed that certain tasks can be constructed simultaneously. The crew sizes will range based on the task. Trench crews will take 10 people, whereas tank construction will require 6 people. Assuming crew members are unskilled, they will require brief safety training prior to construction. Considering these assumptions, an optimistic, 3 month, construction schedule and task duration is shown in Table 2.

Table 2: Construction Schedule

TASK	DURATION (DAY)	ES	EF
Tank Foundation (1)	10	01/01/20	01/14/20
Sed Tank Foundation (2)	10	01/01/20	01/14/20
Sand Filter Foundation (3)	10	01/01/20	01/14/20
Dig Pipe Trench & Lay Pipe (~3000')	60	01/01/20	03/24/20
Pipe Bridges (4 each)	60	01/01/20	03/24/20
Particle Settling Ramp (2)	4	01/15/20	01/20/20
Walls for Tank (1)	8	01/15/20	01/24/20
Walls and Partition (3)	8	01/15/20	01/24/20
Pipe Fittings for Tank (1)	4	01/21/20	01/24/20
Sed Walls & Catchments (2)	8	01/21/20	01/30/20
Filter Media Cleaning (3)	2	01/23/20	01/24/20
Pipe Fittings for Sand Filt (3)	4	01/27/20	01/30/20
Pipe Fittings for Sed Tank (2)	4	01/27/20	01/30/20
Roof & Access Door(1)	8	01/27/20	02/05/20
Roof & Access Door (3)	8	01/27/20	02/05/20
Overflow Basin & Backwash (3)	8	01/31/20	02/11/20
Valves and Connections	10	03/11/20	03/24/20
Quality Check & Final Adjustments	10	03/11/20	03/24/20
TOTAL DURATION	60		

For a complete gantt chart of the construction schedule, see Appendix H. The estimated duration is between 3 and 6 months, assuming that trenching, laying pipes, and laying tank foundations can occur simultaneously. Construction duration estimates span a wide range, due to the uncertainty of weather, manpower, and available supplies. To improve manpower leveling over the duration of the construction schedule, tank foundations can be sequenced. Alterations to the schedule are expected to occur when construction begins.

7.0 Conclusion

Prior to designing an improved water distribution network, it was important to have a firm understanding of the current system. It is of utmost importance to address the needs and desires of the residents of Valle Risco.

The members of the Water Committee informed members of Sultan Consultants that the primary concern is water security. Often times, even in the wet season, water does not flow through the taps. Their goal is to have a storage tank to aide in keeping water available throughout the day, especially during the dry season.

Upon further analysis of the system, Sultan Consultants concluded that some pipe redesign would be necessary. Several existing pipes were broken or leaking, from accidental or intentional puncturing. Pipes will need to be replaced and valves will need to be placed accordingly. In addition to replacement, pipes are recommended to be buried so that breaks can be avoided.

Water treatment is crucial for the health and safety of the community. Sultan Consultants designed for a three-step water treatment system which includes a sedimentation tank, slow sand filtration tank, and chlorine disinfection. These treatment options will ensure potable water quality for the villagers.

The goal of this system is to ensure water quality and security for the city of Valle Risco. After careful consideration, analysis, and computation, Sultan Consultants recommends an optimum design scheme that will improve the current system by replacing old PVC pipes, designing for a treatment system, storage tank, and improve upon the current system. The improved water system will provide the community with access to clean, consistent water, which they do not have readily available to them.

For project implementation, it is up to our client, Tristan Odekirk, to advocate for the project, acquire grant funding, and share the design report with the Water Committee.

8.0 References

1. “3M Science. Applied to Life. 3M United States.” (n.d.). *3M Science. Applied to Life. 3M United States*, <https://www.3m.com/> (Nov. 20, 2019).
2. *Bing Maps* <https://www.bing.com/maps> (Sept. 12, 2019).
3. Davis, J., Lambert, R. (2002). *Engineering in Emergencies: A Practical Guide for Relief Workers.* Practical Action.
4. “*E. coli”* Mayo Clinic <https://www.mayoclinic.org/diseases-conditions/e-coli/symptoms-causes/syc-2037205> (Nov. 20, 2019).
5. Mihelcic, J. R., Fry, L. M., Myre, E. A., Phillips, L. D., and Barkdoll, B. D. (2009). *Field Guide to Environmental Engineering for Developmental Workers*. American Society of Civil Engineers, Reston, VA.
6. Rossman, L. A. (2000). *EPANET 2: Users Manual*. U.S. Environmental Protection Agency. Office of Research and Development. National Risk Management Research Laboratory, Cincinnati, OH.
7. Rossman, L. A. (n.d.). “EPANET 2.2.” United States Environmental Protection Agency, EPA.

9.0 Appendices

Appendix A: Surveying Data

Table 3: Complete Surveying Data

Station	Longitude °N	Latitude °W	Horizontal Distance (ft)	Vertical Distance (ft)	Bearing
1	9.2408	82.4271	100.0	-20.50	235SW
2	9.2406	82.4271	50.0	-6.00	166S
3	9.2405	82.4271	75.5	-11.50	210SW
4	9.2404	82.4271	54.3	-8.50	226SW
5	9.2403	82.4274	57.3	-5.00	210SW
6	9.2402	82.4273	41.7	-4.75	240SW
7	9.2401	82.4274	55.5	-1.75	241SW
8	9.2400	82.4275	49.8	-13.25	236SW
9	9.2400	82.4275	78.0	-4.25	190S
TO SOURCE 1 (West)					
10	9.2404	82.4275	81.4	-9.50	185S
11	9.2402	82.4274	46.0	-7.00	195S
12	9.2401	82.4275	64.7	-5.75	220SW
13	9.2400	82.4275	65.5	0.50	186S
14	9.2398	82.4276	71.0	-8.00	211SW
15	9.2397	82.4276	63.9	-3.25	218SW
16	9.2395	82.4278	77.0	-0.50	200S
17	9.2394	82.4278	58.5	0.50	215SW
18	9.2389	82.4279	65.9	-3.00	215SW
19	9.2391	82.4281	57.8	-12.00	208SW
20	9.2390	82.4281	68.3	-22.75	239SW
21	9.2389	82.4283	63.8	-9.75	203SW
22	9.2388	82.4283	88.2	-12.25	203SW
23	9.2386	82.4284	50.5	-19.00	231SW
24	9.2385	82.4285	49.0	-0.75	232SW
25	9.2385	82.4286	77.4	-3.75	245SW
26	9.2384	82.4288	49.4	-2.75	233SW
27	9.2383	82.4289	38.5	-1.00	200S
28	9.2382	82.4289	59.4	-11.25	206SW
29	9.2380	82.4290	68.4	-9.00	217SW
30	9.2379	82.4291	58.3	-4.75	255W
31	9.2379	82.4293	58.1	-6.75	242SW
32	9.2378	82.4294	49	-6.25	207SW
33	9.2377	82.4295	67	-7.25	227SW
34	9.2376	82.4296	53.5	2.50	250W
35	9.2375	82.4297	47.5	-8.25	268W
36	9.2375	82.4298	46.5	-0.75	246SW
37	9.2375	82.4300	78	-5.25	230SW
38	9.2374	82.4300	34	-3.00	242SW
39	9.2373	82.4301	42	-2.50	231SW
40	9.2372	82.4302	49.5	-3.75	232SW
41	9.2372	82.4304	42.5	-12.50	235SW
42	9.2371	82.4305	56.5	-8.25	270W
43	9.2371	82.4306	36	-1.00	266W
44	9.2371	82.4307	50	-10.25	215SW
45	9.2370	82.4308	41	-13.00	224SW
46	9.2369	82.4308	37.25	11.75	216SW

47	9.2368	82.4309	54	13.50	197S
48	9.2367	82.4309	35	4.00	173S
49	9.2367	82.4309	51	3.25	211SW
50	9.2365	82.4310	58	-9.50	194S
51	9.2363	82.4310	49.5	-7.00	219SW
52	9.2362	82.4311	47.5	-5.75	242SW
53	9.2362	82.4312	51.5	8.00	216SW
54	9.2361	82.4313	64	2.25	199S
55	9.2360	82.4313	50.5	-4.00	203S
56	9.2359	82.4314	89.5	-10.75	210SW
57	9.2357	82.4315	89.5	2.75	194S
58	9.2355	82.4316	46	-2.25	218SW
59	9.2353	82.4316	65.5	12.00	2287W
60	9.2354	82.4318	39.5	11.50	265W
61	9.2354	82.4319	51.5	5.50	238SW
62	9.2353	82.4321	0	0.00	
63	9.2353	82.4316	124.5	-15.50	158S
64	9.2350	82.4315	117.5	-24.00	165S
65	9.2347	82.4315	99	20.50	176S
66	9.2345	82.4314	50	8.25	188S
67	9.2344	82.4314	84	-3.75	179S
68	9.2341	82.4315	66	-3.50	221SW
69	9.2340	82.4315	63.5	-4.50	219SW
70	9.2339	82.4316	39	-1.50	236SW
71	9.2338	82.4317	48	-4.25	211SW
72	9.2338	82.4318	39.5	-1.75	217SW
73	9.2337	82.4318	56.5	-2.00	127SE
74	9.2336	82.4317	67.5	-3.50	207SW
75	9.2334	82.4318	34.5	-11.50	198S
76	9.2334	82.4319	33.25	-13.75	168S
77	9.2333	82.4319	40	-9.00	137SE
78	9.2332	82.4318	52	-9.50	128SE
79	9.2331	82.4317	50	6.25	127SE
80	9.2330	82.4315	39.5	0.00	181S
81	9.2329	82.4316	67	-6.25	171S
82	9.2328	82.4316	59	-6.50	160S
83	9.2326	82.4316	47	-15.50	174S
84	9.2325	82.4316	55.5	2.50	91E
85	9.2325	82.4314	53.5	6.50	73E
86	9.2326	82.4313	43.5	-1.75	68E
87	9.2326	82.4312	57.5	-8.25	27NE
88	9.2327	82.4311	55.5	-4.00	59NE
89	9.2328	82.4310	37.5	2.00	70E
90	9.2354	82.4350	145.5	14.00	147SE
91	9.2351	82.4348	170.5	-1.50	135SE
92	9.2348	82.4344	107	-3.50	132SE
93	9.2347	82.4342	149	17.00	105E
94	9.2345	82.4338	174.5	17.25	134SE

95	9.2342	82.4335	125.75	11.00	105E
96	9.2341	82.4331	120	-1.75	107E
97	9.2341	82.4328	162.5	-14.75	94E
98	9.2340	82.4324	94.5	9.50	107E
99	9.2340	82.4321	127.75	21.00	131SE
100	9.2338	82.4319	88.5	-3.00	138SE
101	9.2336	82.4317	126	-18.25	145SE
102	9.2333	82.4315	124.5	-17.00	159S
103	9.2330	82.4314	142.75	-15.50	159S
104	9.2327	82.4312	95	-7.25	148SE
105	9.2324	82.4311	175.5	-16.00	143SE
106	9.2321	82.4308			

Appendix B: Water Quality Data

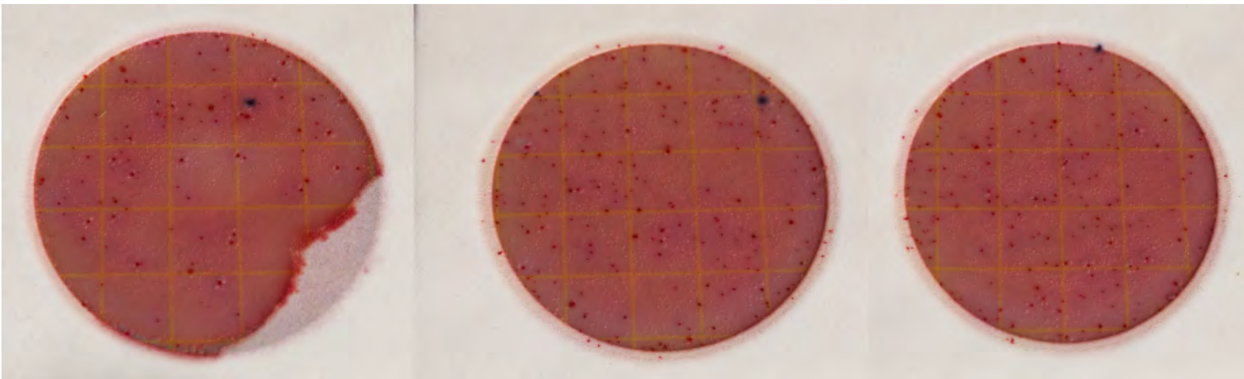

Figure 21: Petrifilms from Armadillo Source

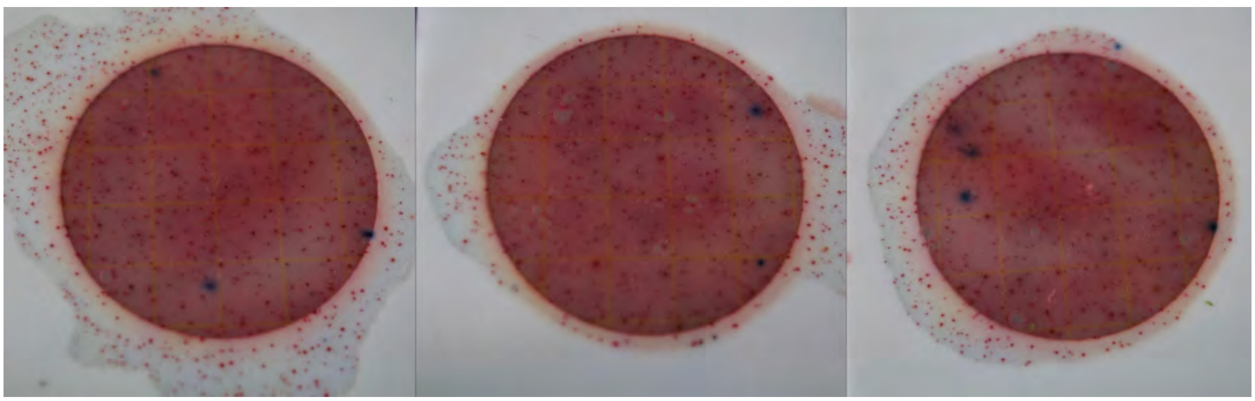

Figure 22: Petrifilms from Mono Congo Source

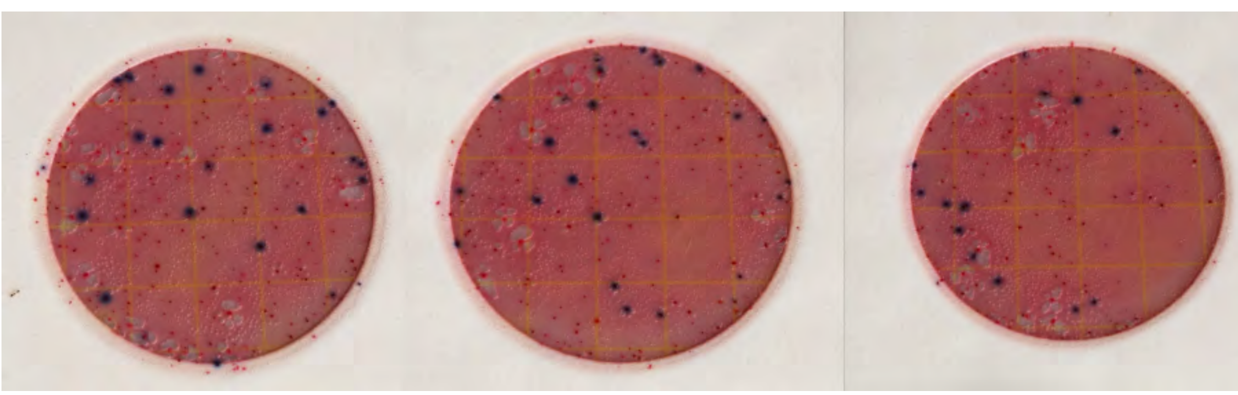

Figure 23: Petrifilms from Tap Water

Table 4: Coliform and E. Coli Test Results for Armadillo Source (CFU/mL)

Armadillo Source	Sample 1	Sample 2	Sample 3
Coliforms	120	120	200
Coliforms with bubbles	15	12	12
E. coli	1	2	1
E. coli with bubbles	1	2	0

Table 5: Coliform and E. Coli Test Results for Mono Congo Source (CFU/mL)

Mono Congo Source	Sample 1	Sample 2	Sample 3
Coliforms	500	600	440
Coliforms with bubbles	8	14	10
E. coli	4	2	3
E. coli with bubbles	0	0	2

Table 6: Coliform and E. Coli Test Results for Tap Source (CFU/mL)

Tap Water	Sample 1	Sample 2	Sample 3
Coliforms	160	160	140
Coliforms with bubbles	22	18	25
E. coli	21	14	22
E. coli with bubbles	11	12	15

Table 7: Average Coliform and E. Coli Test Results for Each Source (CFU/mL)

	Armadillo	Mono Congo	Tap
Coliforms	147	513	153
Coliforms with bubbles	13	11	22
E. coli	1	3	19
E. coli with bubbles	1	1	13

Appendix C: EPANET

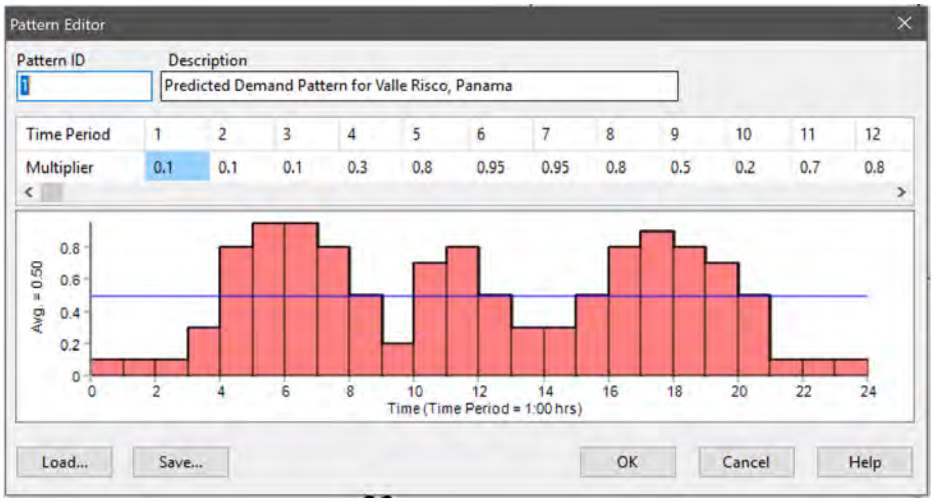

Figure 24: Demand Pattern for EPANET Simulation

Appendix D: Water Storage Tank

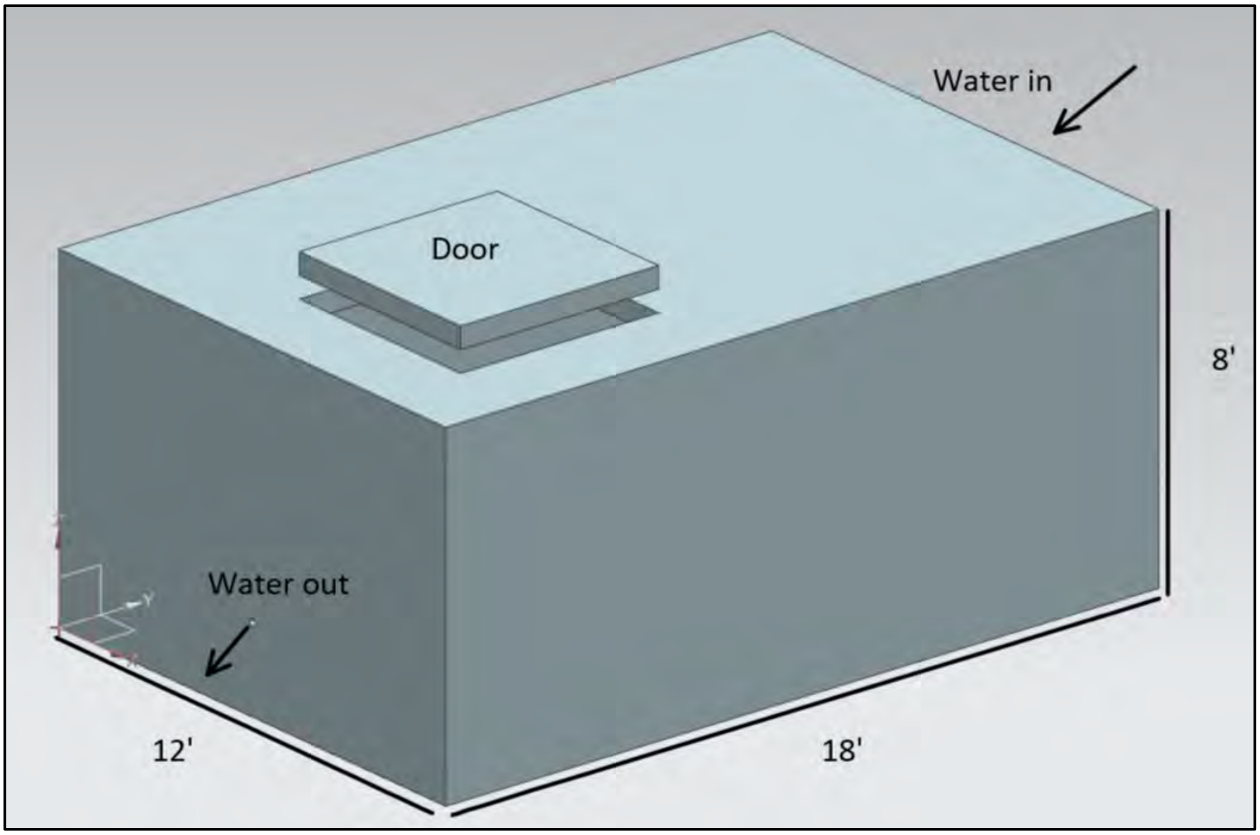

Figure 25: Storage Tank 3D Model

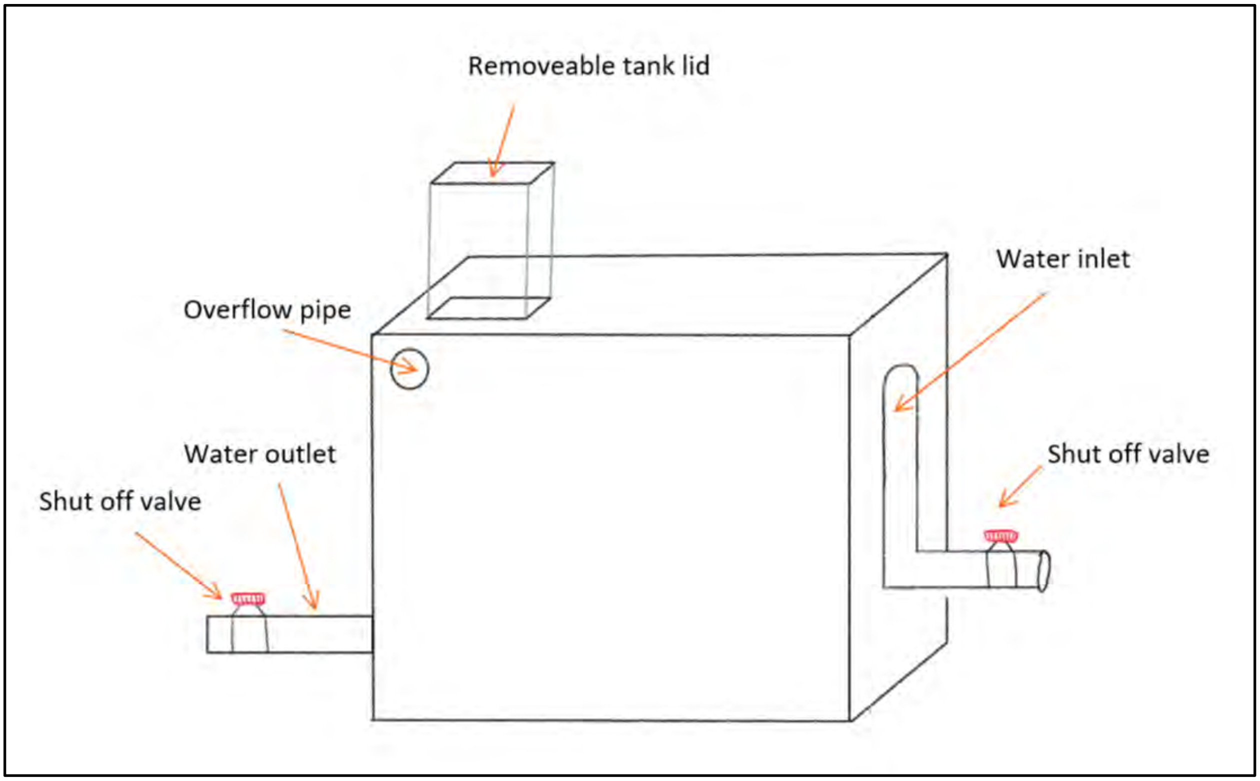

Figure 26: Storage Tank Drawing

Table 8: Water Storage Tank Dimensions

Variable	Dimension
X, length of tank	12 ft
Y, height of tank	8 ft
Z, width of tank	12 ft
r, radius of pipes	2 in
Wall thickness	8 in

Appendix E: Sedimentation Tank

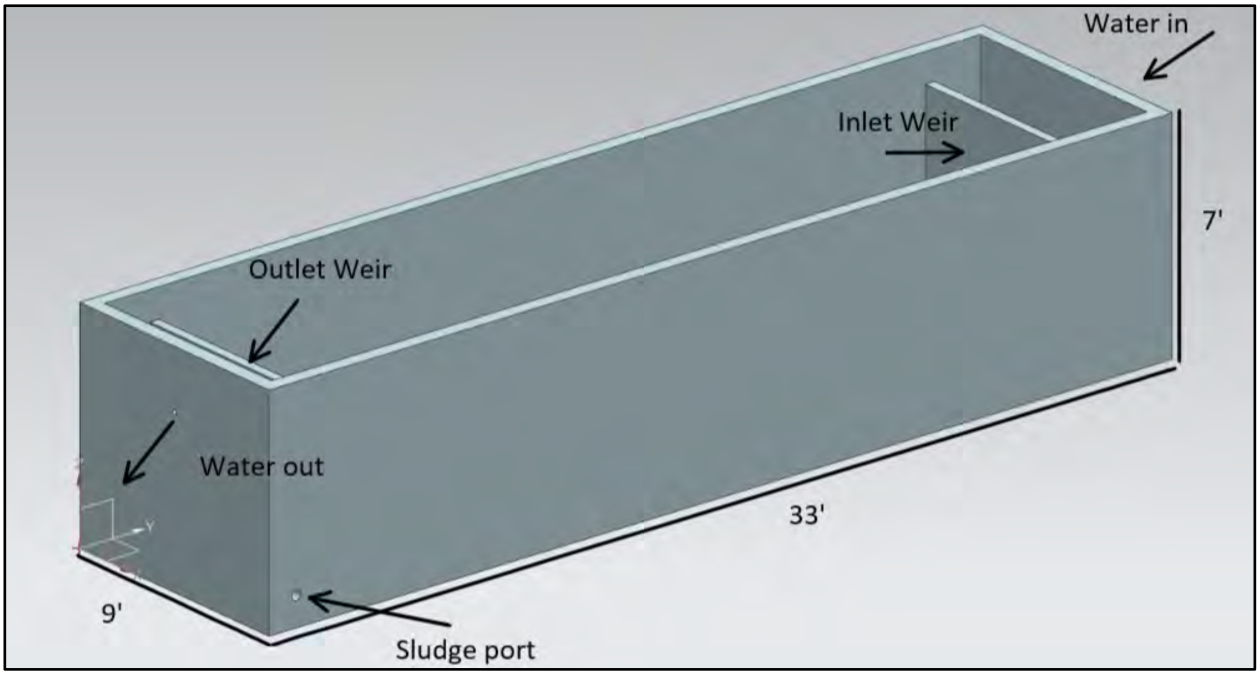

Figure 27: Sedimentation Tank 3D Model

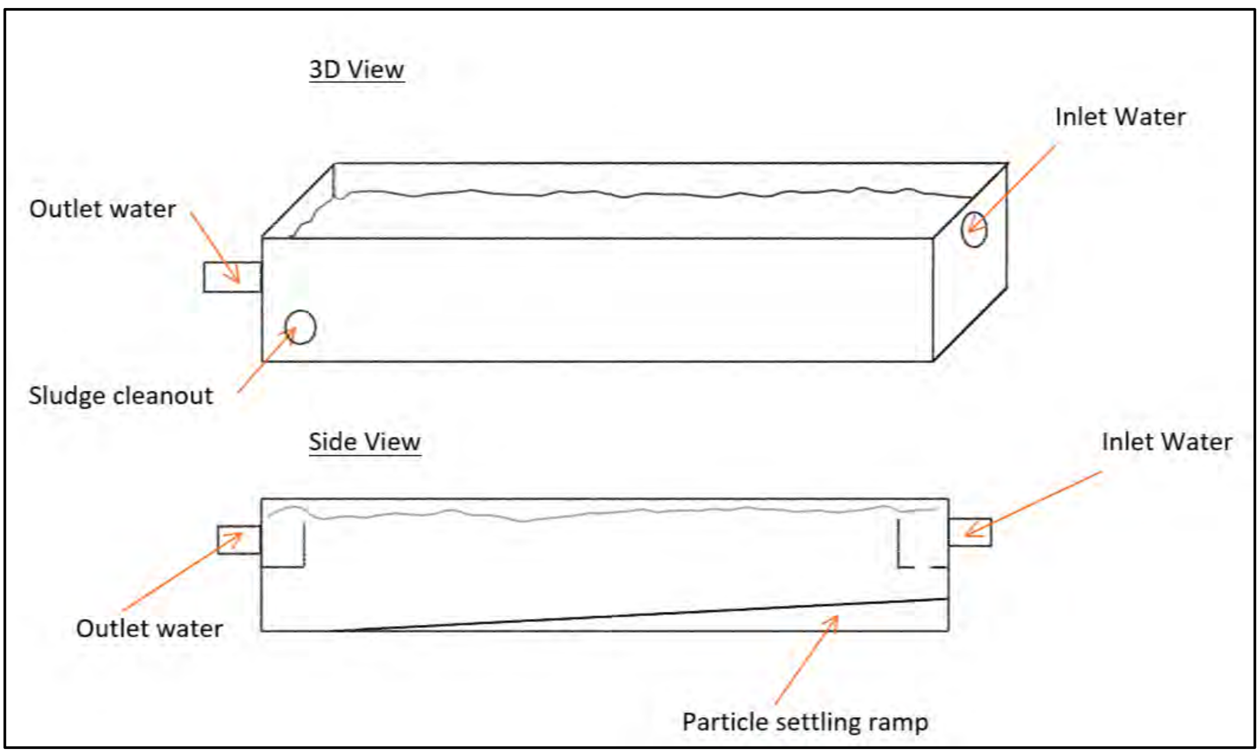

Figure 28: Sedimentation Tank Drawing

Table 9: Sedimentation Tank Dimensions

Variable	Dimension
X, sedimentation tank length	10 m, or *32.8084* (*33*)ft
Y, sedimentation tank height	2 m, or 6.56168 (7) ft
Z, sedimentation tank width	2.5 m, or *8.2021* (*9*) ft
Detention time	1.5 - 4 hours
Reynolds number	<20,000
Froude number	$>10^{-5}$
Bottom slope	1:300 m/m

Equation 1. Sedimentation tank length to depth ratio, from Engineering in Emergencies

$$\frac{L}{D} = \frac{5}{1}$$

$$if\ water\ depth\ is\ 2\ m, Length\ is\ 10\ m, or\ 32.8084\ ft$$

Equation 2. Length to width ratio

$$\frac{L}{W} = \frac{4}{1}$$

$$if\ length\ is\ 10m, width\ is\ 2.5\ m, or\ 8.2021\ ft$$

Appendix F: Slow Sand Filter

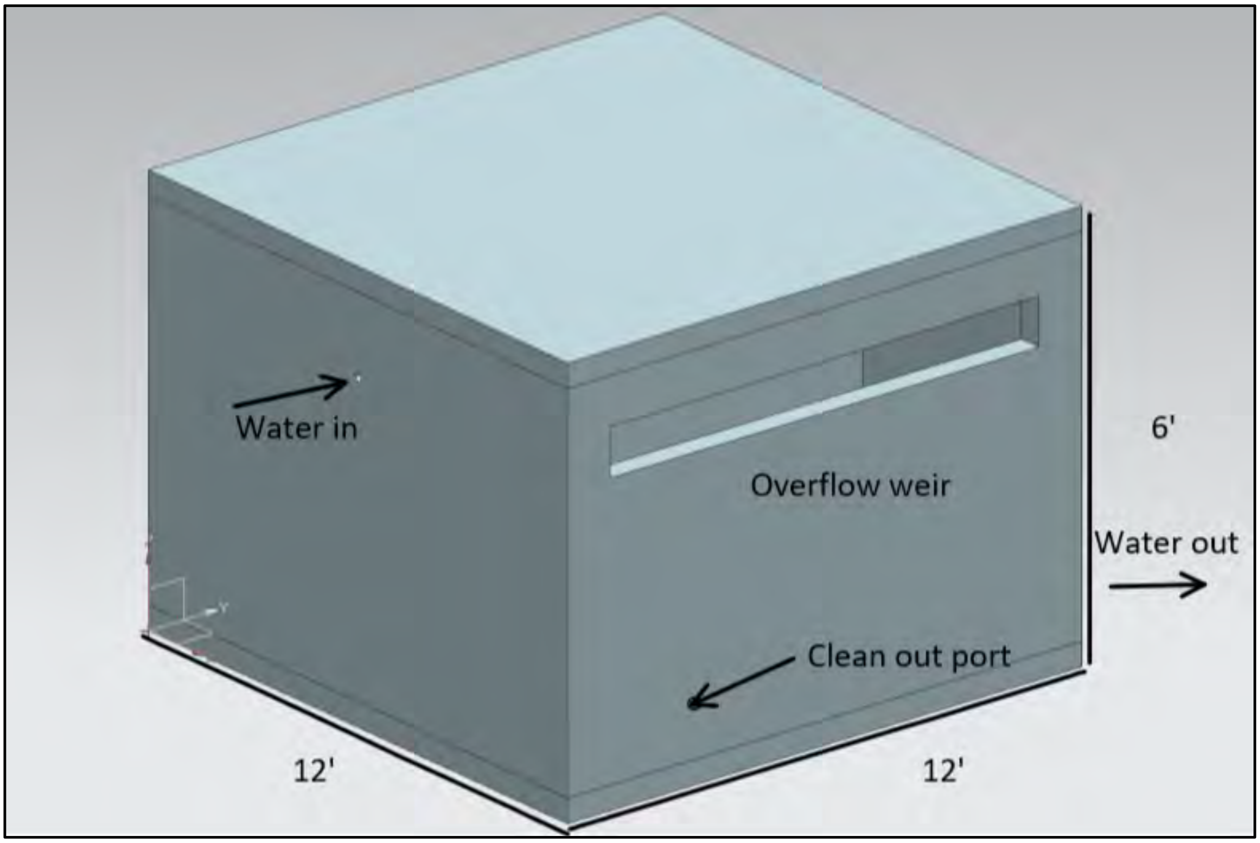

Figure 29: Slow Sand Filter 3D Model

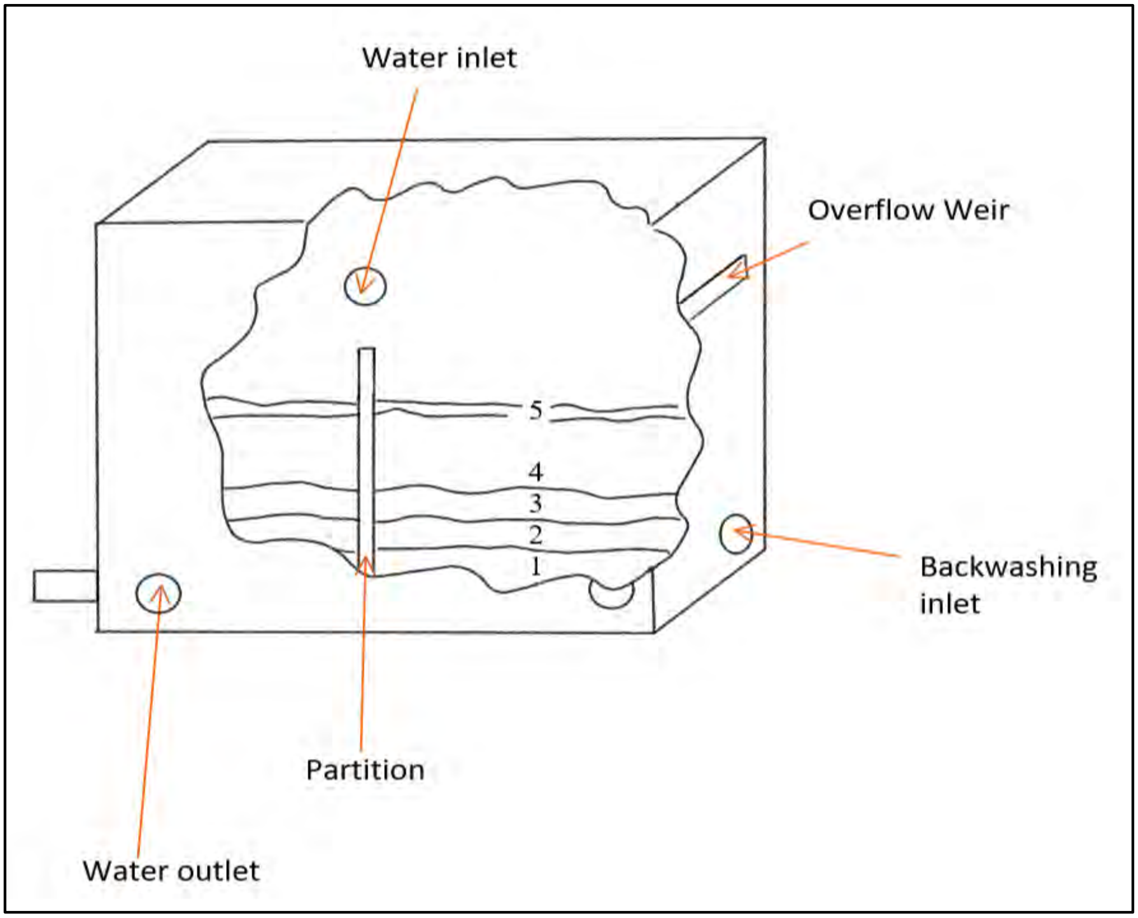

Figure 30: Slow Sand Filter Drawings

Table 10: Sand Filter Tank Dimensions

Variable	Dimension
Number of basins	2
A, area	$22.7124\ m^2$
X, sand filter length	12 ft
Y, sand filter height	8 ft

Z, sand filter width	12 ft
Overflow Weir Height	7 ft
1, large gravel	8 in
2, mid to fine grain gravel	8 in
3, coarse sand	8 in
4, fine sand	36 in
5, biofilm	2 - 4 in

Equation1. Area of Sand Filter, from Chapter 18 Water Treatment

$$A = \frac{Q}{v}$$

Where A is area, Q is flow through the pipes, and v is the velocity through the filter (between 0.1 and 0.2 m/h.

$$Q = 10\ \frac{gal}{min} * \frac{0.00378541\ m^3}{1\ gal} * \frac{60\ min}{1\ hr} = 2.27124\ \frac{m^3}{h}$$

$$A = \frac{2.27124\ \frac{m^3}{h}}{0.1\ \frac{m}{h}}$$

$$A = 22.7124\ m^2$$

Appendix G: Stream/Pipe Crossings

Unit weights of Schedule 40 PVC pipe:
2" pipe 68 lb/100 ft
4" pipe 201 lb/100ft

Sta 33 span is 58.3'
Estimate Sta 11 at 70'
Estimate Sta 44 at 40'
Estimate Sta 4 at 20'

Example calculation for largest span crossing (at station 11)

$$Weight\ of\ Water\ = \frac{62.4\ lb}{ft^3}\ x\ \frac{(\frac{2.067in}{12in})^2 * .25 * \pi}{1} = 1.45\ lb/ft$$

$$Total\ Weight\ per\ foot\ = \frac{68\ lb}{100\ ft} + \frac{201lb}{100ft} + 1.45lb/ft\ = 4.14\ lb/ft$$

Estimate sag: 2 ft

$$Horizontal\ Tension = \frac{(weight\ pipe\ per\ unit\ length)\ x\ (length\ of\ span)^2}{8\ x\ sag}$$

$$= \frac{(4.14lb/ft))\ x\ (70ft)^2}{8\ x\ 2ft} = 1268\ lb$$

$$Angle\ of\ Tension\ = arctan\ (\frac{4\ x\ sag}{length\ of\ span}) = arctan\ (\frac{4\ x\ 2ft}{70ft}) = 6.5\ \circ$$

$$Total\ Tension\ = \frac{horizontal\ tension}{cos(angle\ of\ tension)} = \frac{1268lb}{cos(6.5)} = 1277lb$$

$$Factored\ Total\ Tension\ = 3\ x\ Total\ Tension\ = 3\ x\ 1276lb\ = 3829lb$$

From Appendix A-2 [5], a $7\ x\ 7\ \frac{7}{32}$ steel cable should be used

Appendix H: Cost Estimate

Table 11: Detailed Optimum Cost Estimate

Item	Unit	Quantity	Unit Price	Total Cost	Comments
2" PVC	20 feet	135	$20.00	$2,700.00	from sources to junction box and treatment to storage tank
1.5" PVC	20 feet	80	$18.00	$1,440.00	from storage tank to trunk lines
1" PVC	20 feet	80	$15.00	$1,200.00	from trunk lines to houses
.75" PVC	20 feet	18	$12.75	$230.00	from junction box to treatment
.5" PVC	20 feet	20	$12.00	$240.00	houses to faucet
2" PVC Connections	each	135	$0.75	$101.25	
1.5" PVC Connections	each	80	$0.75	$60.00	
1" PVC Connections	each	80	$0.50	$40.00	
.75" PVC Connections	each	18	$0.50	$9.00	
.5" PVC Connections	each	20	$0.50	$10.00	
2" PVC Elbow	each	12	$2.00	$24.00	
1.5" PVC Elbow	each	20	$1.00	$20.00	
1" PVC Elbow	each	50	$0.50	$25.00	
.5" PVC Elbow	each	105	$0.25	$26.25	
PVC Glue	each	4	$25.00	$100.00	US glue
Air Release Valves	each	4	$3.25	$13.00	
Shut-off Valves	each	24	$3.25	$78.00	20 shut off valves and 4 clean out valves
Concrete block	each	1800	$1.00	$1,800.00	
Loose Cement	pound	100	$0.50	$50.00	for poured concrete and grout
Bag of Sand	1/66 yd^3	20	$40.00	$800.00	for poured concrete and grout
Bag of Aggregate	1/66 yd^3	20	$40.00	$800.00	for poured concrete and foundation
Reinforced steel	20 feet	100	$1.30	$130.00	for tanks, access door handles and tank ladders
Cable	foot	300	$0.75	$225.00	for stream/pipe crossings
Chlorine Pucks	each	100	$1.00	$100.00	
Screens for intakes	each	2	$25.00	$50.00	one for each source
		Sub Total		$10,300.00	
		Contingency 10%		$1,000.00	
		Total		$11,300.00	

Table 12: Mid-range Cost Estimate

Item	Unit	Quantity	Unit Price	Total Cost	Comments
2" PVC	20 feet	10	$20.00	$200.00	replacing only pipes with leaks
1" PVC	20 feet	5	$15.00	$75.00	replacing only pipes with leaks
PVC Glue	each	1	$25.00	$25.00	US glue
Air Release Valves	each	7	$3.25	$22.75	
Shut-off Valves	each	1	$3.25	$3.25	
Concrete block	each	480	$1.00	$480.00	Tank walls, 12' x 14' x 8'
Loose Cement	pound	30	$0.50	$15.00	for poured concrete and grout
Bag of Sand	1/66 yd^3	10	$40.00	$400.00	for poured concrete and grout
Bag of Aggregate	1/66 yd^3	10	$40.00	$400.00	for poured concrete and foundation
Reinforced steel	20 feet	30	$1.30	$39.00	for tank, access door handle and tank ladder
Chlorine Pucks	each	100	$1.00	$100.00	
Screens for Intakes	each	2	$25.00	$50.00	one for each source
		Sub Total		$1,900.00	
		Contingency 10%		$190.00	
		Total		$2,090.00	

Table 13: Basic Cost Estimate

Item	Unit	Quantity	Unit Price	Total Cost	Comments
2" PVC	20 feet	10	$20.00	$200.00	replacing only pipes with leaks
1" PVC	20 feet	5	$15.00	$75.00	replacing only pipes with leaks
PVC Glue	each	1	$25.00	$25.00	US glue
Air Release Valves	each	7	$3.25	$22.75	
Loose Cement	pound	10	$0.50	$5.00	for valve boxes
Bag of Sand	1/66 yd^3	4	$40.00	$160.00	for valve boxes
Bag of Aggregate	1/66 yd^3	4	$40.00	$160.00	for valve boxes
Screens for Intakes	each	2	$25.00	$50.00	one for each source
		Sub Total		$700.00	
		Contingency 10%		$70.00	
		Total		$770.00	

Operations and Maintenance

Included with the design, operations and maintenance guidelines to ensure the safety and effectiveness of the distribution and filtration system. The storage tank will require weekly observation, to check water volume, valve functionality, and system operation. The sedimentation tank will require manual cleaning, with a person raking the bottom of the tank towards the sludge outlet pipes, where the sediment can be collected and disposed of. The sand filtration tank will require bi-weekly cleaning, where water will be fed through the backwashing port through one basin, allowing trapped particles to flow over the backwash weir. The backwash water will need to be diverted away from the tank to not erode the tank foundation. Water diversion can be accomplished via trench or concrete run off ramp. After storm or flood events, the sedimentation and sand filtration tanks will require extra cleaning. Periodic valve checks should occur to ensure the functionality of the air release, clean out, and shut off valves. System maintenance checks are crucial to guarantee system success. A comprehensive maintenance guideline is shown below.

Table 14: Maintenance Frequency Table

Maintenance Frequency Guideline	
Task	Frequency
Storage tank check	Once a week
Sedimentation tank raking	Bi-weekly, or after storm events
Sand filtration tank backwashing	Bi-weekly, or after storm events
Junction box check and cleaning	Once a week
Valve checks	Once a month
Chlorine puck check and replacement	Once a week