Water Supply and Distribution for the community of Quebrada Pinzón, Bocas del Toro, Panama

Quian Designs

Submitted by:

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Submitted on:

December 11, 2015

Michigan Technological University

Department of Civil and Environmental Engineering

Houghton, MI, USA

Letter of Transmittal

Date: December 11, 2015
To: Briana Arnold
From: CE4916 Quian Designs (QD)
Re: Final Report

Dear Ms. Arnold,

This is the report that addresses water supply and distribution for the section of 'Las Delicias' in Quebrada Pinzón through two alternative water supply and distribution systems which include a (1) Ram Pump System and (2) Rainwater Harvesting Systems.

Analysis of data collected in Panama allowed QD to design a ram pump water supply distribution network which uses the river downhill of Las Delicias as the main water source. This multi component system has been modeled using EPANET 2.0 and is designed to provide water fit for non-potable uses such as laundry, gardening, latrines and so on. This system which comprises a hydraulic ram pump system, screen filters, retention wall, common storage/supply tank, and PVC pipe distribution network will require joint ownership by all the residents of Las Delicias. The second alternative is an individual rainwater harvesting system which supplies potable water to each structure in Las Delicias. This system comprises a collection system which uses PVC gutters, a filtration and disinfection system which uses a self-cleaning mesh filter and an in-line chlorinator, and a plastic storage tank. A three dimensional model of this system has been created using SketchUp and this design is highly scalable and can be replicated for other structures in Quebrada Pinzón. Lastly, a detailed alternatives analysis was performed in order to critically assess and compare both systems based on technical and social constraints along with a failure modes and effects analysis (FMEA) framework to make the best recommendation to you and the residents of Las Delicias.

We would like to thank you for the opportunity to work with you and the residents of Quebrada Pinzón to enhance our skills and contribute to the society we are a part of. Please contact Quisna Designs if you have any questions or concerns and would like information beyond what has been incorporated in this report.

Sincerely,

Roshni Sachar
Nicholas Wienold
Surbhi Thakur
Jeremy Mack

Water Supply and Distribution for the community of Quebrada Pinzón, Bocas del Toro, Panama

Quian Designs

Submitted to:
Dr. David Watkins, PE
Mr. Mike Drewyor, PE, PS
Ms. Briana Arnold, PCV

Submitted by:
Quian Designs
Roshni Sachar
Surbhi Thakur
Nicholas Wienold
Jeremy Mack

Mission Statement

The mission of Quian Designs is to engineer functional, sustainable, and cost effective systems in order to improve the quality of life in the increasingly connected and developing. Quian Designs is focused toward providing the engineering calculations for the design of high quality water supply and distribution systems to rural communities that take responsibility and ownership of these systems by helping with construction and timely maintenance.

Purpose

Quian Designs (QD) is a group of four Civil and Environmental Engineering undergraduate students from Michigan Technological University's 2015 International Senior Design Program. QD traveled to the remote Ngöbe community of Quebrada Pinzón in the province of Bocas Del Toro, Panama in August 2015 in order to survey and collect data to assess the existing water supply and distribution systems within the community. The proposed Rainwater Harvesting system and river pump system will provide potable water to the Las Delicias section of this community and improve their health and quality of life.

Disclaimer

This report, titled "Water Supply and Distribution for the community of Quebrada Pinzón, Bocas del Toro, Panama," represents the efforts of Quian Designs, a Senior Design group of undergraduate students in the Civil and Environmental Engineering Department of Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report ***should not*** be considered professional engineering.

Acknowledgements

Quian Designs is sincerely thankful to everyone who supported the team and this project from preliminary trip planning to the completion of this report. Special thanks to:

Dr. David Watkins, Course Instructor
Mr. Mike Drewyor, Course Instructor
Dr. Brian Barkdoll, Advisor
Ms. Briana Arnold, PCV
Dr. William Bulleit, MTU Instructor

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Executive Summary

Quian Designs (QD) is a group of four Civil and Environmental Engineering undergraduate students from Michigan Technological University's 2015 International Senior Design Program. QD traveled to the remote Ngöbe community of Quebrada Pinzón in the province of Bocas Del Toro, Panama in August 2015 in order to assess the existing water supply and distribution systems within the community. QD was hosted by Briana Arnold, a Peace Corps Volunteer (PCV) who has lived on-site since June 2014.

The overall mission of this project was to improve the health and quality of life of community members by providing access to clean water in the Las Delicias section of the community. Las Delicias is a secluded section of the community which consists of three structures; one church and two houses. This mission was accomplished by collecting data, surveying the community, performing a site assessment, and then returning to MTU to model and design two different water supply and distribution system alternatives.

QD surveyed an elevation line within the community and performed water quality testing throughout the community (taps, tanks, supply tank, etc.) and used the information to design two alternative systems: a ram pump distribution system and individual rainwater harvesting systems in order to supply potable water to each structure of Las Delicias.

Collected river data and survey lines were used to generate the design for a hydraulic ram pump distribution system with one supply tank for Las Delicias in entirety. A small portion of the river is diverted through screens and filters before flowing into a hydraulic ram pump. An analysis of the ram pump system was performed in EPANET 2.0 in order to determine the pressure and flow rates within the system. A total of 2600 feet of 3 inch diameter PVC (Polyvinyl Chloride) pipe will be used in this system. The total cost of this system is estimated to be 3221 USD.

The second design alternative comprises individual rainwater harvesting systems to provide an uninterrupted supply of potable water to Las Delicias. Each system will contain three main components: collection, filtration, and disinfection. The total cost of this system is estimated to be 777 USD for Structure A and 579 USD for Structure B.

A combination of cost, feasibility, and constructability technical design constraints were used with social constraints to evaluate the two alternatives. QD recommends the second design alternative for Quebrada Pinzón due to its cost effectiveness, simple maintenance regime, and easy implementation. The collected data, analysis, assessment of the community, and design recommendations in this report will provide important information about construction, operation, and maintenance of the proposed systems. This information can be considered when requesting funding for this project.

1.0 Introduction

Quian Designs (QD) is a group of four Civil and Environmental Engineering undergraduate students from Michigan Technological University's 2015 International Senior Design Program. QD traveled to the remote Ngöbe community of Quebrada Pinzón in the province of Bocas Del Toro, Panama in August 2015 (map in Figure 1) in order to assess the existing water supply and distribution systems within the community. QD was hosted by Briana Arnold, a US Peace Corps Volunteer (PCV) in the Agricultural Development sector who has lived in Quebrada Pinzón since June 2014. Pinzón is a small, rural community that is comprised of mostly farmers. Interactions with the community and Arnold gave QD an understanding of the technical problems within the community.

The community currently uses a gravity-fed water distribution system which was installed in 2013. Las Delicias, a secluded section of the community which consists of two houses and a church, is not connected to the gravity-fed aqueduct system because it is located at a higher elevation than the water storage tank. Arnold and the residents of Las Delicias demonstrated interest in having a water supply system. QD conducted a series of onsite surveying and data collection activities, along with water quality testing in order to understand the topography and water resources within Las Delicias. Two alternative systems have been designed in order to determine which design best meets the needs of Las Delicias, and a final recommendation based on an extensive alternatives analysis is given in this report. Additionally, QD's experiences, understanding, and general information gained along this trip are discussed.

Figure 1. Map of the Province of Bocas del Toro

2.0 Background

2.1 Site Details and Census Information

Located about 35 meters above sea level, Quebrada Pinzón is approximately 4,200 meters (2.62 miles) inland from the Main Highway 11 via a 25-minute automobile ride along a 2 track dirt road; this included crossing 4 streams and various rolling hills. Within a 5-mile radius from the main community sector (labeled in Figure 2), Quebrada Pinzón is home to 220 total residents within 35 households according to a recent census summarized within *Proyecto BioComunidad*, a Panamanian governmental report rationalizing selection of the most vulnerable communities for a set of interventions and services to combat the roots of extreme poverty. Due to the school located within the community (*Centro educativo Quebrada Pinzón* established in 1994) only ranging from kindergarten to middle school, only 20% of the students continue into high school. The financial burden associated with traveling out of the community for further education has resulted in an average education level of 6th grade. The main income source is the agricultural products grown on each farmer's *finca* (a small orchard comprising of cacao, plantains, and other hanging fruits). Additional income is generated from small shops or family members who have gained employment outside of the community; these incomes result in a monthly average income of 144 Balboas (USD) per household.

2.2 Community Cultural Dynamics

QD interacted extensively with Briana Arnold in order to gain a deeper understanding of the social and cultural atmosphere at Quebrada Pinzón. Briana Arnold was preceded by an Environmental Health volunteer who helped plan and construct community facilities and infrastructure which included: an aqueduct system, sanitary latrines, and an expansion of the school building. These recent improvements have played a role in preparing the community members for an influx of new information and an understanding of humanitarian volunteer work. Briana Arnold described how her experiences interacting with the community have been more open and direct because of the trust platform already established by the previous Peace Corps volunteer. This was also evident from the warm welcome that QD received from Briana Arnold's host family and other community members. The atmosphere that was created by the PCVs presence, combined with the forward thinking dynamic that the Bio Comunidad project injects into the community, has facilitated the acceptance of new projects and ideas. Bio Comunidad projects have been implemented by the Panamanian Government in rural communities to improve infrastructure and environmental health.

Briana Arnold stressed that from her experiences, the family units are stronger than communal committees in Quebrada Pinzón. As a result of this dynamic, the water committee that was established along with the aqueduct system in 2013 did not last very long, as there was a lack of cooperation, responsibility, and ownership by the committee members. The residents of Quebrada Pinzón also have a general distrust of a hierarchy system that involves a high-ranking foreign member. Only two years ago, all taxis were blocked from entering the community since the *Ngöbe* people did not want an outsider making a profit off of them. After three months of *pasar*-ing, the practice of walking from house to house to casually talk to others, one taxi driver was allowed to make trips into Quebrada Pinzón.

2.3 Community Layout and Associated Systems

The general layout of the community is shown in Figure 2. Outlined in orange, the main sector of Quebrada Pinzón is comprised of a cluster of 13 houses and the school. Every house in this section is tied into the aqueduct system that was established in 2013. The aqueduct system is comprised of a collection/sedimentation tank, a 5000-gallon storage tank, and the series of taps at houses and public structures. This system will be discussed in more detail in later sections.

An outlying sector of Quebrada Pinzón outlined in red below, referred to as Las Delicias, and includes two houses and a church. A community member's house is located on the southern end of those limits and has a functioning rainwater harvesting system. The church located near the southern house has biweekly gatherings of 5-20 people but no existing water supply. On the north end of Las Delicias, an elderly couple has a smaller rainwater harvesting system with a slightly smaller storage tank. Both systems have been expressed to be insufficient, and the three groups within Las Delicias have collectively expressed interest in an additional water supply/distribution system.

Figure 2. Map of Quebrada Pinzón (1"=400')

2.4 Problem Description & Objectives

The three structures located in Las Delicias are not connected to the existing aqueduct system used by the main section of the village. These houses are located at a higher elevation, and are located far away from the storage tank, as seen in Figure 2. Two of the houses have some sort of existing rainwater harvesting system. The first house to the north has an adequate rainwater harvesting system; however, there is no filtration or purification process, and the existing storage tank is insufficient for the resident's usage. Figure 3 shows the current storage tank at the first house. The second house from the north does not have an efficient delivery system from the rain gutter to the storage tank. Although there is sufficient storage for the residents, the tank may not be collecting all of the water collected by the rooftop gutter system. There is also no existing filtration or purification system. Figure 4 shows the current storage tank at the second house. The church, which is the third building in Las Delicias, does not have any water supply system. Figure 5 shows the current church structure.

Throughout this report the three structures of Las Delicias will be referred to as structure A, B, and C. Structure A is the church, and structures B and C are family homes. Quian Designs has come up with two design alternatives to solve this problem. The first alternative is a River Pump Design in which a pumping system will be used to draw water from a river situated downhill of Las Delicias. The second alternative is to engineer individual rainwater harvesting systems for all three structures in Las Delicias.

Figure 3. Existing Tank at Structure C

Figure 4. Storage Tank at the Structure B Elevated on Wooden Stilts

Figure 5. Community Church and Kitchen (Structure A)

Based on a preliminary assessment of Las Delicias and Briana Arnold's ambitions for the community, QD's overall goal for this project was to ensure that all the residents of Las Delicias have access to basic water infrastructure. In order to achieve this goal of providing an uninterrupted supply of potable water to the residents, QD identified three main tasks:
(1) Evaluation of the topography and water resources of Las Delicias to come up with at least two feasible design alternatives
(2) Model, design, and engineer the two proposed systems
(3) Make a final recommendation to the community based on a detailed alternatives and failure modes and effects (FMEA) analysis.

3.0 Data Collection and Analysis

3.1 Topographic Survey

A survey of the ridgeline that connects the three structures in Las Delicias was required in order to find the highest point and changes in elevation between them. Basic surveying equipment was used for this process given the remoteness of the area and the rough terrain. A Rangefinder was used to collect information regarding the distances and angles between surveying stations. A compass was used to measure bearing angles. GPS waypoints were recorded at each station as backup information. These tools were also used in order to survey from the high point in the ridgeline for a possible location for the tank should the Aqueduct System be constructed.

Figure 6 displays the surveyed elevations between the three structures in Las Delicias. Raw data was plotted in Excel to get a visual profile of elevation difference. Point A is structure 1, point B is structure 2, point C is structure 3, and point D is the highest location between all three structures and would be the most appropriate site for a potential storage tank. Complete survey data is provided in Appendix A.

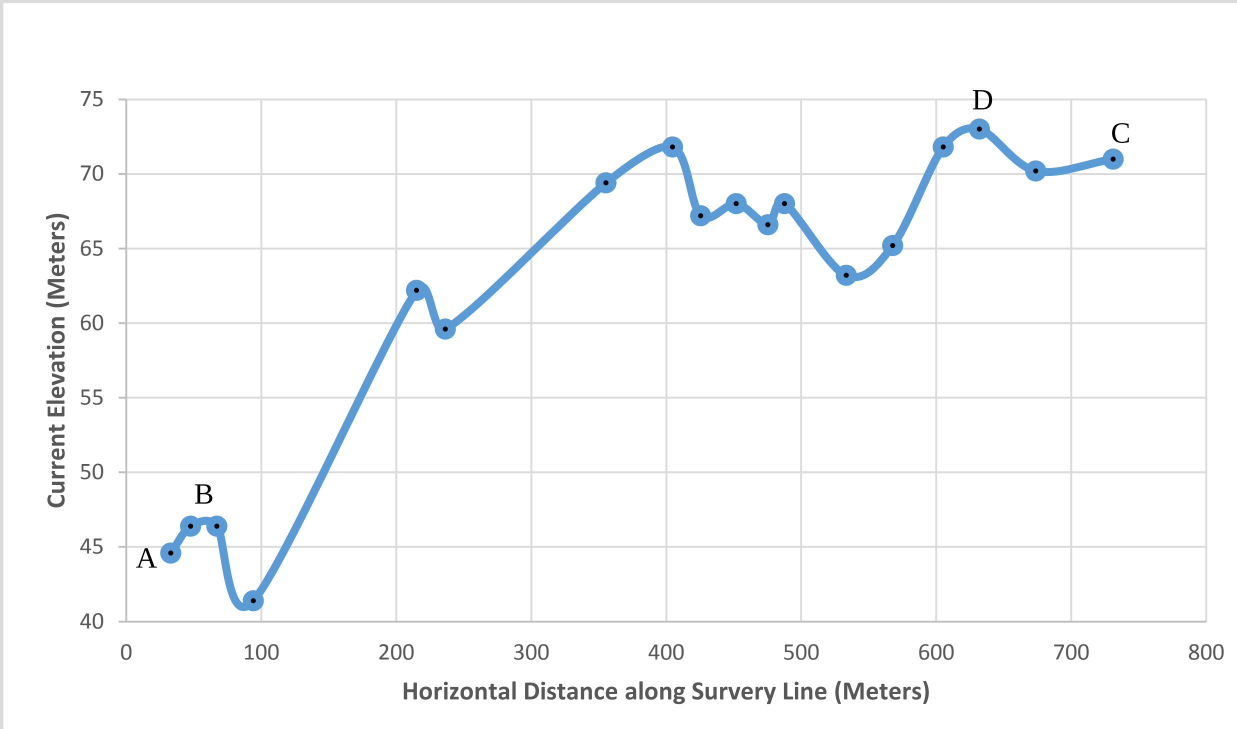

Figure 6. Las Delicias Elevations

3.2 River Measurements

Velocity and slope measurements of the river were also required. A section the river was surveyed using the above mentioned equipment in order to determine an average slope. The velocity of the river was determined by using a floating object, and recording the time it took for that object to travel a measured distance. A representative section of the river was found to perform this test. The cross-section of the river was measured, and, for modeling purposes is estimated to have a triangular cross-section.

Cross section and average time data is shown in Table 10 and Table 11 in Appendix B. A length of approximately 20 feet was measured, and a floating object was sent down the river, and the distance-time method was used to determine the velocity of the river. Three trials were conducted for each of the three equal river sections. All time averages are provided in Table 11. This data is further used in our calculations for designing a ram pump, discussed in Section 4.1.1.

3.3 Rainwater Catchment Areas

The surface areas of the rooftops of the structures considered in this design were determined by measuring the length and width of the buildings. The height from the center of the roof to the edge of the roof was also measured in order to determine the pitch of the roof.

Table 1 shows the measured lengths, widths, and heights of the two structures in need of catchment systems to determine their rain catchment areas. It is important to note that the church is comprised of four separate roofs: church, kitchen, gathering space, and dining area.

Table 1. Rooftop Area Measurements

	Length(ft)	**Width(ft)**	**Roof Area (ft^2)**
Structure B	25.5	25.6	653
Structure A (Church)			
Kitchen	12.6	15.4	194
Dining Hall	20.5	24.7	506
Gathering Space	23.5	15.5	364
Prayer Area	24.7	38.2	944

3.4 Water Quality Tests

Water quality tests were performed at two locations, the river and the rainwater storage tank at the first house. These two locations were selected because they are most fit for providing water to a potential water distribution system in Las Delicias. The tests were performed by sampling 1 ml of water and using 3M Petrifilms to check for E. coli and Coliform contamination. The E. Coli/ Coliform (EC/CC) film can test for both E. Coli and Coliform, while the Coliform (CC) film can only test for Coliform. Both types of petrifilms were used and all of them were incubated using body heat for 24 hours.

Two trials were performed for the rainwater quality test; using a pipette, rainwater was collected from a water storage tank from one of the houses in Las Delicias. Of two trials, only one trial displayed results that could be interpreted properly. Figure 7A shows the colonies that grew on the EC/CC petrifilm. Blue colonies with a surrounding air bubble indicate a confirmed E. coli colony (about 95% of E. coli produce gas), while red dots indicate coliform colonies. There is one blue colony present on the EC/CC film; however, there is no surrounding air bubble to confirm E. coli growth. It is recommended by the 3M Petrifilm Interpretation Guide to count all blue colonies without gas and/or blue zones as presumptive E. coli. The team will use the 3M recommendation and count the blue colony as E. coli [4].

Figure 7B shows colonies that grew on the CC petrifilm. Air bubbles trapped around red colonies indicate confirmed coliform. There are three confirmed coliform colonies in Figure 7B, and six unconfirmed colonies [5]. Confirmed E. coli colonies are circled in blue in Figure 7A, and confirmed coliform colonies are circled in red in Figure 7B.

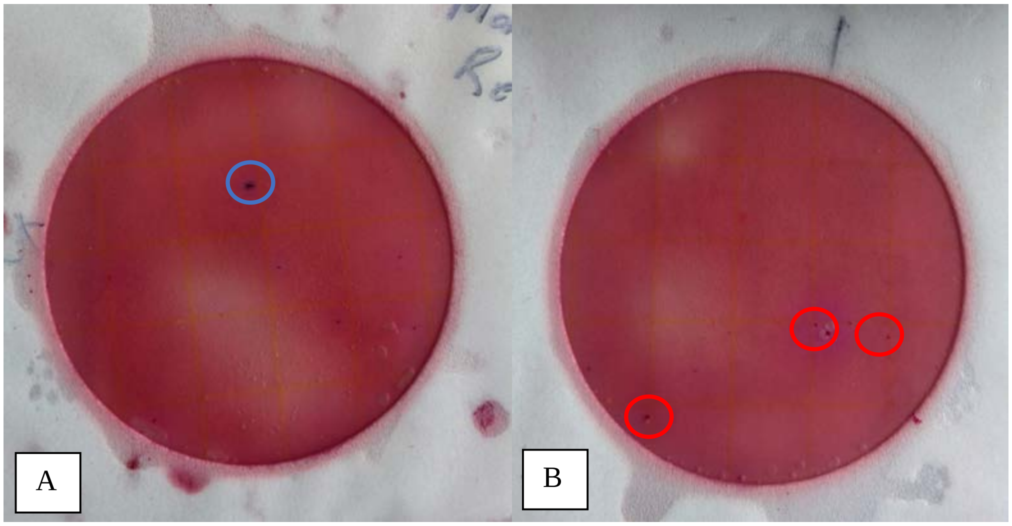

Figure 7. Rainwater Quality Test A) EC/CC petrifilm, B) CC petrifilm

One trial was performed for the river water quality test. Using a pipette, water was collected from a river that flows near the Las Delicias area. This water was tested because it could be used as a water source if a ram pump is implemented. Similar to the rainwater quality test, both EC/CC and CC Petrifilms were used. Figure 8A shows EC/CC growth and 8B shows CC growth.

Figure 8A does not display any E. coli colonies, but it does display many coliform colonies. It is determined that there are too many coliform colonies to count. Unfortunately, due to incubation issues and non-ideal conditions, the results from the CC Petrifilm in Figure 8B are indeterminate. Too many air bubbles are present for proper growth to occur.

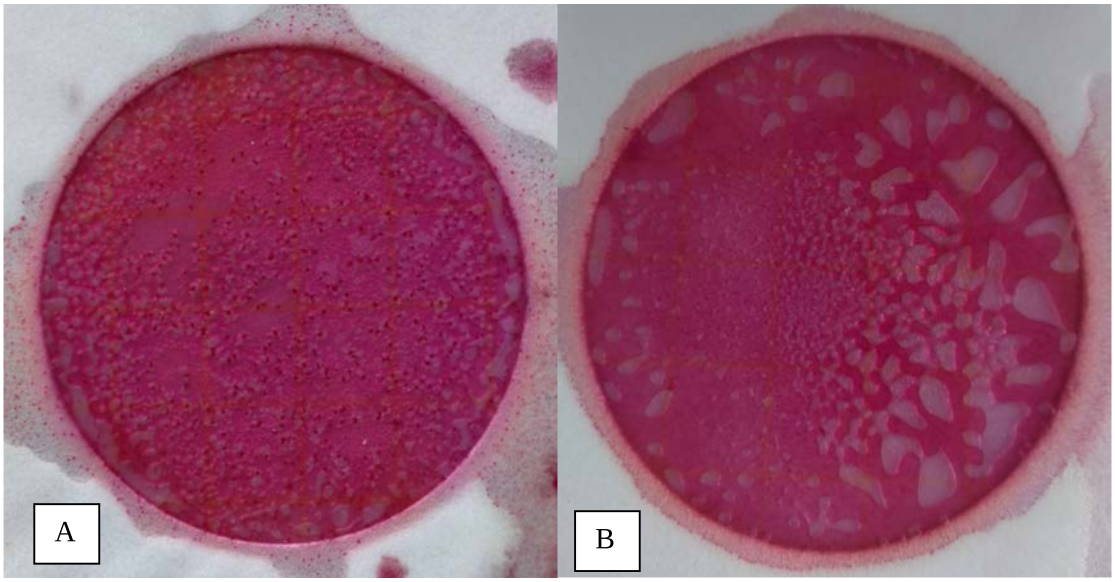

Figure 8. River Water Quality Test A) EC/CC Petrifilm, B) CC Petrifilm

3.5 Regulations

QD will be following the US Environmental Protection Agency (EPA) standards for drinking water quality. In addition to removal of rocks, debris, organic matter, and suspended solids, eliminating fecal contamination is very important. Total coliform, E. coli, and fecal coliform are the main bacterial species that are indicators of fecal contamination. EPA water quality standards require fecal coliform and E. coli concentrations to be zero in drinking water. The EPA recommends that “systems which serve fewer than 1000 people may test once a month or less frequently” for presence of coliform [8].

It was determined from the water quality tests that the rainwater samples contained both E. coli and total coliform, whereas the river water samples only contained coliform. Typically, the river water is expected to be more contaminated; however, rainwater collected from roofs can be contaminated from animal droppings and thus QD has ensured that these E. coli and coliform concentrations will be within the US EPA regulatory limits after the rainwater is treated for potable use in order to maintain health and safety standards within the community.

4.0 Design Alternatives

QD has come up with two design alternatives to achieve the project goals. The first alternative is a River Pump Design in which a pumping system will be used to draw water from a river situated downhill of Las Delicias. The second alternative is to engineer individual rainwater harvesting systems for all the three structures in Las Delicias.

4.1 Design Alternative One: River/Pump Design

The River Pump Design utilizes a nearby rivers flowrate and energy via a hydraulic ram pump in order to deliver a constant flow into a large storage tank. From this storage tank, located on the highest point of the survey line, a PVC pipe network distributes water to Las Delicias via a gravity system. A series of alternative pump designs and pump network configurations were examined before finalizing this system to propose the most feasible system with appropriate filtration and disinfection technologies.

4.1.1 Pump System

The initial data collection and preliminary analysis of available pumps resulted in the selection of a ram pump system over a gas or solar powered pump. One rationale is that no individual component in the ram pump system is exceedingly expensive, whereas the malfunction or destruction of the gas powered motor or a solar panel would burden the community to repair or replace. Another aspect of this system is that continuous labor is not required to keep the system flowing; in contrast, solar panels must be cleared of debris and gasoline requires refueling. QD has determined from our understanding of the community dynamics that the refueling process would be burdensome and could potentially create rift within the committee to oversee this process.

An in depth explanation as to the inner workings of the hydraulic ram pump can be referenced in in *Land to House* [4]. In short, the hydraulic ram pump utilizes the river's flowrate and head to provide bursts of pressure into a delivery pipe that ultimately delivers water to the supply tank above. The equation that governs this interaction is provided below [Jordan, 1984]

$$Q_{output} = \frac{2*Q_{input}*H_d}{3*H_s} \quad \textbf{[Equation 1]}$$

Where: Q output = Desired flow rate into storage tank (lps)
Q input = Redirected flow rate from river into pump (lps)
Hd = Falling head into pump form river (meters)
Hs = Height difference between pump and storage tank

Using the monthly demand, field data and the equation above, the formula was simplified to the following relationship. This accounts for a 10% loss in collection at the storage tank and reduces the constant from ⅔ to ¼ since the fittings and pressure camber will not be equivalent to those produced commercially.

$$Q_{output} = \frac{1 * Q_{input} * H_d}{4 * H_s} \rightarrow 1.45\ meters * lps = Q_{input} * H_d \qquad \textbf{[Equation 2]}$$

From this relationship, there is a tradeoff between head overcome (H_s) by increasing input flowrate. Due to a gradual slope of the river and adjacent landscape (2.7%) and high river flow rate (170 lps), it became apparent that diverting a larger flow rate was favorable to increasing the head difference. Combining this knowledge with the natural landscape, the placement of the collection system was planned as indicated below.

4.1.2 Collection System

This system begins with the collection system from the river (marked by the yellow pin in Figure 9). The cross sectional dimensions of the river here is 12 feet wide and about 8 in deep on the eastern bank; a sketch of this is provided in Appendix A. Placed at a 45-degree angle in the river, a 6-inch tall, 3-foot long concrete retention wall is to be installed. At periods of high water profiles, the river will be able to flow over the structure as it will effectively act as a broad crested weir. While the retention wall will be a gravity structure, the wall will be supported by boulders and cobbles on the downstream side that also actively prevent scour downstream. Similarly, rip rap (large stones and boulders) will be moved from the riverbed to the shoreline in order to armor it against scour. Large screens are included to prevent twigs, leaves, and general large debris accumulated in the water from the origin and course of the river.

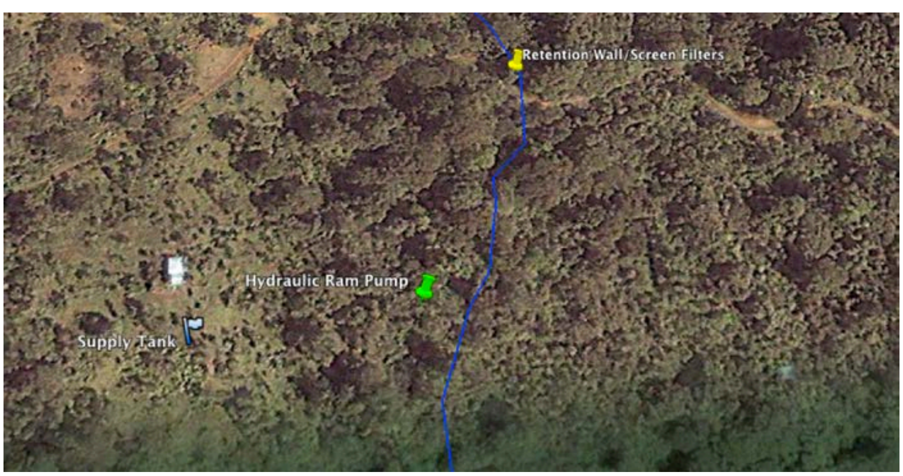

Figure 9. Plan view of river near Las Delicias

The diverted flow then is directed by a 3” buried pipe into the sedimentation tank due south (marked by the red pin in Figure 9). The size of the sedimentation tank was determined using the methods discussed in the book “Wastewater Engineering, Treatment and Reuse.” Please refer to Table 15, Appendix A these calculations. It was determined that this style of sedimentation tank is not appropriate or feasible for this design alternative due to the huge amount of surface area required at this flowrate. QD has looked into sedimentation basins, and high scale screen and mesh filters in order to ensure that the river water is as clear as possible before it is pumped up to the storage tank, but these methods were found to be not economically feasible. During the rainfall season, the river water level rises with higher flowrates and turbidity which would require a multi-stage treatment process and this was determined to be uneconomical for the scale of this project.

Following proper sedimentation, the water will flow into 1-¼” diameter PVC pipe in a direct line towards the hydraulic ram pump (green pin in Figure 1). Since the check valves must be at a right angle to the ground surface to operate effectively, a concrete slab and retention wall have been designed as shown in Figure 8 provided in Appendix A. The pump will utilize the power of the input flow by using approximately 90% of the flow into the tank to pressure the remaining 10%. Thus, the vast majority of the water is spurted out of the check valve. In an effort to prevent this run off from degrading the soil around the slab, a 3” PVC pipe will channel the “waste” water back into the river.

The final step in the collection system is the delivery of water into the storage tank (indicated by the flag in Figure 1). The delivery pipe is scheduled to be 1-¼” flexible rubber tubing buried 6” under the surface. This material was selected to prevent livestock from damaging the line that will run directly through their pasture. A parallel tube will run in the opposite direction of flow in order to channel overflow back into the river; this overflow may occur due to decreased usage or overproduction from the ram pump system in high rains. The storage tank shall be detailed further in the next section.

4.1.3 Storage Tank Sizing

Initially, the size of the tank was determined by comparing the supply and demand of the system. The results of this analysis are shown below in Table 2. As stated in Section 4.1, the flowrate of the ram pump was designed in relation to the total weekly demand.

Table 2. Water Demand at Las Delicias

Structure	Individual Water Consumption Per Day (gallons)	Number of People	Frequency Per Week	Gallons Per Week	Monthly Total Consumption
Building A	30	30	1	900	3600
Building B	30	7	5	1050	4200
Building C	30	5	7	1050	4200
Total Demand:				3000	12000
Supply				3037	12148
Difference				37	148

A 3000 gallon tank was determined to be excessive by QD. Therefor an analysis was performed to determine the water level in the tank throughout the course of a day. The daily demand of all three of the structures was used as it is the higher of the two demand patterns (See Figure 14). The two figures below illustrate the demand from the tank. Figure 10 shows the supply of water from the pump along with the demand. Figure 11 shows the quantity of water in the tank as a result of the demand. Based on this analysis, it was determined that a 500 gallon tank would provide enough water throughout the course of a day, while providing a reasonable factor of safety to ensure that the tank does not go dry. Refer to Appendix C for exact values of these graphs.

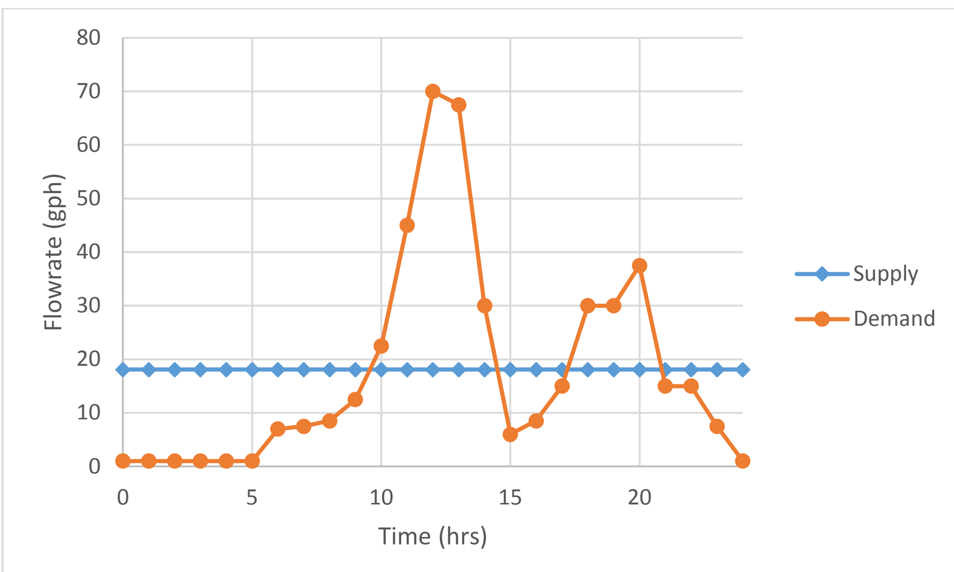

Figure 10. Supply of Ram Pump and Demand of Structures A, B and C

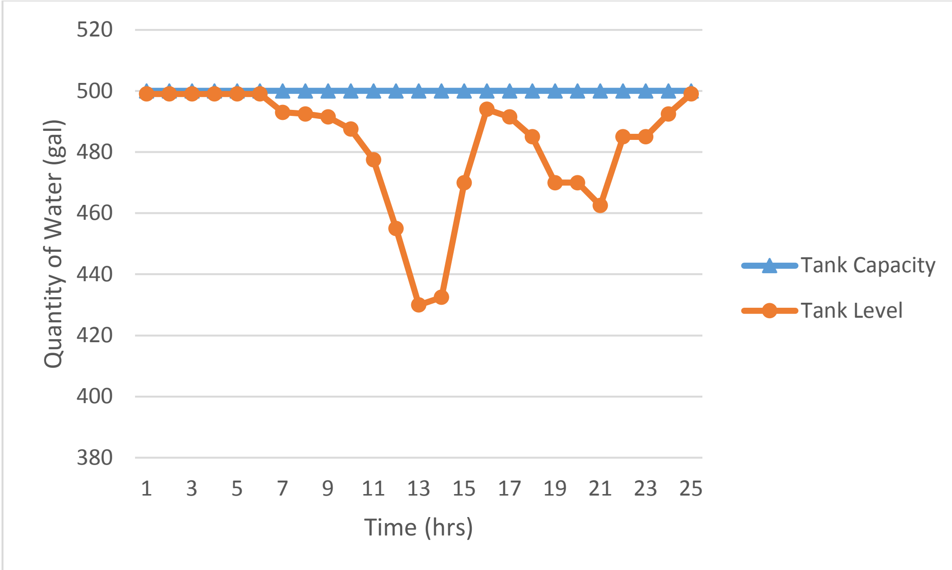

Figure 11. Quantity of Water in Tank Based on Highest Demand Pattern

4.1.4 EPANET Model and Demand Patterns

An analysis on EPANET 2.0 provided the pressure and flow rates within the ram pump system. An EPANET model of the pipe network system was created in order to identify any possible issues with the design. A flow analysis was performed for each of the two patterns. Two patterns were necessary because the demand differs on the weekends compared to the week days. A layout of the EPANET model is displayed below in Figure 12.

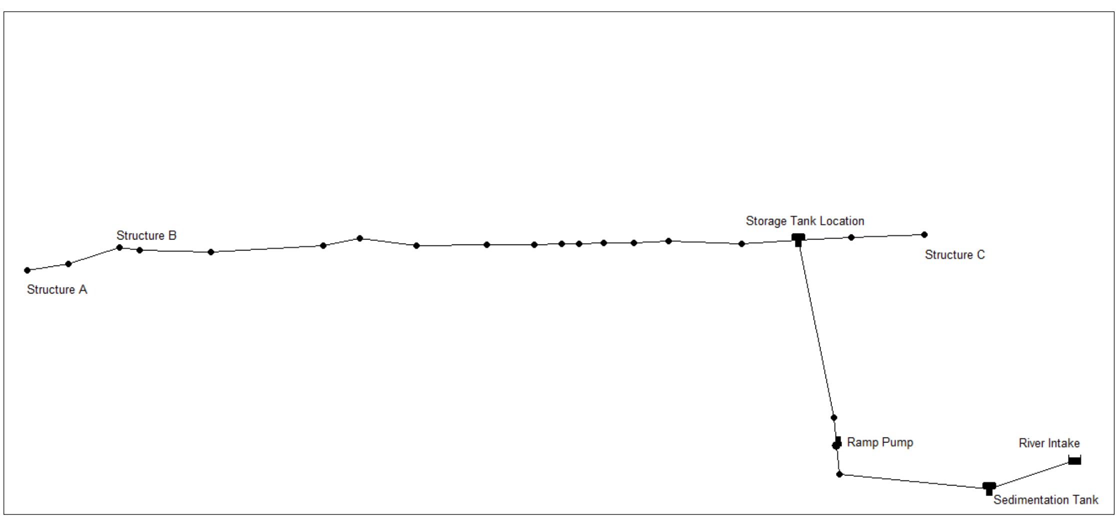

Figure 12. EPANET Model Layout

Flow units are in gallons per minute (gpm), and the Hazen Williams equations were used for the head loss calculations. Pipe roughness of 140 was used. The elevations of each node, and the lengths of the pipe were obtained during the on-site survey. EPANET required that the River intake be modeled as a reservoir. This was not ideal; however it allowed for the system to function properly. The pump curve and characteristics were obtained from QD's research of ideal ram pump conditions. It was assumed that the pump could provide 0.3013 gpm and a head of 62.3 feet.

The demand pattern the system was modeled on a 24-hour cycle. Two patterns were created: one for buildings B and C, and the other for buildings A, B, and C. The demand from Buildings B and C (being residential structures) was assumed to have two peaks: the first from noon to 1 pm, the other from 7 p.m. to 8 p.m.. These peaks are modeled to occur at these times because the people in Quebrada Pinzón generally take two showers a day: one in the afternoon, the other at night. Water use was assumed to begin at 6 a.m. and end at 10 p.m. These times were based on QD's experiences while within the community and the Peace Corps Volunteer's observations [1]. According to this model, the pump can prodyve a flowrate of 0.39 gpm. Refer to the pump curve in Appendix C for the EPANET estimated pump curve.

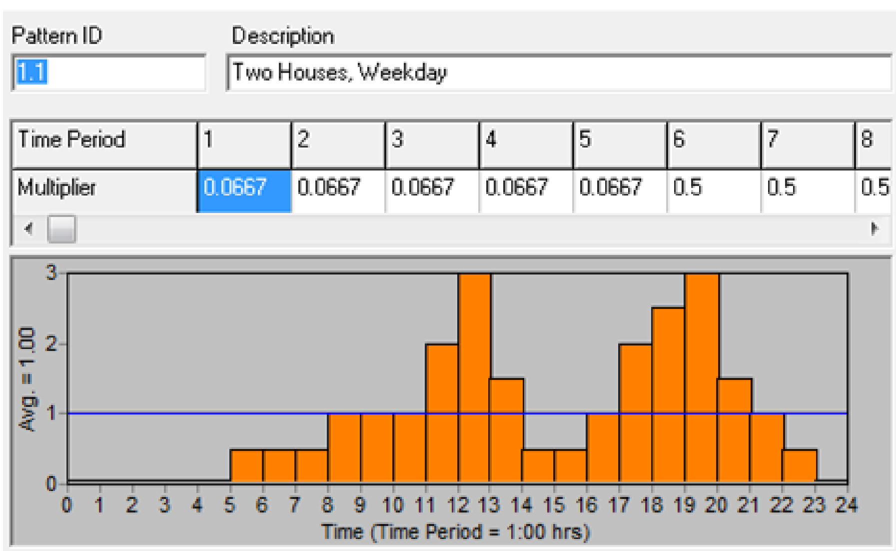

Figure 13. Building B and C water demand, weekday

Demand for Buildings A, B, and C, was modeled by summing the demand from buildings B and C with the demand for Building A. Building A has a high demand for a relatively short period of time only on the weekends. Refer to Figure 13 & Figure 14 for each of the daily patterns.

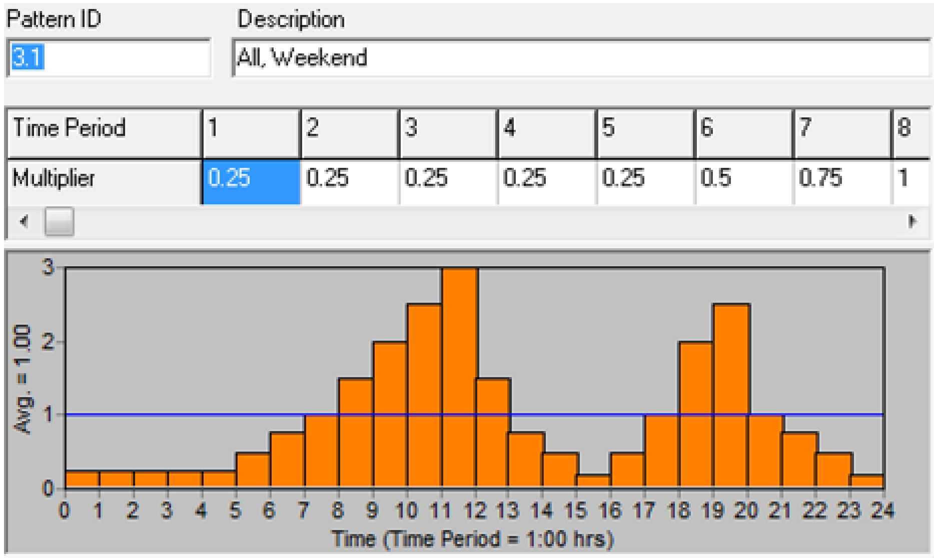

Figure 14. Building A, B, and C demand, weekend

Based on this analysis, it was determined that this gravity fed pipe network would be feasible. However, the flow rates during both demand patterns have low values. This is of concern because it will lead to slow discharge at the tap in the buildings.

4.2 Design Alternative Two: Household Rainwater Harvesting Systems

The Household Rainwater Harvesting System design alternative involves a rainwater catchment and disinfection system designed for the individual structures in Las Delicias. Zinc rooftops will serve as the catchment area in this design, and gutters/PVC pipes will be used to catch and direct the collected water to a filtration and disinfection system. The purified water will be collected in a storage tank that will have a tap system to facilitate usage. The benefits of this design are its low cost, high feasibility, and easy maintenance approach. Different aspects of this design are discussed below.

4.2.1 Long Term Rainfall Variability

Rainfall data for Changuinola, the largest city in Bocas del Toro, is used to conduct data analysis for the rainwater harvesting design alternative. Two data sets spanning different time periods (i.e. years 1960-1972 and 2000-2012) are compared in order to get a sense of long term variability of rainfall and decide which data set to use for further analysis. The two data sets have been tabulated in Table 18 and 19 in Appendix D, and a plot depicting the monthly average rainfall for both the time periods with vertical error bars is displayed below in Figure 15.

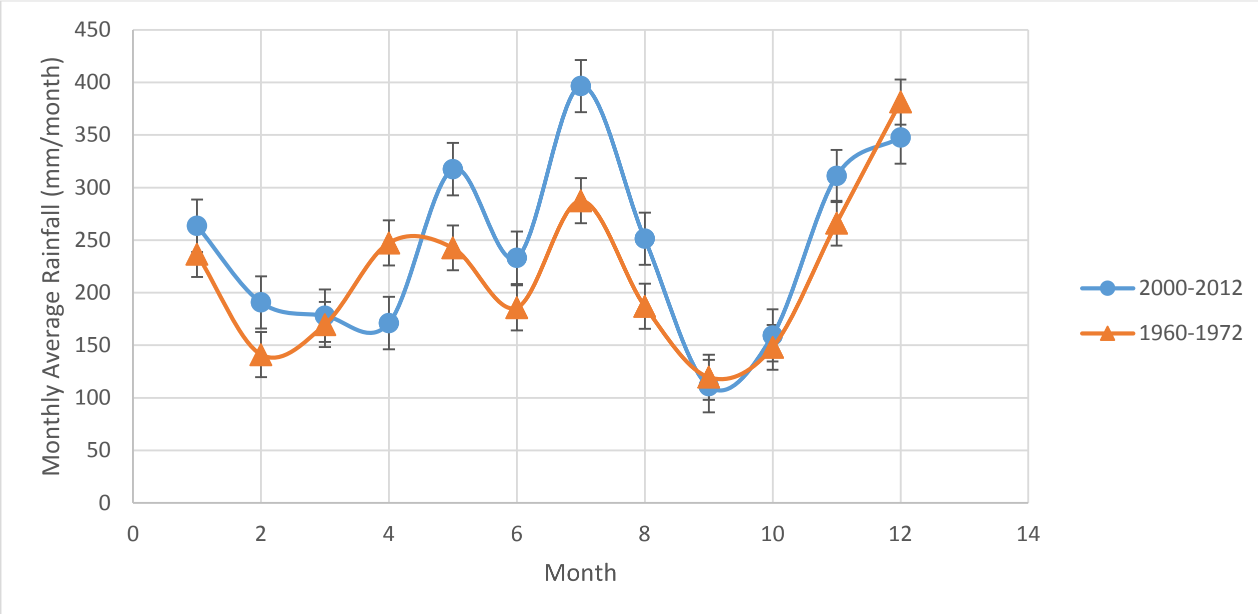

Figure 15. Long Term Rainfall Comparison for Periods 1960-1972 and 2000-2012 in Changuinola
(Error bars indicate one standard deviation or standard error of the individual data points from the true value; overlapping error bars indicate that the difference in mean of the two data sets is statistically insignificant and are vice-versa)

It is evident from the above plot that the rainfall patterns have significantly changed over the past six decades. Data analysis was performed in Microsoft Excel in order to compare the means of the two data sets to determine if the two data sets are statistically different from each other or not. The t-statistic and the p-value are determined to be 4.178 and 0.0024, respectively. A high t-statistic and very low p-value indicate that the means of the two data sets are significantly different from each other. Since the data for time period 2000-2012 is more recent and representative of current rainfall patterns, QD used this data to perform further calculations for this design.

4.2.3 Rainfall Data Analysis

Rainfall data from Changuinola is compiled from an online weather source [2]. Monthly rainfall averages in Changuinola from 2000 to 2012 are displayed in Table 3. Average precipitation per day of rainfall is presented in column 4 of Table 3. This information is used to determine rainwater harvesting potential and reliability for the individual household rainwater harvesting system design. Reliability and storage analysis for the rainwater harvesting system for Structures A and B is explained in detail in section 4.2.5.

Table 3. Changuinola Rainfall Averages from 2000 to 2012

Month	Precipitation (mm)	Average Rainfall Days	Average Rain per day(mm)
January	263.6	20	13.2
February	190.8	15	12.7
March	178.2	16	11.1
April	171.1	16	10.7
May	317.5	19	16.7
June	233.2	19	12.3
July	396.5	23	17.2
August	251.4	19	13.2
September	111.2	16	7.0
October	159.4	18	8.9
November	311	19	16.4
December	347.7	20	17.4

4.2.4 Rooftop Areas and Gutters

Rainfall will be collected using 3 inch PVC pipe as gutters on roofing of the structures. In Las Delicias structures A and B are in need of complete rainwater harvesting systems. Structure A consists of four separate roofs; church, kitchen, gathering space, and a dining area. Table 1 in Appendix D displays the roof measurements for the two structures.

Equation 3 is used to determine harvesting potential, assuming 90% collection efficiency and with all the roofs being used to collect water. Harvested water (gallons) is equal to the catchment area (feet squared) multiplied by the rainfall depth (inches) and a conversion factor of 0.623 gallons per feet squared per inch.

$$Harvested\ water\ (gal) = \ catchment\ area\ (ft^2) * \ rainfall\ depth\ (in.) * \ 0.623\ * \ 0.90$$

[**Equation 3**]

Table 4 displays how many gallons can be harvested on an average rain day for each month assuming 100% efficiency. Structure A has a significantly higher catchment volume due to its large roof area. An efficiency of 90% is used for the storage analysis shown in Table 5. Rooftop areas are tabulated in Table 1 in Appendix D.

Table 4. Daily Catchment of Two Structures

Month	**Rain per day(inches)**	**Structure B (gallons)**	**Structure A (gallons)**
January	0.52	211	649
February	0.50	204	627
March	0.44	178	549
April	0.42	171	527
May	0.66	268	823
June	0.48	197	605
July	0.68	276	849
August	0.52	212	652
September	0.27	111	342
October	0.35	142	436
November	0.64	262	806
December	0.68	278	857

4.2.5 Reliability and Storage Analysis

Reliability of the rainwater harvesting system is determined by performing a storage analysis for each month for both structure A and B. Storage analysis is used to determine how much water will be left over from a previous rain storm based on how much water is removed from the tank each day to meet the daily demand. Storage tank sizes have been determined by using the World Health Organization (WHO) recommended demand per person, i.e. 30 gallons a day/person, and the number of residents at each structure. QD recommends a 500-gallon tank for structure A and a 300 gallon tank for Structure B.

Table 5 shows a storage analysis for Structure B for the month of January, a typical month. The analysis is a simulation which takes into account precipitation, collection, demand, and remaining water storage. Dry days were selected randomly. Daily demand is subtracted from the collected water in the storage tank to determine if the system meets the need or partially meets the need. If the system does not fully meet the daily demand, the cells in the last column are highlighted in red. Storage analyses for each month for Structure A and B are summarized in Appendix F.

Table 5. Storage Analysis for Structure B (January)

JANUARY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5181	175	175	175	0	175	175
2	0.5181	175	350	350	450	-100	0
3	0.5181	175	175	175	0	175	175
4	0.5181	175	350	350	0	350	350
5		0	350	350	0	350	350
6	0.5181	175	525	500	0	500	500
7		0	500	500	0	500	500
8	0.5181	175	675	500	0	500	500
9	0.5181	175	675	500	450	50	50
10		0	50	50	0	50	50
11	0.5181	175	225	225	0	225	225
12	0.5181	175	400	400	0	400	400
13	0.5181	175	575	500	0	500	500
14	0.5181	175	675	500	0	500	500
15		0	500	500	0	500	500
16	0.5181	175	675	500	450	50	50
17		0	50	50	0	50	50
18	0.5181	175	225	225	0	225	225
19		0	225	225	0	225	225
20	0.5181	175	400	400	0	400	400
21	0.5181	175	575	500	0	500	500
22	0	0	500	500	0	500	500
23	0.5181	175	675	500	450	50	50
24	0	0	50	50	0	50	50
25	0.5181	175	225	225	0	225	225
26	0	0	225	225	0	225	225
27	0.5181	175	400	400	0	400	400
28	0.5181	175	575	500	0	500	500
29	0.5181	175	675	500	0	500	500
30	0	0	500	500	450	50	50

The reliability of the overall system is determined by finding the percentage of days in each month when the system will completely meet the daily water demand. Table 5 has the normal demand is set to 150 gallons a day, and 70 gallons a day is assumed for dry days, based on the need for rationing. The system will be 100% reliable for the month of January with this limit on water usage. The reliability levels for two different demand options are shown in Table 6 and Table 7. Table 6 displays the reliability for Structure B assuming the recommended daily demand of 180 gallons a day. It is noticed that the system will not be reliable throughout the year with this demand. Table 7 displays adjusted demands for each month to reach 100% reliability. By conserving more water during dry months, the reliability of the system will increase greatly.

Table 6. Reliability for the recommended demand of 180 gallons/day during wet months and 70 gallons/day for dry months

Structure B		
Month	**Reliability (%)**	**% of Total Demand met**
January	100.00	70.3
February	76.67	51.0
March	76.67	50.6
April	70.00	44.3
May	100.00	84.9
June	100.00	72.2
July	96.67	84.8
August	100.00	67.2
September	60.00	31.6
October	63.33	45.0
November	63.33	78.8
December	100.00	93.0

It is important to note in the above table that a 0% daily reliability indicates that the demand of 180 gallons/day is not fully met on any day; however, the average demand for these months is being met partially, and this indicates that if the water is used conservatively during the dry spells, the rainwater harvesting system will be reliable. In order to achieve a 100% reliability for Structure B throughout the year, the adjusted demand for structure B is calculated and tabulated below in Table 7.

Table 7. Adjusted Demand for 100% Reliability

Structure B			
Month	**Reliability (%)**	**Normal Demand (gallons)**	**Dry Day Demand (gallons)**
January	100.00	120	110
February	100.00	110	70
March	100.00	110	70
April	100.00	110	50
May	100.00	130	100
June	100.00	150	80
July	100.00	150	130
August	100.00	150	80
September	100.00	80	40
October	100.00	80	60
November	100.00	80	60
December	100.00	180	110

A similar analysis was conducted for structure A and the results are tabulated in Table 8. It is evident from Table 8 that the rainwater harvesting system design is very reliable for Structure A. The lowest reliability at 40% is obtained for the month of September which is a dry month. The calculations are based on a storage tank volume of 500 gallons.

Table 8. Reliability for Structure A

Structure A	
Month	**Reliability (%)**
January	80.00
February	100.00
March	100.00
April	50.00
May	100.00
June	100.00
July	100.00
August	100.00
September	25.00
October	25.00
November	25.00
December	100.00

It is important to note that structure A has a higher reliability than structure B (except in September through November) because of the following reasons:

- Since structure A is a church, water is only used on Sunday for a weekly community gathering. This allows for accumulation of water in the storage tank over the weekdays which is available for use every Sunday. Structure B is a family home where water is used for drinking, laundry, and cooking daily.
- Structure A has a bigger catchment area which collects more water than structure B.
- The system for structure A is designed for a higher storage (500 gallon) tank as compared to the system for structure B which is designed for a 300 gallon storage tank. This is because the demand at structure A is very high only once a week as opposed to structure B where there is a daily demand and less potential for water accumulation and thus tank overflow.

4.2.6 Storage Tank Sizing and Material

As mentioned earlier, storage tank sizes have been determined by using the recommended demand per person - 30 gallons a day/person - and number of residents at each structure. QD recommends a 500 gallon plastic tank for structure A and a 300 gallon plastic tank for structure B. Due to the increased demand that is associated with clean and accessible water, a major consideration within this system is to allow for additional storage tanks to be connected in parallel with the main storage tank. Plastic storage tanks are prevalent within the Bocas del Toro area, as mentioned by the PCV at Quebrada Pinzón. Plastic is a lightweight and non-degradable material which makes it a reliable option. A plastic tank on wooden stilts allows for more flexibility with system layout as opposed to a fixed Ferro cement tank. QD thus recommends using plastic tanks for this system.

4.2.7 Water Treatment

As mentioned previously, rainwater will be collected through gutters made from PVC pipes, which will be attached along the roofs of the structures. The water will be directed to one corner where it will then be flushed through a mesh self-cleaning filter to remove most of the larger objects such as leaves and twigs. The filter is designed to remove particles up to 0.955 mm in size. A schematic of a potential filter is shown below in Figure 16. The advantage of using such a filter is easy maintenance and cleaning. The filter is self-cleaning and any debris will slide off the filter.

Figure 16. Picture of the self-cleaning filter [10]

The initial filtration of this proposed system will only remove larger objects; smaller particles such as dirt, animal droppings, and small debris will still remain. To resolve this issue, Quian Designs recommends implementing a first flush system. This system works by diverting the first flush of contaminated water during a rainstorm into a separate chamber. As water level rises, a floating ball rises until it reaches the top where it rests on a seat inside the chamber. This will prevent the chamber from filling more, and the rest of the water will flow over the ball and into the main storage tank. The bottom of the first flush system can be removed for cleaning after each rainstorm. This system also has the advantage of easy maintenance and cleaning. A schematic of the first flush system is shown below in Figure 17 [7].

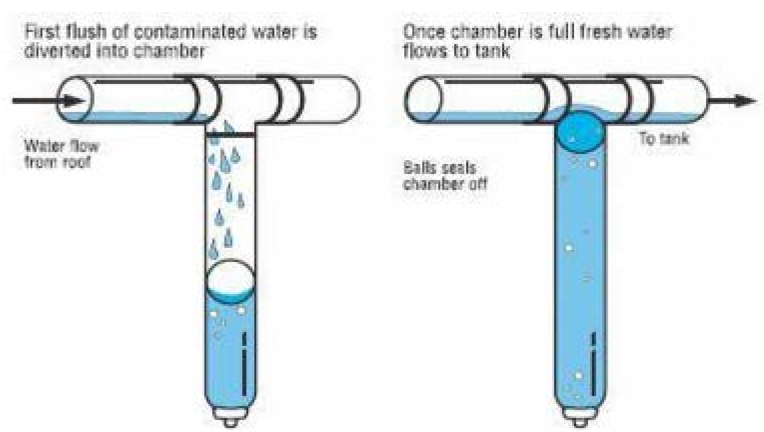

Figure 17. First Flush System [7]

Chlorination is recommended for disinfection of the harvested rainwater to ensure that it is safe for drinking purposes. MINSA's in-line chlorinator is a device that is extensively used in Panama for rural water supply and distribution systems. This chlorinator will be placed before the storage tank to ensure enough contact time for effective disinfection before distribution to the community members. "Chlorine tablets can be purchased from MINSA and these tablets are reported to contain 60% calcium hypochlorite and are designed to have 2 grams dissolved in every 1,000 Liters of water" [6]. A schematic of the in-line chlorinator is provided below in Figure 18. A detailed discussion about chlorination is provided in Appendix E.

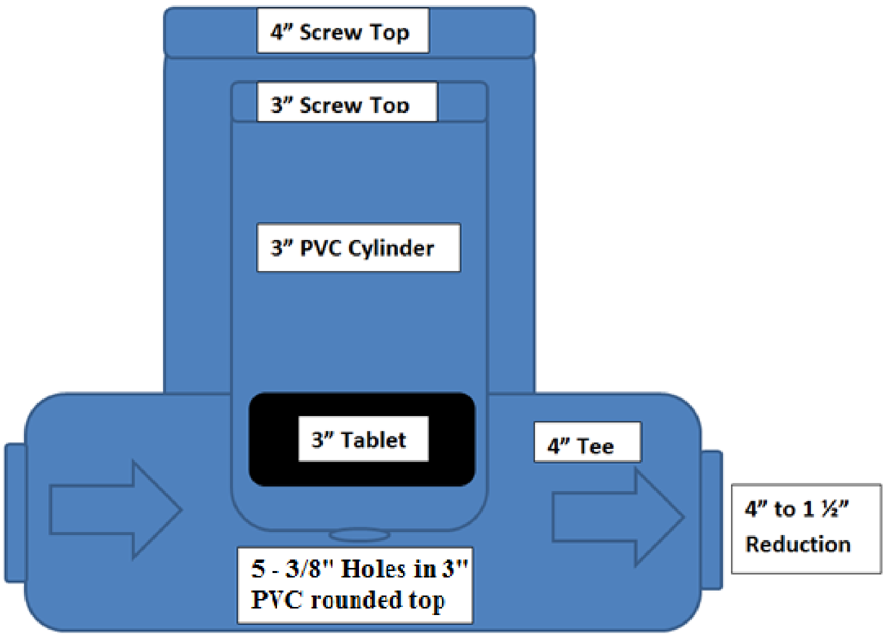

Figure 18. In-line Chlorinator [9]

4.2.8 3D Model

A complete 3D model for structure B is created in SketchUp, a 3D modeling computer program. A completed design with all components is shown in Figure 19. Structure B is a two story house with the kitchen located on the first floor. The 300-gallon storage tank will be placed in the back of the house, and it will be elevated using wooden posts. Bottom of the wooden posts can be lined with an aluminum sheet to prevent termite damage. The elevation will provide pressure for the water to flow into the first floor of the house. Potable water will be directly supplied from the tap inside the house, and residents will not have an issue with transporting water from the tank to inside the house. The outlet pipe from the tank in Figure 19 is extended to the edge of the house because for this case the kitchen and window where the pipe entered the house is located on side.

This pipe can also be directly run to the house or along the wall. Schematic of piping will be different for each structure depending on how the structure is orientated and where the storage tanks is located.

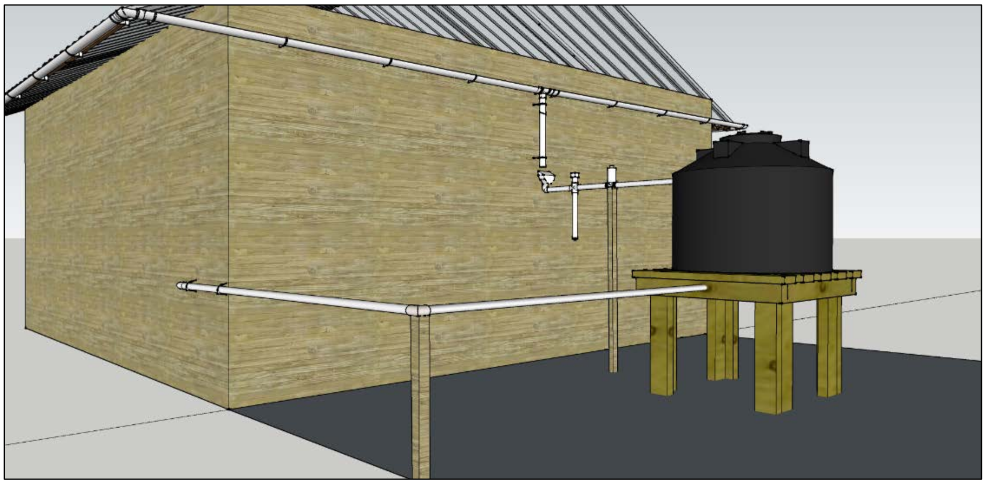

Figure 19. Full Design for Structure B

Rainwater will be collected with PVC gutters as shown in Figure 20. The pipes are cut in half and hooked onto the roof using metal hooks on the side of the structure for support as shown in Figure 21. Water will flow through the gutters into the filtration system.

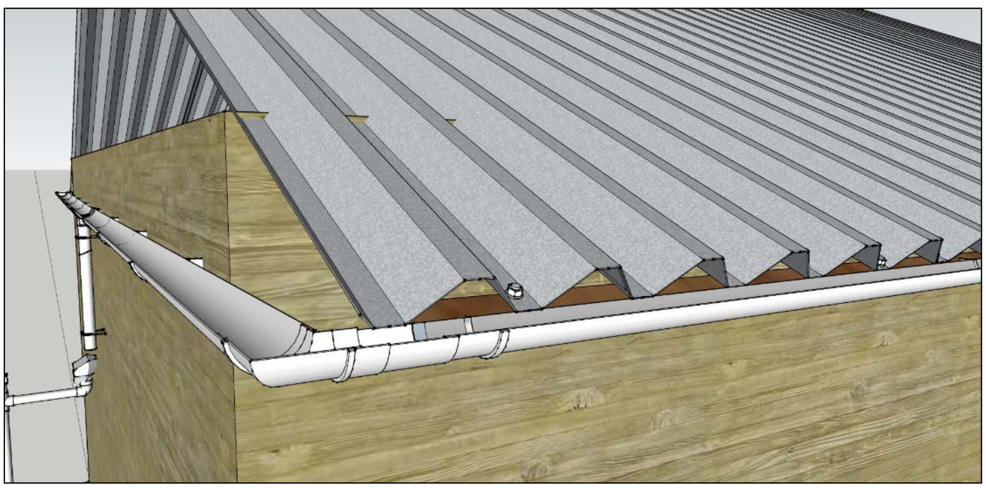

Figure 20. Design Collection Components

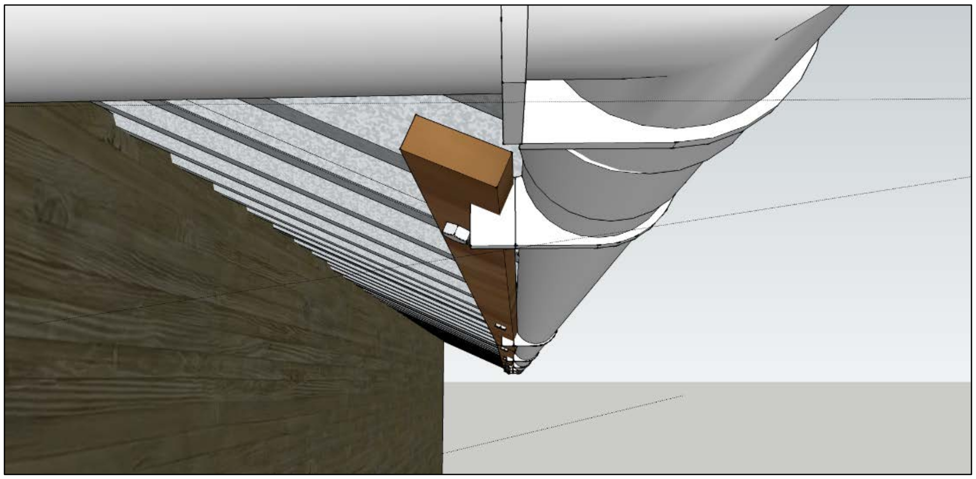

Figure 21. Hooks for Gutter Support

Figure 22 displays the filtration and disinfection components from left to right. Rainwater will flow down the PVC gutters and first go through the self-cleaning filter. Larger debris will slide off the filter and the water will flow into the first flush system. Following the first flush, the filtered water will flow through the in-line chlorinator and thereafter into the storage tank.

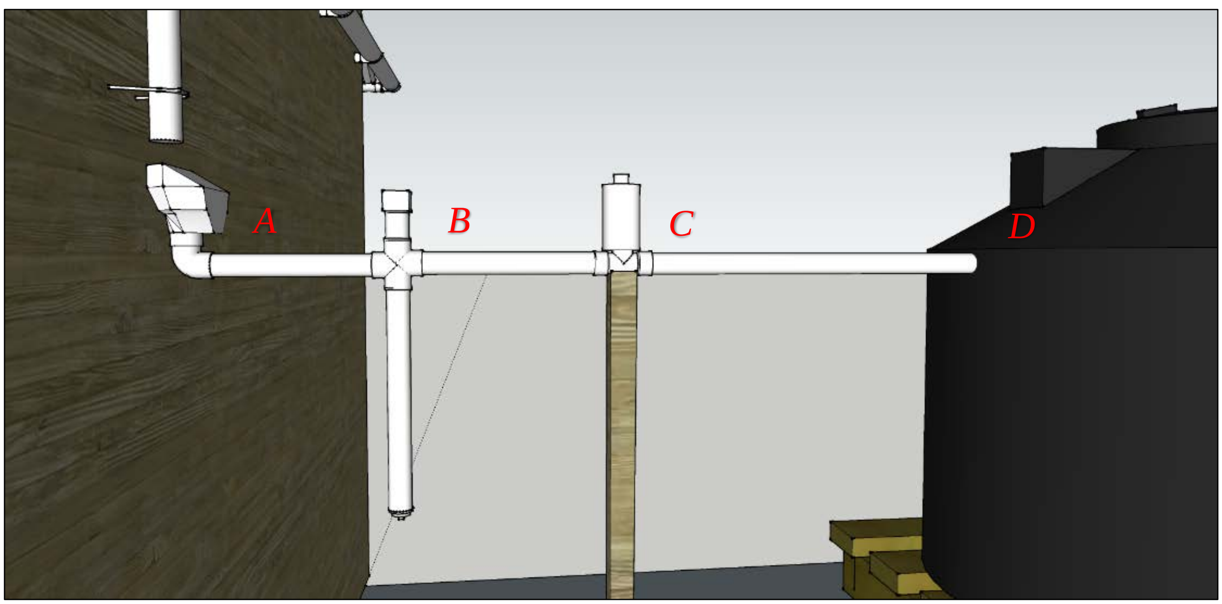

Figure 22. Design Filtration and Disinfection Components; (a) self-cleaning filter, (b) first flush system, (c) in-line chlorinator, and (d) plastic storage tank.

5.0 Design Alternatives Analysis

QD has conducted an analysis of both the design alternatives based on design constraints and a Failure Modes and Effects Analysis (FMEA) framework, which are explained in section 5.1 and 5.2 respectively.

5.1 Design Constraints

QD has conducted an analysis of both the design alternatives based on the technical and social factors that constrain Las Delicias, as determined from interactions with the PCV and site visit. These constraints are discussed below.

Technical Constraints

- Feasibility: Las Delicias is located on the top of a hill and is secluded from the main section of the community. The nearest river is a little over 20 meters below the highest point in the area.

- Cost: There is a limited amount of funding available for this project. The four different sources of funding for this project include money from the Panamanian government as Quebrada Pinzón is a BioComunidad site; donation of PVC piping from a local supplier, a grant from the US Peace Corps which can be a maximum of $2000; and some funds from the individual households in Quebrada Pinzón.

- Constructability: The remoteness of Las Delicias and the rough terrain of the area will influence the constructability of the hydraulic ram pump and rainwater harvesting systems.

- Sustainability: The community of Quebrada Pinzón has witnessed a significant amount of development in the last few years, with establishment of the current gravity-fed aqueduct system, latrines, and expansion of the school. This development process is expected to carry on in the future, especially since Quebrada Pinzón has been chosen as a BioComunidad project site. Therefore, QD's final recommendation should be environmentally sustainable and long lasting.

Social Constraints

- Responsibility within the community: It was evident from the PCV's past experiences that the Quebrada Pinzón community members have been unsuccessful at taking responsibility and ownership for shared systems such as the current aqueduct.
- Interest within the community: Las Delicias is the only part of the community that has demonstrated keen interest for a new and improved water supply and distribution system. QD has tried to achieve the maximum

scalability with the final design recommendation facilitating easy replication if more interest is demonstrated by other households within the community.

- Routine Maintenance: All engineered systems need regular maintenance, and the easier and more convenient this process is, the better it is for a rural community like Quebrada Pinzón. Additionally, due to the lack of cooperation between the community members of Quebrada Pinzón, as has been demonstrated by incidents in the past, the routine maintenance for a common system will be more difficult to achieve than for to individual systems.

5.2 Failure Modes and Effects Analysis (FMEA)

The FMEA framework has been used to analyze all the possible modes of failure in all the components of both design alternatives. Each failure mode is assigned an occurrence probability rating ranging from 1-10 and a severity (based on impact) rating ranging from 1-4. A Risk Priority Number (RPN) is calculated by multiplying the probability and severity rating for each failure mode. The RPN average of both the design alternatives is compared to each other and the alternative which has a lesser RPN average is determined to be more reliable and less risky. The probability and severity rating system is described in Table 9 and 10, respectively. The complete FMEA framework for the ram pump design and rainwater harvesting system design is explained in sections 5.2.1 and 5.2.2.

Table 9. Probability Rating Guide

Probability of Occurrence of a Failure Mode	**Ranking**
Highly Unlikely	1-2
Unlikely	3-4
Neutral	5-6
Likely	7-8
Highly Likely	9-10

Table 10. Severity Rating Guide

Severity of a Failure Mode	**Ranking**
Very less significant	1
Somewhat significant	2
Significant	3
Harms human health	4

5.2.1 Design Alternative One: Ram Pump System

The ram pump system is comprised of five components: collection system, ram pump, filtration system, supply tank, and distribution network. The collection system consists of a diversion wall and filter grates. The diversion wall could fail by sliding failure or general dislodgment by debris, which would cause a reduction or complete loss of water intake capacity. The filters may become clogged by small debris (twigs, leaves, etc.) which would result in a reduced intake. These failure modes could all be avoided by preventive measures and routine inspection.

The pump section consists of a hydraulic ram pump and the connecting pipe network. The hydraulic ram pump has multiple failure modes: check valve issues, clogging or low intake, and foundation failure. These would all cause a significant issue and more likely result in complete stoppage of the entire system. These failures could all be remedied, but the solution could take significant labor, technical knowledge, and travel times. The filtration system consists of a 5 micron mesh filter which can fail as a result of clogging due to debris and larger solid particles. This can be prevented by routine cleaning and maintenance of the mesh filter.

The supply tank could have cracking failures due to weathering. This would cause water to leak, and would then cause a reduction of storage water. The probability of this failure is not very high, and it is not very severe unless the crack causes the tank to lose structural integrity suddenly. The distribution network would most likely have loose pipes at the junctions due to pressure in the system and abnormal pressure can cause pipe breakage. This would cause a leak in the flow and would reduce the flow to whatever is downpipe of the system. These failures are not catastrophic and are easily corrected; however, enough of these events will significantly reduce the effectiveness of the system. The RPN average for this system was calculated to be 8. A detailed explanation of each failure mode along with its probability and severity ratings, has been tabulated in Table 1 in Appendix G.

5.2.2 Design Alternative Two: Rainwater Harvesting Systems

The rainwater harvesting system has four components namely the collection system, filtration, disinfection, and storage. The collection system consists of zinc roofs and PVC gutters. Clogging and cracking are possible failure modes of the gutters which can lower water supply and result in shortage of water. These failure modes can be prevented by periodic cleaning, proper maintenance, and timely replacement of the gutters.

The filtration system which consists of a mesh filter and a first flush system, can be impacted by overflow, clogging, cracking of the pipe, and malfunction of the first flush system. None of these failure modes can negatively impact human health; however, reliability and functioning of the system can be affected due to reduction of water supply. MINSA's in-line chlorinator which is used for disinfection is also subject to clogging, especially during wet days, as high flow rates result in poor mixing of the chlorine tablets. This failure mode is severe because poor mixing of chlorine can lead to insufficient contact time in the storage tank. This can adversely impact human health because an insufficient contact time leads to inefficient removal of pathogens.

Lastly, the main failure mode for a plastic storage tank was determined to be particle build up in the bottom of the tank which can be caused due to improper functioning of the filtration system. This can be prevented by timely cleaning of the storage tank and the filtration system. The RPN average for this system was calculated to be 6. A detailed explanation of each failure mode along with its probability and severity ratings has been tabulated in Table 2 in Appendix G.

6.0 Final Recommendation

Based on the methods outlined in Section 5.0 Design Alternatives Analysis, QD recommends the Rainwater Harvesting System for the community.

The FMEA analysis has determined that a failure in the ram pump design has a relatively high probability and a failure in any aspect of the system would have a more significant impact on the users of the system than a failure of the Rainwater Harvesting system. The RPN average was calculated to be 8 for the pump system and 6 for the rainwater harvesting system. A higher level of technical skill is required to fix components of the ram pump system as compared to the rainwater harvesting system.

Furthermore, it is not feasible to treat the river water for drinking due to the cost constraints of the project. During the site visit, QD was unable to determine the source of the river and has thus been unable to reach a conclusion about the contents of the river water and the necessary processes that would be required to treat it.

The reliability of the ram pump system is questionable, especially during peak rainstorm events. Based on QD's calculations, the ram pump would pump water up the required elevation, but this system would require skilled labor for construction, maintenance, and repair. The amount of moving parts increases the likelihood of the need to replace them periodically.

Since the ram pump system would be shared by the three structures within Las Delicias, joint ownership, cooperation, and organization would be required among all the residents. Additional advantages of the rainwater harvesting alternative lies in its cost effectiveness, a simple maintenance regime, and easy implementation. This has been summarized in Table 11.

Table 11. Final Recommendation (Summary)

Constraint	**Alternative One**	**Alternative Two**
Feasibility and Constructability	Feasible but harder to construct	Feasible and easy to construct
Cost	3300 USD	800 USD (Structure A) 600 USD (Structure B)
Ownership of the system	Joint	Individual
Probability of system failure	RPN average = 8	RPN average = 6
Ease of repair and maintenance	High technical skill required	Technical skill not required
Water Quality	Fit for non-potable uses only	Fit for both potable and non-potable uses

7.0 Cost Estimate

7.1 General Construction Material Costs

The costs of concrete were determined via a receipt from the store *Centro de Materials Almirante*, in Almirante, Bocas del Toro, Panamá which were provided to an iDesign student. The thickness of the storage tanks was estimated to be six inches. A mix design of a ratio of 3:2:1—3 parts cement, 2 parts fine aggregate, and 1 part coarse aggregate—was used for the concrete. Half inch rebar will be used for this concrete. The bar is to not be placed within two inches of the edge of the concrete in order to protect it from corrosion. Each bar will be placed every six inches. A 100 gallon Ferro cement tank was also designed if the community were to choose this option, as it is easier to construct than the traditional concrete design. This concrete design will only use cement with fine aggregate, and chicken wire for reinforcement. These tanks have thinner walls, and will limit the size of the tanks. PVC costs were calculated using the length of the slope of the survey which was used to determine the amount of piping needed for the distribution network. The price of the various diameter PVC pipes was given to QD by Briana Arnold.

7.1.1 Tank Elevation Material

Concrete, metal, and timber were considered to build a stand in order to elevate the storage tank. Concrete was eliminated because it will need forms to construct and a decent amount of time to cure. Metal stands are subject to heavy rusting due to the climate of the area. Finally, local timber was chosen because it is the most cost effective and easily accessible material. A zinc band will be wrapped around the base of the stand in order to protect it from insects (mounding termites) and erosion; this protection was added to account for this threat as recommended by Dr. William Bulleit.

7.2 Design Alternative One: Ram Pump System

A cost estimate of the ram pump design is provided in Table 12. It is assumed that a self-constructed ram pump is going to be used by the community as opposed to a preassembled one due to cost constraints. An expanded cost estimate of the self-constructed ram pump is provided in Table 13.

Table 12. Cost Estimate for Ram Pump System

Item/Category	Quantity	Unit	Unit Cost	Total Cost per item ($)
Retention Wall				
Concrete	2.25	cft	$6.89	$15.50
Labor (creation and placement)	10	hrs	$3.00	$30.00
Riprap (labor for movement of existing rocks)	3	hrs	$3.00	$9.00
Screens	3	each	$10.00	$30.00
Pump				
Ram Pump (preassembled)	1	each	$175.00	Not Using
or Self Constructed	1	total	$106.50	$106.50
w Labor	5 hours	per 2 people	$3.00	$30.00
Pump Stand				
Concrete	2.25	cft	$6.89	$15.50
Labor	6	hrs	$3.00	$18.00
Piping Costs				
PVC (3')	2592	ft	$0.63	$1,620.00
PVC (1-1/4")	$3.50	per 20ft	550	$96.25
Flexible Hose	$50.00	per 100	440	$220.00
Connector @ Storage tank	$4.00	per item	2	$8.00
Tank Material (500 gal)				
Concrete	17.86	cft	$6.89	$209.86
Filtration (*For non-potable uses*)				
Debris Screen	1	each	$201	$201
12" x 12" Stainless Steel 5 Micron Mesh Filter	1	each	$90	$90
Total Cost				**$3300**

Table 13. Constructed Ram Pump Cost Breakdown

Cost and Component Breakdown for Community Built Ramp Pump			
Part	**Cost per Piece ($)**	**Quantity**	**Cost for parts ($)**
4"x24" PVC Pressure Pipe	$5.00	2.00	$10.00
4" PVC Snap-In Drain, Waste & Vent Cleanout Assembly	$6.50	1.00	$6.50
Brass Swing Check Value (1-1/4")	$20.00	1.00	$20.00
PVC Inline Check Valve	$5.00	1.00	$5.00
PVC Ball Valve (1-1/4")	$4.00	2.00	$8.00
PVC Union (1-1/4")	$2.00	2.00	$4.00
Pipe wrap Tape	$8.00	3.00	$24.00
Pipe Wrench	$10.00	2.00	$20.00
PVC Cement & Primer	$9.00	1.00	$9.00
		Total Cost	**$110**

7.3 Design Alternative Two: Rainwater Harvesting Systems

A rainwater harvesting system has been designed for Structures A and B in Las Delicias and the total material and construction costs for each design have been tabulated below in Table 14 and 15. The total material and construction cost is calculated to be $777 and $579 for Structures A and B respectively. Labor costs for each system is $42 and shipping from the United States to Panama will be done in bulk for both structures for $80.

Table 14. Rainwater Harvesting System Material, Labor, and Maintenance Costs for Structure A

Household Rainwater Harvesting System (Structure A)			
Item	**Cost($)**	**Unit**	**Total cost per item($)**
500 gallon plastic tank	500	1	500
Metal Protection Band	18	1	18
PVC Gutters	$12.50/20ft	80 (ft)	50
Self-Cleaning Filter	30	1	30
First Flush System	30	1	30
In Line Chlorinator	25	1	25
Calcium Hypochlorite Tablets	2	20	40
Labor ($/day)	3	7	42
Shipping from US	40	1	40
Total Cost			**$800**

Table 15. Rainwater Harvesting System Material, Labor, Operation, and Maintenance Costs for Structure B

Household Rainwater Harvesting System (Structure B)			
Item	**Cost($)**	**Unit**	**Total cost per item($)**
300 gallon plastic tank	300	1	300
Metal Protection Band	18	1	18
PVC Gutters	$12.50/20ft	86 (ft)	54
Self-Cleaning Filter	30	1	30
First Flush System	30	1	30
In Line Chlorinator	25	1	25
Calcium Hypochlorite Tablets	2	20	40
Labor ($/day)	3	7	42
Shipping from US	40	1	40
Total Cost			**$600**

8.0 Construction Schedule

The construction of the rainwater harvesting system involves four main stages: preliminary preparation, site planning, construction, and initiation of system function. These tasks involve various sub tasks which are outlined as follows:

- Preliminary Steps/Preparation
  - Purchase of locally available materials in Almirante, Bocas del Toro
  - Online purchase of the self-cleaning filter and the first flush system
- Site Planning
  - Preparation of PVC gutters
  - Marking of the system layout
  - Preparation of wood for tank stand
- Construction
  - Gutter Installation including roof cleaning and installation of supports
  - Installation of the self-cleaning mesh filter, the first flush system, and the in line chlorinator
  - Erection of the wooden tank stand
  - Placement of the wooden tank
  - Connection of all the components of the filtration and disinfection system
- Initiation of system functioning and testing
- Education of maintenance and safety concerns and procedures for the residents of Las Delicias

The construction of the rainwater harvesting system is estimated to take 28 days for Structure B. This duration takes initial site preparation time, shipping of materials, and system testing time into account. The proposed construction schedule assumes that two laborers are working on the installation process at a time. The construction schedule takes unforeseen weather circumstances such as heavy rain into account by allotting extra time to certain tasks. These tasks can be carried out simultaneously on both the structures or in sequence as deemed fit by the PCV and the residents of Las Delicias. A summary of all the tasks and their estimated time durations is provided in Table 16. A Gantt chart outlining all the different construction stages and sub tasks is provided in Appendix I.

Table 16. Construction Schedule Summary (Main Tasks)

Task	Estimated Duration (days)
Preparation and Preliminary Steps	11
Site Planning	2
Construction	4
Initiation of system function and testing	6
Education about maintenance and safety concerns for residents of Las Delicias	6

9.0 Conclusion

The goal of Quian Designs is to design a water distribution system that will provide an uninterrupted supply of potable water to the neighborhood of Las Delicias. Quian Designs spent one week in August of 2015 in the community to gather data that will help to construct this system. The team has worked through the fall 2015 semester to create the final design for a water distribution system.

Quian Designs recommends the implementation of a Rainwater Harvesting system for each individual household that is interested in going forward with the project. The system has been designed to be easy to implement, and have low maintenance requirements, low cost, and high reliability. Each system will consist of PVC pipe gutters for rain collection, mesh and first flush systems for removal of contaminants, and in-line chlorinators for effective disinfection.

Individual households will be responsible for their own systems, and this will help to avoid the lack of ownership that has been a previous issue in the community. Furthermore, the implementation of one system may pique the interest of other members in the community. Community members may follow the example, and soon it is hoped that this design will expand to more than just the Las Delicias area. Construction costs and schedule have been provided in detail for the Rainwater Harvesting System. The project should be implemented with ease if the schedule is followed. The system should be constructed as detailed in the prepared plans. Overall, this final report includes all information essential to the construction and funding of the Rainwater Harvesting system.

10.0 References

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11.0 Appendices

Appendix A: Summary of Survey Data
Appendix B: Summary of River Data
Appendix C: Pump Calculations, Storage Tank, and Sedimentation Tank
Appendix D: Rainfall Data
Appendix E: Chlorination
Appendix F: Storage Analysis
Appendix G: Alternatives Analysis
Appendix H: Rainwater Harvesting 3D Model Views
Appendix I: Construction Schedule

Appendix A

Summary of Survey data

Table 1: Survey Data

Station	Horizontal	Summation	Vertical	Current Elevation	Slope	Angle	"+/-"	Bearing Angle	Bearing
Main Line at Las Delicias									
0	0	0	0	45	0	0		0	
1	33	33	0.4	44.6	33	-0.8	-1	8	nw
2	14.8	47.8	1.8	46.4	15	7.4	1	34	nw
3	19.4	67.2	0	46.4	19.5	-0.4	-1	12	ne
4	27	94.2	5	41.4	27.5	-10.8	-1	4	nw
5	121	215.2	20.8	62.2	123	9.8	1	4	nw
6	21.2	236.4	2.6	59.6	119.5	-7.2	-1	20	nw
7	119	355.4	9.8	69.4	119.5	4.8	1	18	nw
8	49.4	404.8	2.4	71.8	49.5	2.8	1	12	nw
9	20.8	425.6	4.6	67.2	21.5	-12.8	-1	63	nw
10	26.4	452	0.8	68	26.5	2	1	30	nw
11	23.4	475.4	1.4	66.6	23.5	-3.6	-1	28	nw
12	12.4	487.8	1.4	68	12.5	7	1	64	nw
13	45.6	533.4	4.8	63.2	46	-6	-1	32	nw
14	34.4	567.8	2	65.2	34.5	3.6	1	2	nw
15	37.4	605.2	6.6	71.8	38	10.2	1	16	nw
16	26.8	632	1.2	73	27	2.8	1	27	nw
17	41.8	673.8	2.8	70.2	12	-1.2	-1	13	nw

Appendix B

Summary of River data

From the information obtained on site by QD, the water surface profile of the river was calculated in order to determine the flow rate, and the available energy of the river. These calculations were necessary for the determination of the feasibility of the ram pump system. Tables 1 and 2 report the measured values obtained on site. Table 3 provides the known, or calculated variables necessary to calculate the water surface profile. Tables 4 and 5 report the calculated Water Surface Profile. The equations used for these calculations as well as the variable definitions, are listed below Table 5.

Table 1: Summary of River Data

Cross Section Data: Triangular Model		Unit
Surface Width	9	ft
Depth	3	ft
Length	19.42	ft

Table 2: Time Averages for three Trials at three River Sections

River Section	**1**	**2**	**3**
Time (sec)	32	74	75
Time (sec)	27	115	115
Time (sec)	26	95	95
Average (sec)	28.33	94.67	95.00

Table 3: Known values

T	9	ft
y	3	ft
m	1.5	ft
P	10.8	ft
So	0.027	
n	0.07	
Cm	1.49	
g	32.2	ft/s^2

Table 4: Flow Characteristics

Flow Category	Energy (ft)	Depth (ft)
Normal	2.5841	2.58
Critical	1.5008	1.44
Existing	3.0031	3

Table 5: Water Surface Profile of River

Area ft^2	Velocity ft/sec	Flow Rate cft/s	Yn ft	Yc ft
13.5	0.44484	6.01	2.58	1.44

Equations for water surface profile calculations

$Q=Av$

$A=my^2$

$P=2y\,(1+m^2)^{1/2}$

$T=2my$

Q^2 / g = A^3/T

$E=Y_n + (Q^2/2gA^2)$

Where:

Q = discharge rate for design conditions (cfs)
g = acceleration due to gravity (32.2 ft/sec2)
A = cross-sectional area (ft2)
T = top width of water surface (ft)
Q = Flow Rate, (ft^3/s)
v = Velocity, (ft/s)
n = Manning's Roughness Coefficient
m=Side Slope
R = Hydraulic Radius, (ft)
S = Channel Slope, (ft/ft)
Y_n=Normal Depth
E=Energy gradient

Figure 1: North facing view of current river condition at point of proposed retention wall

Appendix C

Pump Calculations, Sedimentation Tank, and Storage Tank

Pump Calculations

$$Monthly\ Demand = 12000\ gal \rightarrow 0.017283\ lps. \rightarrow\ Qoutput = 1.1 * (0.017283) = 0.19\ lps$$

$$Q_{output} = \frac{2 * Qinput * Hd}{3 * Hs} \rightarrow Q_{output} = \frac{Qinput * Hd}{4 * Hs} \rightarrow 0.19\ lps = \frac{Qinput * Hd}{4 * 19\ meters} \rightarrow 14.5\ meters * lps = Q_{input} * H_d$$

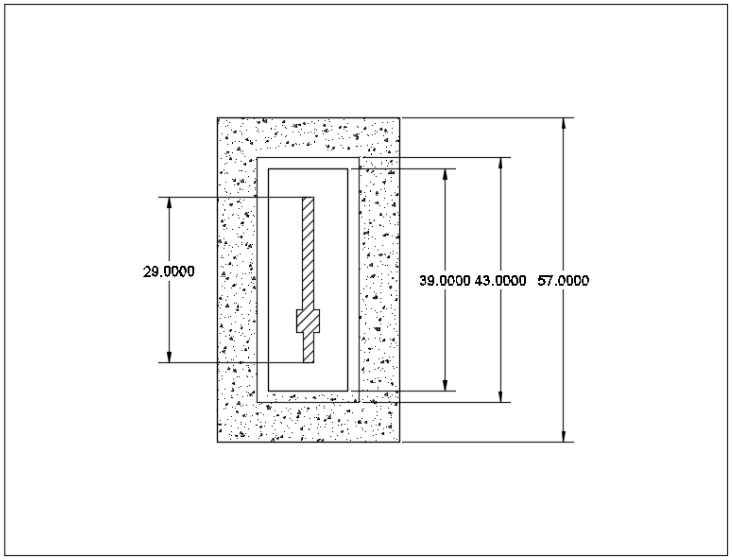


Figure 1: Plan View (in inches) for the dimensions of a pump enclosure

Equations for the Sedimentation Tank Calculations in River Pump Design

$$v_p(t) = \left(g\left(\rho_p - \rho_w\right)\left(d_p\right)^2\right)/(18\mu)$$

$$W = \frac{Q}{L * v_h}$$

$$Nr = \frac{\rho_w d_p v_p(t)}{\mu}$$

Where

$v_{p(t)}$ is the settling velocity of the design particle
g is the acceleration due to gravity
$_p$ is the density of the particle
p_w is the density of water
d_p is the diameter of the design particle
W is width
Q is the flowrate
L is the length
µ is the dynamic viscosity of water
N_r is the Reynold's number

Table 1 reports the calculations used to determine the size of the sedimentation tank. The variables are defined below.

Table 1: Sedimentation Tank Calculations

Constants				Assumed Values		
g	32.2	ft/s		vh	1	ft/s
temp	80	°F		H	5	ft
pw	1.934	slug/ft^3		pp	2	
µ	0.001799	(lb*s)/ft^3				
dp	6.56168E-05					
Q	6	cft/s				

Trial	Nr	Cd	vpt (ft/s)
0	1.99327E-08	-	2.83E-07

Tank Dimensions		
A	21233669.06	sq ft
L	17694724.21	ft
W	1.2	ft

g = gravity
pw = density of water
µ = dynamic viscosity of water
dp = density of design particle
Q = flow rate of the fiver
vh = horizontal settling velocity

H = height of the sedimentation tank
pp = density of design particle
A = Area of Tank
L = Length of Tank
W = Width of Tank

Table 2 shows the final analysis performed in order to determine the sizing of the storage tank.

Table 2: Storage Analysis of Ram Pump Supply and Demand

Supply (gph)	Demand (gph)	Quantity Remaining (gal)
18.078	1	499
18.078	1	499
18.078	1	499
18.078	1	499
18.078	1	499
18.078	1	499
18.078	7	493
18.078	7.5	492.5
18.078	8.5	491.5
18.078	12.5	487.5
18.078	22.5	477.5
18.078	45	455
18.078	70	430
18.078	67.5	432.5
18.078	30	470
18.078	6	494
18.078	8.5	491.5
18.078	15	485
18.078	30	470
18.078	30	470
18.078	37.5	462.5
18.078	15	485
18.078	15	485
18.078	7.5	492.5
18.078	1	499

Below is the EPANET generated pump curve of the ram pump.

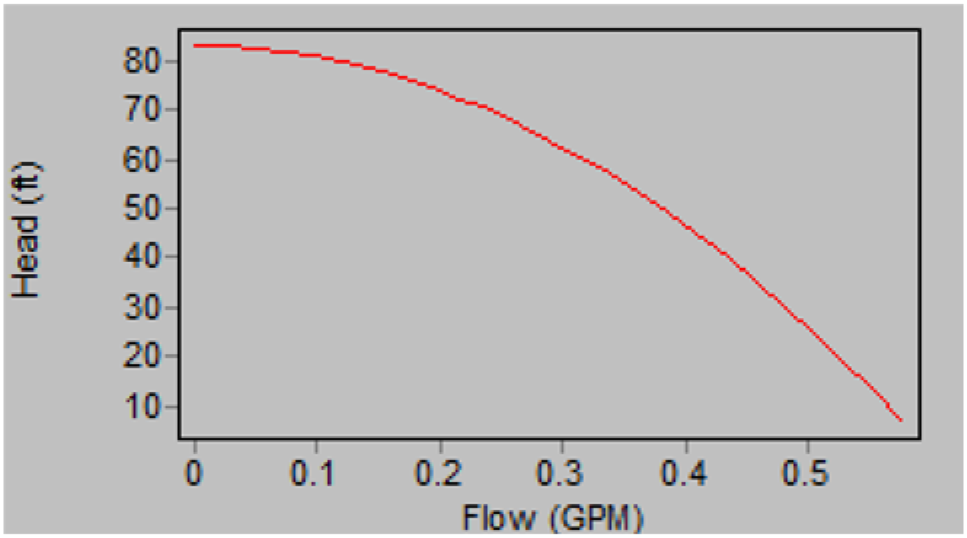


Figure 2: EPANET generated Pump Curve

The demand pattern the system was modeled on a 24-hour cycle. Two patterns were created: Pattern 1.1 for buildings B and C, and Pattern 3.1 for buildings A, B, and C. The demand from Buildings B and C (being residential structures) was assumed to have two peaks: the first from noon to 1 pm, the other from 7 p.m. to 8 p.m.. These peaks are modeled to occur at these times because the people in Quebrada Pinzón generally take two showers a day: one in the afternoon, the other at night. Water use was assumed to begin at 6 a.m. and end at 10 p.m. These times were based on QD's experiences while within the community and the Peace Corps Volunteer's observations [1]. According to this model, the pump can provide a flowrate of 0.39 gallons per minute. Tables 3 through 6 report the results of the analysis. Tables 3 and 5 report the conditions at the junctions between the pipes, and Tables 4 and 6 report the conditions in each pipe.

Table 3: Pattern 1.1 Junction Analysis

Node ID	Elevation ft	Demand GPM	Head ft	Pressure psi
Junc 10	147.64	0.16	242.50	41.10
Junc 20	146.33	0.00	242.50	41.67
Junc 30	152.23	0.04	242.50	39.11
Junc 40	135.83	0.00	242.50	46.22
Junc 50	204.07	0.00	242.50	16.65
Junc 60	195.54	0.00	242.50	20.35
Junc 70	227.69	0.00	242.50	6.42
Junc 80	235.57	0.00	242.50	3.00
Junc 90	220.47	0.00	242.50	9.55
Junc 100	223.10	0.00	242.50	8.41
Junc 110	218.51	0.00	242.50	10.39
Junc 120	223.10	0.00	242.50	8.41
Junc 130	207.35	0.00	242.50	15.23
Junc 140	213.91	0.00	242.50	12.39
Junc 150	235.57	0.00	242.50	3.00
Junc 160	239.5	0.00	242.50	1.30
Junc 170	230.32	0.00	242.50	5.28
Junc 180	232.94	0.03	242.50	4.14
Junc 300	167.98	0.00	191.95	10.39
Junc 310	170	0.00	242.51	31.42
Resvr R1	182.15	701.80	182.15	0.00
Tank T1	239.50	0.16	242.50	1.30
Tank T2	190.98	-702.18	191.98	0.43

Table 4: Pattern 1.1 Junction Analysis

Link ID	Length ft	Flow GPM	Velocity fps	Unit Headloss ft/Kft
Pipe 2	49.21	0.16	0.01	0.00
Pipe 3	63.98	0.19	0.01	0.00
Pipe 4	90.22	0.19	0.01	0.00
Pipe 5	403.54	0.19	0.01	0.00
Pipe 6	392.06	0.19	0.01	0.00
Pipe 7	392.06	0.19	0.01	0.00
Pipe 8	162.40	0.19	0.01	0.00
Pipe 9	70.54	0.19	0.01	0.00
Pipe 10	86.94	0.19	0.01	0.00
Pipe 11	77.10	0.19	0.01	0.00
Pipe 12	41.01	0.19	0.01	0.00
Pipe 13	150.92	0.19	0.01	0.00
Pipe 14	113.19	0.19	0.01	0.00
Pipe 15	124.67	0.19	0.01	0.00
Pipe 16	88.58	0.19	0.01	0.00
Pipe 17	39.37	0.03	0.00	0.00
Pipe 18	137.80	0.03	0.00	0.00
Pipe 20	203.81	0.38	0.10	0.06
Pipe 1	108.27	0.16	0.01	0.00
Pipe P4	10.01	-701.80	31.85	982.02
Pipe P5	500.56	0.38	0.10	0.06
Pump 21	#N/A	0.38	0.00	-50.56

Table 5: Pattern 3.1 Junction Analysis

Node ID	Elevation ft	Demand GPM	Head ft	Pressure psi
Junc 10	147.64	0.16	242.50	41.10
Junc 20	146.33	0.00	242.50	41.67
Junc 30	152.23	0.04	242.50	39.11
Junc 40	135.83	0.00	242.50	46.22
Junc 50	204.07	0.00	242.50	16.65
Junc 60	195.54	0.00	242.50	20.35
Junc 70	227.69	0.00	242.50	6.42
Junc 80	235.57	0.00	242.50	3.00
Junc 90	220.47	0.00	242.50	9.55
Junc 100	223.10	0.00	242.50	8.41
Junc 110	218.51	0.00	242.50	10.39
Junc 120	223.10	0.00	242.50	8.41
Junc 130	207.35	0.00	242.50	15.23
Junc 140	213.91	0.00	242.50	12.39
Junc 150	235.57	0.00	242.50	3.00
Junc 160	239.5	0.00	242.50	1.30
Junc 170	230.32	0.00	242.50	5.28
Junc 180	232.94	0.03	242.50	4.14
Junc 300	167.98	0.00	191.95	10.39
Junc 310	170	0.00	242.51	31.42
Resvr R1	182.15	701.80	182.15	0.00
Tank T1	239.50	0.16	242.50	1.30
Tank T2	190.98	-702.18	191.98	0.43

Table 6: Pattern 3.1 Pipe Flowrates

Link ID	Length ft	Flow GPM	Velocity fps	Unit Headloss ft/Kft
Pipe 2	49.21	0.16	0.01	0.00
Pipe 3	63.98	0.19	0.01	0.00
Pipe 4	90.22	0.19	0.01	0.00
Pipe 5	403.54	0.19	0.01	0.00
Pipe 6	392.06	0.19	0.01	0.00
Pipe 7	392.06	0.19	0.01	0.00
Pipe 8	162.40	0.19	0.01	0.00
Pipe 9	70.54	0.19	0.01	0.00
Pipe 10	86.94	0.19	0.01	0.00
Pipe 11	77.10	0.19	0.01	0.00
Pipe 12	41.01	0.19	0.01	0.00
Pipe 13	150.92	0.19	0.01	0.00
Pipe 14	113.19	0.19	0.01	0.00
Pipe 15	124.67	0.19	0.01	0.00
Pipe 16	88.58	0.19	0.01	0.00
Pipe 17	39.37	0.03	0.00	0.00
Pipe 18	137.80	0.03	0.00	0.00
Pipe 20	203.81	0.38	0.10	0.06
Pipe 1	108.27	0.16	0.01	0.00
Pipe P4	10.01	-701.80	31.85	982.02
Pipe P5	500.56	0.38	0.10	0.06
Pump 21	#N/A	0.38	0.00	-50.56

Appendix D

Rainfall Data

Table 1: Catchment areas of Structure A and B

	Length(ft)	Width (ft)	Roof Area (ft2)
Structure B	25.5	25.6	652.8
Structure A			
Kitchen	12.6	15.4	194.04
Dining Hall	20.5	24.7	506.35
Gathering Space	23.5	15.5	364.25
Church	24.7	38.2	943.54

Table 2: Average monthly rainfall at Changuinola for time period 2000-2012

2000-2012	Month	Precipitation (mm/month)	Average Rainfall Days	Rain per day(mm)	Rain per day (inches)
1	January	263.6	20	13.2	0.51876
2	February	190.8	15	12.7	0.49911
3	March	178.2	16	11.1	0.43623
4	April	171.1	16	10.7	0.42051
5	May	317.5	19	16.7	0.65631
6	June	233.2	19	12.3	0.48339
7	July	396.5	23	17.2	0.67596
8	August	251.4	19	13.2	0.51876
9	September	111.2	16	7	0.2751
10	October	159.4	18	8.9	0.34977
11	November	311	19	16.4	0.64452
12	December	347.7	20	17.4	0.68382

Table 3: Average monthly rainfall at Changuinola for time period 1960-1972

1960-1972	Month	Precipitation (mm/month)	Average Rainfall Days	Rain per day(mm)	Rain per day (inches)
1	January	236.4923077	20	11.82462	0.464707
2	February	141.1461538	15	9.409744	0.369803
3	March	169.7384615	16	10.60865	0.41692
4	April	247.3615385	16	15.4601	0.607582
5	May	242.6307692	19	12.77004	0.501863
6	June	185.6923077	19	9.773279	0.38409
7	July	287.4538462	23	12.49799	0.491171
8	August	187.0846154	19	9.846559	0.38697
9	September	119.5923077	16	7.474519	0.293749
10	October	147.9923077	18	8.221795	0.323117
11	November	266.0846154	19	14.00445	0.550375
12	December	381.3692308	20	19.06846	0.749391

Appendix E

Chlorination

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

Chlorination is recommended for disinfection in the proposed rainwater harvesting system. Two parameters which are very important to take into consideration while treating water with chlorine are chlorine concentration and contact time. The Ct method is commonly used in order to predict and evaluate the effectiveness of chlorine treatment in a water system. 'C' is the free chlorine concentration and 't' is the total contact time.

The following equation is used to calculate Ct:

$$Ct = C \times t$$

$$where: C\ is\ the\ \text{free chlorine concentration"}\ in\ units\ of\ mg\ Cl_2/L$$

$$t\ is\ the\ \text{total contact time"}\ in\ units\ of\ (\text{min})$$

$$Ct\ is\ the\ \text{Ct value"}\ in\ units\ of\ (min * mg\ Cl_2/L)$$

Different Ct values are required in a water system in order to ensure complete destruction of pathogens in a system. Ct values for common water-borne pathogens are tabulated below 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 cholera	0.5	20	7
Rotavirus	0.05	4	7

As seen in Table 1, a Ct value of 35 min*mg Cl_2/L is required to kill *E. Histolytica*. The target minimum Ct value to kill all pathogens will be set to 40 min*mg Cl_2/L in order to ensure that chlorination is effective.

2.0 C (Free Chlorine Concentration) Calculation

Free Chlorine concentration is the amount of chlorine that is available to disinfect the water and kill pathogens. Two values that are important to consider when taking free chlorine measurements are:

1. Maximum Total Chlorine Concentration: According to the World Health Organization (WHO), the maximum residual disinfectant level (MRDL) in water should be no more than 5 mg Cl_2 /L. Potable water with a higher chlorine concentration can harm human health. Since the Ct method only takes "free chlorine" concentrations into account, it is safe to limit the chlorine concentration to 3 mg Cl_2 /L. Sampling in order to make sure that this concentration is not exceeded should be done at the influent pipe where the chlorinated water enters the storage tank.
2. Free chlorine concentration needed to achieve the require Ct value: It is important for the free chlorine concentration to be large enough to achieve the required Ct value to destroy pathogens.

3.0 Contact time (t) Calculation

The following equation should be used in order to determine the contact time in the storage tank:

$$Contact\ Time\ in\ storage\ tank\ (min) = \frac{Tank\ Volume\ (L)}{Influent\ Flowrate\ \left(\frac{L}{min}\right)} * Tank\ Baffling\ Factor$$

The tank "baffling factor" in the above equation is used to account for incomplete mixing of the chlorinated water in the storage tank.

4.0 Determining number of chlorine tablets needed

MINSA recommends using an iterative approach to determine whether the number of chlorine tablets being used for a system are appropriate or not. This approach is outlined below in Figure 1. It is recommended to ask the community's local MINSA technician, the number of chlorine tablets to use to begin chlorination; however, if a technician is not available, it is recommended to start chlorination with 1 tablet.

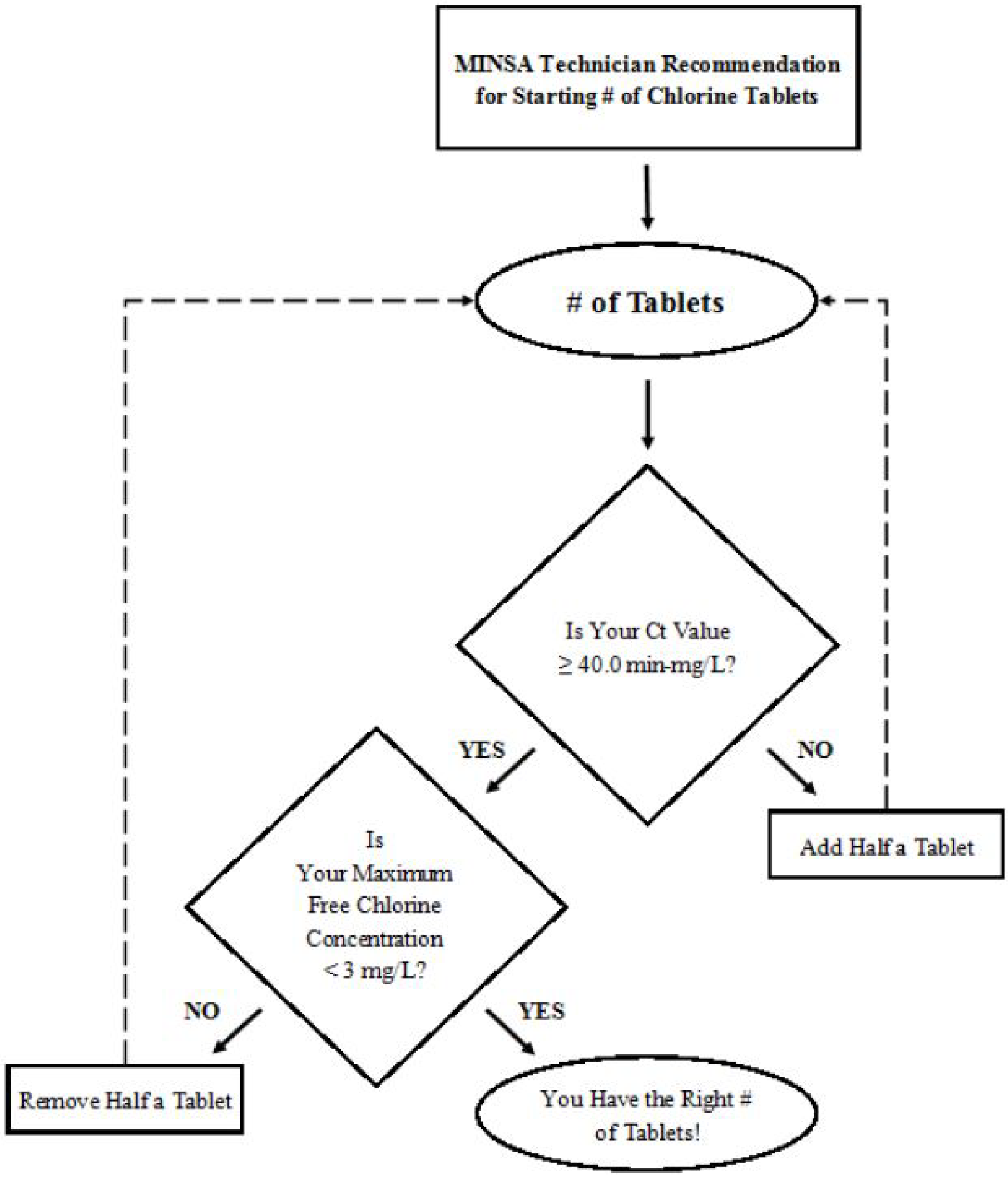


Figure 1: Determination of the correct number of chlorine tablets

Appendix F

Storage Analysis

Structure A

Table 1: Storage Analysis for Structure A during January. Daily demand set to 100 gallons/day.

JANUARY	Rain (inchs)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5181	175	175	175	0	175	175
2	0.5181	175	350	350	450	-100	0
3	0.5181	175	175	175	0	175	175
4	0.5181	175	350	350	0	350	350
5		0	350	350	0	350	350
6	0.5181	175	525	500	0	500	500
7		0	500	500	0	500	500
8	0.5181	175	675	500	0	500	500
9	0.5181	175	675	500	450	50	50
10		0	50	50	0	50	50
11	0.5181	175	225	225	0	225	225
12	0.5181	175	400	400	0	400	400
13	0.5181	175	575	500	0	500	500
14	0.5181	175	675	500	0	500	500
15		0	500	500	0	500	500
16	0.5181	175	675	500	450	50	50
17		0	50	50	0	50	50
18	0.5181	175	225	225	0	225	225
19		0	225	225	0	225	225
20	0.5181	175	400	400	0	400	400
21	0.5181	175	575	500	0	500	500
22	0	0	500	500	0	500	500
23	0.5181	175	675	500	450	50	50
24	0	0	50	50	0	50	50
25	0.5181	175	225	225	0	225	225
26	0	0	225	225	0	225	225
27	0.5181	175	400	400	0	400	400
28	0.5181	175	575	500	0	500	500
29	0.5181	175	675	500	0	500	500
30	0	0	500	500	450	50	50

Table 2: Storage Analysis for Structure A during February. Daily demand set to 100 gallons/day

FEBRUARY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5008	169	219	219	0	219	219
2		0	219	219	0	219	219
3	0.5008	169	388	388	0	388	388
4		0	388	388	0	388	388
5		0	388	388	0	388	388
6	0.5008	169	557	500	0	500	500
7		0	500	500	450	50	50
8		0	50	50	0	50	50
9	0.5008	169	219	219	0	219	219
10		0	219	219	0	219	219
11		0	219	219	0	219	219
12	0.5008	169	388	388	0	388	388
13	0.5008	169	557	500	0	500	500
14		0	500	500	450	50	50
15	0.5008	169	219	219	0	219	219
16		0	219	219	0	219	219
17	0.5008	169	388	388	0	388	388
18	0.5008	169	557	500	0	500	500
19		0	500	500	0	500	500
20	0.5008	169	669	500	0	500	500
21	0.5008	169	669	500	450	50	50
22		0	50	50	0	50	50
23	0.5008	169	219	219	0	219	219
24	0.5008	169	388	388	0	388	388
25		0	388	388	0	388	388
26	0.5008	169	557	500	0	500	500
27		0	500	500	0	500	500
28		0	500	500	450	50	50
29	0.5008	169	219	219	0	219	219
30		0	219	219	0	219	219

Table 3: Storage Analysis for Structure A during March. Daily demand set to 100 gallons/day.

MARCH	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.4385	148	367	367	0	367	367
2	0.4385	148	515	500	0	500	500
3		0	500	500	0	500	500
4	0.4385	148	648	500	0	500	500
5		0	500	500	450	50	50
6	0.4385	148	198	198	0	198	198
7	0.4385	148	346	346	0	346	346
8		0	346	346	0	346	346
9	0.4385	148	494	494	0	494	494
10	0.4385	148	642	500	0	500	500
11		0	500	500	0	500	500
12	0.4385	148	648	500	450	50	50
13		0	50	50	0	50	50
14	0.4385	148	198	198	0	198	198
15		0	198	198	0	198	198
16	0.4385	148	346	346	0	346	346
17		0	346	346	0	346	346
18	0.4385	148	494	494	0	494	494
19	0.4385	148	642	500	450	50	50
20		0	50	50	0	50	50
21	0.4385	148	198	198	0	198	198
22		0	198	198	0	198	198
23	0.4385	148	346	346	0	346	346
24		0	346	346	0	346	346
25	0.4385	148	494	494	0	494	494
26	0.4385	148	642	500	450	50	50
27		0	50	50	0	50	50
28		0	50	50	0	50	50
29		0	50	50	0	50	50
30	0.4385	148	198	198	0	198	198

Table 4: Storage Analysis for Structure A during April. Daily demand set to 100 gallons/day.

APRIL	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.421	142	340	340	0	340	340
2		0	340	340	0	340	340
3		0	340	340	450	-110	0
4		0	0	0	0	0	0
5		0	0	0	0	0	0
6	0.421	142	142	142	0	142	142
7		0	142	142	0	142	142
8	0.421	142	284	284	0	284	284
9		0	284	284	0	284	284
10	0.421	142	426	426	450	-24	0
11		0	0	0	0	0	0
12	0.421	142	142	142	0	142	142
13	0.421	142	284	284	0	284	284
14		0	284	284	0	284	284
15	0.421	142	426	426	0	426	426
16	0.421	142	569	500	0	500	500
17		0	500	500	450	50	50
18	0.421	142	192	192	0	192	192
19		0	192	192	0	192	192
20	0.421	142	334	334	0	334	334
21	0.421	142	476	476	0	476	476
22		0	476	476	0	476	476
23		0	476	476	0	476	476
24	0.421	142	619	500	450	50	50
25		0	50	50	0	50	50
26	0.421	142	192	192	0	192	192
27	0.421	142	334	334	0	334	334
28		0	334	334	0	334	334
29	0.421	142	476	476	0	476	476
30	0.421	142	619	500	0	500	500

Table 5: Storage Analysis for Structure A during May. Daily demand set to 100 gallons/day.

MAY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6579	222	722	500	450	50	50
2	0.6579	222	272	272	0	272	272
3		0	272	272	0	272	272
4	0.6579	222	494	494	0	494	494
5		0	494	494	0	494	494
6	0.6579	222	716	500	0	500	500
7	0.6579	222	722	500	0	500	500
8	0.6579	222	722	500	450	50	50
9	0.6579	222	272	272	0	272	272
10		0	272	272	0	272	272
11	0.6579	222	494	494	0	494	494
12	0.6579	222	716	500	0	500	500
13	0.6579	222	722	500	0	500	500
14		0	500	500	0	500	500
15	0.6579	222	722	500	450	50	50
16	0.6579	222	272	272	0	272	272
17		0	272	272	0	272	272
18		0	272	272	0	272	272
19	0.6579	222	494	494	0	494	494
20	0.6579	222	716	500	0	500	500
21		0	500	500	0	500	500
22	0.6579	222	722	500	450	50	50
23	0.6579	222	272	272	0	272	272
24		0	272	272	0	272	272
25	0.6579	222	494	494	0	494	494
26		0	494	494	0	494	494
27	0.6579	222	716	500	0	500	500
28		0	500	500	0	500	500
29	0.6579	222	722	500	450	50	50
30		0	50	50	0	50	50

Table 6: Storage Analysis for Structure A during June. Daily demand set to 100 gallons/day.

JUNE	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.4832	163	213	213	0	213	213
2		0	213	213	0	213	213
3	0.4832	163	376	376	0	376	376
4		0	376	376	0	376	376
5	0.4832	163	539	500	0	500	500
6		0	500	500	450	50	50
7	0.4832	163	213	213	0	213	213
8	0.4832	163	376	376	0	376	376
9	0.4832	163	539	500	0	500	500
10		0	500	500	0	500	500
11	0.4832	163	663	500	0	500	500
12	0.4832	163	663	500	0	500	500
13	0.4832	163	663	500	450	50	50
14	0.4832	163	213	213	0	213	213
15	0.4832	163	376	376	0	376	376
16		0	376	376	0	376	376
17	0.4832	163	539	500	0	500	500
18	0.4832	163	663	500	0	500	500
19	0.4832	163	663	500	0	500	500
20		0	500	500	450	50	50
21	0.4832	163	213	213	0	213	213
22		0	213	213	0	213	213
23	0.4832	163	376	376	0	376	376
24	0.4832	163	539	500	0	500	500
25	0.4832	163	663	500	0	500	500
26		0	500	500	0	500	500
27	0.4832	163	663	500	450	50	50
28	0.4832	163	213	213	0	213	213
29	0.4832	163	376	376	0	376	376
30	0.4832	163	539	500	0	500	500

Table 7: Storage Analysis for Structure A during July. Daily demand set to 100 gallons/day.

JULY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6787	229	729	500	0	500	500
2		0	500	500	0	500	500
3	0.6787	229	729	500	0	500	500
4		0	500	500	450	50	50
5	0.6787	229	279	279	0	279	279
6	0.6787	229	508	500	0	500	500
7		0	500	500	0	500	500
8	0.6787	229	729	500	0	500	500
9	0.6787	229	729	500	0	500	500
10		0	500	500	0	500	500
11	0.6787	229	729	500	450	50	50
12	0.6787	229	279	279	0	279	279
13		0	279	279	0	279	279
14	0.6787	229	508	500	0	500	500
15	0.6787	229	729	500	0	500	500
16	0.6787	229	729	500	0	500	500
17		0	500	500	0	500	500
18	0.6787	229	729	500	450	50	50
19	0.6787	229	279	279	0	279	279
20		0	279	279	0	279	279
21	0.6787	229	508	500	0	500	500
22		0	500	500	0	500	500
23		0	500	500	0	500	500
24	0.6787	229	729	500	0	500	500
25	0.6787	229	729	500	450	50	50
26		0	50	50	0	50	50
27	0.6787	229	279	279	0	279	279
28	0.6787	229	508	500	0	500	500
29	0.6787	229	729	500	0	500	500
30		0	500	500	0	500	500

Table 8: Storage Analysis for Structure A during August. Daily demand set to 100 gallons/day

AUGUST	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5209	176	676	500	450	50	50
2		0	50	50	0	50	50
3	0.5209	176	226	226	0	226	226
4	0.5209	176	402	402	0	402	402
5	0.5209	176	578	500	0	500	500
6		0	500	500	0	500	500
7	0.5209	176	676	500	0	500	500
8		0	500	500	450	50	50
9	0.5209	176	226	226	0	226	226
10	0.5209	176	402	402	0	402	402
11		0	402	402	0	402	402
12	0.5209	176	578	500	0	500	500
13		0	500	500	0	500	500
14	0.5209	176	676	500	0	500	500
15	0.5209	176	676	500	450	50	50
16		0	50	50	0	50	50
17	0.5209	176	226	226	0	226	226
18		0	226	226	0	226	226
19	0.5209	176	402	402	0	402	402
20		0	402	402	0	402	402
21	0.5209	176	578	500	0	500	500
22	0.5209	176	676	500	450	50	50
23		0	50	50	0	50	50
24	0.5209	176	226	226	0	226	226
25	0.5209	176	402	402	0	402	402
26		0	402	402	0	402	402
27	0.5209	176	578	500	0	500	500
28	0.5209	176	676	500	0	500	500
29	0.5209	176	676	500	450	50	50
30		0	50	50	0	50	50

Table 9: Storage Analysis for Structure A during September. Daily demand set to 100 gallons/day

SEPTEMBER	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.2736	92	142	142	0	142	142
2	0.2736	92	235	235	0	235	235
3		0	235	235	0	235	235
4	0.2736	92	327	327	0	327	327
5	0.2736	92	419	419	0	419	419
6		0	419	419	450	-31	0
7	0.2736	92	92	92	0	92	92
8		0	92	92	0	92	92
9	0.2736	92	185	185	0	185	185
10		0	185	185	0	185	185
11		0	185	185	0	185	185
12	0.2736	92	277	277	0	277	277
13		0	277	277	450	-173	0
14		0	0	0	0	0	0
15	0.2736	92	92	92	0	92	92
16		0	92	92	0	92	92
17	0.2736	92	185	185	0	185	185
18	0.2736	92	277	277	0	277	277
19	0.2736	92	369	369	0	369	369
20		0	369	369	450	-81	0
21	0.2736	92	92	92	0	92	92
22		0	92	92	0	92	92
23	0.2736	92	185	185	0	185	185
24	0.2736	92	277	277	0	277	277
25	0.2736	92	369	369	0	369	369
26		0	369	369	0	369	369
27	0.2736	92	462	462	450	12	12
28	0.2736	92	104	104	0	104	104
29		0	104	104	0	104	104
30	0.2736	92	197	197	0	197	197

Table 10: Storage Analysis for Structure A during October. Daily demand set to 100 gallons/day

OCTOBER	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.3486	118	382	382	0	382	382
2	0.3486	118	382	382	0	382	382
3		0	500	500	0	500	500
4	0.3486	118	382	382	450	-68	0
5	0.3486	118	382	382	0	382	382
6		0	500	500	0	500	500
7	0.3486	118	382	382	0	382	382
8		0	500	500	0	500	500
9	0.3486	118	382	382	0	382	382
10		0	500	500	0	500	500
11	0.3486	118	382	382	450	-68	0
12	0.3486	118	382	382	0	382	382
13		0	500	500	0	500	500
14	0.3486	118	382	382	0	382	382
15	0.3486	118	382	382	0	382	382
16		0	500	500	0	500	500
17	0.3486	118	382	382	0	382	382
18		0	500	500	450	50	50
19	0.3486	118	382	382	0	382	382
20		0	500	500	0	500	500
21	0.3486	118	382	382	0	382	382
22		0	500	500	0	500	500
23	0.3486	118	382	382	0	382	382
24		0	500	500	0	500	500
25	0.3486	118	382	382	450	-68	0
26		0	500	500	0	500	500
27	0.3486	118	382	382	0	382	382
28	0.3486	118	382	382	0	382	382
29	0.3486	118	382	382	0	382	382
30	0.3486	118	382	382	0	382	382

Table 11: Storage Analysis for Structure A during November. Daily demand set to 100 gallons/day

NOVEMBER	Rain (inch)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6444	218	600	500	0	500	500
2	0.6444	218	718	500	450	50	50
3		0	50	50	0	50	50
4	0.6444	218	268	268	0	268	268
5	0.6444	218	485	485	0	485	485
6		0	485	485	0	485	485
7	0.6444	218	703	500	0	500	500
8	0.6444	218	718	500	0	500	500
9		0	500	500	450	50	50
10		0	50	50	0	50	50
11		0	50	50	0	50	50
12	0.6444	218	268	268	0	268	268
13	0.6444	218	485	485	0	485	485
14	0.6444	218	703	500	0	500	500
15		0	500	500	0	500	500
16	0.6444	218	718	500	450	50	50
17	0.6444	218	268	268	0	268	268
18	0.6444	218	485	485	0	485	485
19		0	485	485	0	485	485
20		0	485	485	0	485	485
21	0.6444	218	703	500	0	500	500
22	0.6444	218	718	500	0	500	500
23		0	500	500	450	50	50
24	0.6444	218	268	268	0	268	268
25		0	268	268	0	268	268
26	0.6444	218	485	485	0	485	485
27		0	485	485	0	485	485
28	0.6444	218	703	500	0	500	500
29	0.6444	218	718	500	0	500	500
30		0	500	500	450	50	50

Table 12: Storage Analysis for Structure A during December. Daily demand set to 100 gallons/day

DECEMBER	Rain (inch)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6844	231	281	281	0	281	281
2	0.6844	231	512	500	0	500	500
3		0	500	500	0	500	500
4	0.6844	231	731	500	0	500	500
5	0.6844	231	731	500	0	500	500
6		0	500	500	0	500	500
7	0.6844	231	731	500	450	50	50
8		0	50	50	0	50	50
9	0.6844	231	281	281	0	281	281
10	0.6844	231	512	500	0	500	500
11		0	500	500	0	500	500
12	0.6844	231	731	500	0	500	500
13		0	500	500	0	500	500
14	0.6844	231	731	500	450	50	50
15	0.6844	231	281	281	0	281	281
16	0.6844	231	512	500	0	500	500
17		0	500	500	0	500	500
18	0.6844	231	731	500	0	500	500
19	0.6844	231	731	500	0	500	500
20	0.6844	231	731	500	0	500	500
21		0	500	500	450	50	50
22	0.6844	231	281	281	0	281	281
23		0	281	281	0	281	281
24	0.6844	231	512	500	0	500	500
25	0.6844	231	731	500	0	500	500
26		0	500	500	0	500	500
27	0.6844	231	731	500	0	500	500
28	0.6844	231	731	500	450	50	50
29		0	50	50	0	50	50
30	0.6844	231	281	281	0	281	281

Structure B

Table 13: Storage Analysis for Structure B during January. Daily demand set to 100 gallons/day

JANUARY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5181	190	190	190	100	90	90
2	0.5181	190	280	280	100	180	180
3	0.5181	190	370	300	100	200	200
4	0.5181	190	390	300	100	200	200
5		0	200	200	100	100	100
6	0.5181	190	290	290	100	190	190
7		0	190	190	100	90	90
8	0.5181	190	280	280	100	180	180
9	0.5181	190	370	300	100	200	200
10		0	200	200	100	100	100
11	0.5181	190	290	290	100	190	190
12	0.5181	190	380	300	100	200	200
13	0.5181	190	390	300	100	200	200
14	0.5181	190	390	300	100	200	200
15		0	200	200	100	100	100
16	0.5181	190	290	290	100	190	190
17		0	190	190	100	90	90
18	0.5181	190	280	280	100	180	180
19		0	180	180	100	80	80
20	0.5181	190	270	270	100	170	170
21	0.5181	190	360	300	100	200	200
22	0	0	200	200	100	100	100
23	0.5181	190	290	290	100	190	190
24	0	0	190	190	100	90	90
25	0.5181	190	280	280	100	180	180
26	0	0	180	180	100	80	80
27	0.5181	190	270	270	100	170	170
28	0.5181	190	360	300	100	200	200
29	0.5181	190	390	300	100	200	200
30	0	0	200	200	100	100	100

Table 14: Storage Analysis for Structure B during February. Daily demand set to 100 gallons/day

FEBRUARY	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5008	184	284	284	100	184	184
2		0	184	184	100	84	84
3	0.5008	184	267	267	100	167	167
4		0	167	167	100	67	67
5		0	67	67	100	-33	0
6	0.5008	184	184	184	100	84	84
7		0	84	84	100	-16	0
8		0	0	0	100	-100	0
9	0.5008	184	184	184	100	84	84
10		0	84	84	100	-16	0
11		0	0	0	100	-100	0
12	0.5008	184	184	184	100	84	84
13	0.5008	184	267	267	100	167	167
14		0	167	167	100	67	67
15	0.5008	184	251	251	100	151	151
16		0	151	151	100	51	51
17	0.5008	184	234	234	100	134	134
18	0.5008	184	318	300	100	200	200
19		0	200	200	100	100	100
20	0.5008	184	284	284	100	184	184
21	0.5008	184	367	300	100	200	200
22		0	200	200	100	100	100
23	0.5008	184	284	284	100	184	184
24	0.5008	184	367	300	100	200	200
25		0	200	200	100	100	100
26	0.5008	184	284	284	100	184	184
27		0	184	184	100	84	84
28		0	84	84	100	-16	0
29	0.5008	184	184	184	100	84	84
30		0	84	84	100	-16	0

Table 15: Storage Analysis for Structure B during March. Daily demand set to 100 gallons/day

MARCH	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.4385	161	161	161	100	61	61
2	0.4385	161	221	221	100	121	121
3		0	121	121	100	21	21
4	0.4385	161	182	182	100	82	82
5		0	82	82	100	-18	0
6	0.4385	161	161	161	100	61	61
7	0.4385	161	221	221	100	121	121
8		0	121	121	100	21	21
9	0.4385	161	182	182	100	82	82
10	0.4385	161	243	243	100	143	143
11		0	143	143	100	43	43
12	0.4385	161	204	204	100	104	104
13		0	104	104	100	4	4
14	0.4385	161	164	164	100	64	64
15		0	64	64	100	-36	0
16	0.4385	161	161	161	100	61	61
17		0	61	61	100	-39	0
18	0.4385	161	161	161	100	61	61
19	0.4385	161	221	221	100	121	121
20		0	121	121	100	21	21
21	0.4385	161	182	182	100	82	82
22		0	82	82	100	-18	0
23	0.4385	161	161	161	100	61	61
24		0	61	61	100	-39	0
25	0.4385	161	161	161	100	61	61
26	0.4385	161	221	221	100	121	121
27		0	121	121	100	21	21
28		0	21	21	100	-79	0
29		0	0	0	100	-100	0
30	0.4385	161	161	161	100	61	61

Table 16: Storage Analysis for Structure B during April. Daily demand set to 100 gallons/day

APRIL	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.421	154	215	215	100	115	115
2		0	115	115	100	15	15
3		0	15	15	100	-85	0
4		0	0	0	100	-100	0
5		0	0	0	100	-100	0
6	0.421	154	154	154	100	54	54
7		0	54	54	100	-46	0
8	0.421	154	154	154	100	54	54
9		0	54	54	100	-46	0
10	0.421	154	154	154	100	54	54
11		0	54	54	100	-46	0
12	0.421	154	154	154	100	54	54
13	0.421	154	209	209	100	109	109
14		0	109	109	100	9	9
15	0.421	154	163	163	100	63	63
16	0.421	154	217	217	100	117	117
17		0	117	117	100	17	17
18	0.421	154	172	172	100	72	72
19		0	72	72	100	-28	0
20	0.421	154	154	154	100	54	54
21	0.421	154	209	209	100	109	109
22		0	109	109	100	9	9
23		0	9	9	100	-91	0
24	0.421	154	154	154	100	54	54
25		0	54	54	100	-46	0
26	0.421	154	154	154	100	54	54
27	0.421	154	209	209	100	109	109
28		0	109	109	100	9	9
29	0.421	154	163	163	100	63	63
30	0.421	154	217	217	100	117	117

Table 17: Storage Analysis for Structure B during May. Daily demand set to 100 gallons/day

MAY	Rain(inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6579	241	359	300	100	200	200
2	0.6579	241	441	300	100	200	200
3		0	200	200	100	100	100
4	0.6579	241	341	300	100	200	200
5		0	200	200	100	100	100
6	0.6579	241	341	300	100	200	200
7	0.6579	241	441	300	100	200	200
8	0.6579	241	441	300	100	200	200
9	0.6579	241	441	300	100	200	200
10		0	200	200	100	100	100
11	0.6579	241	341	300	100	200	200
12	0.6579	241	441	300	100	200	200
13	0.6579	241	441	300	100	200	200
14		0	200	200	100	100	100
15	0.6579	241	341	300	100	200	200
16	0.6579	241	441	300	100	200	200
17		0	200	200	100	100	100
18		0	100	100	100	0	0
19	0.6579	241	241	241	100	141	141
20	0.6579	241	382	300	100	200	200
21		0	200	200	100	100	100
22	0.6579	241	341	300	100	200	200
23	0.6579	241	441	300	100	200	200
24		0	200	200	100	100	100
25	0.6579	241	341	300	100	200	200
26		0	200	200	100	100	100
27	0.6579	241	341	300	100	200	200
28		0	200	200	100	100	100
29	0.6579	241	341	300	100	200	200
30		0	200	200	100	100	100

Table 18: Storage Analysis for Structure B during June. Daily demand set to 100 gallons/day

JUNE	Rain(inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.4832	177	277	277	100	177	177
2		0	177	177	100	77	77
3	0.4832	177	254	254	100	154	154
4		0	154	154	100	54	54
5	0.4832	177	231	231	100	131	131
6		0	131	131	100	31	31
7	0.4832	177	209	209	100	109	109
8	0.4832	177	286	286	100	186	186
9	0.4832	177	363	300	100	200	200
10		0	200	200	100	100	100
11	0.4832	177	277	277	100	177	177
12	0.4832	177	354	300	100	200	200
13	0.4832	177	377	300	100	200	200
14	0.4832	177	377	300	100	200	200
15	0.4832	177	377	300	100	200	200
16		0	200	200	100	100	100
17	0.4832	177	277	277	100	177	177
18	0.4832	177	354	300	100	200	200
19	0.4832	177	377	300	100	200	200
20		0	200	200	100	100	100
21	0.4832	177	277	277	100	177	177
22		0	177	177	100	77	77
23	0.4832	177	254	254	100	154	154
24	0.4832	177	331	300	100	200	200
25	0.4832	177	377	300	100	200	200
26		0	200	200	100	100	100
27	0.4832	177	277	277	100	177	177
28	0.4832	177	354	300	100	200	200
29	0.4832	177	377	300	100	200	200
30	0.4832	177	377	300	100	200	200

Table 19: Storage Analysis for Structure B during July. Daily demand set to 100 gallons/day

JULY	Rain(inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6787	249	449	300	100	200	200
2		0	200	200	100	100	100
3	0.6787	249	349	300	100	200	200
4		0	200	200	100	100	100
5	0.6787	249	349	300	100	200	200
6	0.6787	249	449	300	100	200	200
7		0	200	200	100	100	100
8	0.6787	249	349	300	100	200	200
9	0.6787	249	449	300	100	200	200
10		0	200	200	100	100	100
11	0.6787	249	349	300	100	200	200
12	0.6787	249	449	300	100	200	200
13		0	200	200	100	100	100
14	0.6787	249	349	300	100	200	200
15	0.6787	249	449	300	100	200	200
16	0.6787	249	449	300	100	200	200
17		0	200	200	100	100	100
18	0.6787	249	349	300	100	200	200
19	0.6787	249	449	300	100	200	200
20		0	200	200	100	100	100
21	0.6787	249	349	300	100	200	200
22		0	200	200	100	100	100
23		0	100	100	100	0	0
24	0.6787	249	249	249	100	149	149
25	0.6787	249	398	300	100	200	200
26		0	200	200	100	100	100
27	0.6787	249	349	300	100	200	200
28	0.6787	249	449	300	100	200	200
29	0.6787	249	449	300	100	200	200
30		0	200	200	100	100	100

Table 20: Storage Analysis for Structure B during August. Daily demand set to 100 gallons/day

AUGUST	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.5209	191	291	291	100	191	191
2		0	191	191	100	91	91
3	0.5209	191	282	282	100	182	182
4	0.5209	191	373	300	100	200	200
5	0.5209	191	391	300	100	200	200
6		0	200	200	100	100	100
7	0.5209	191	291	291	100	191	191
8		0	191	191	100	91	91
9	0.5209	191	282	282	100	182	182
10	0.5209	191	373	300	100	200	200
11		0	200	200	100	100	100
12	0.5209	191	291	291	100	191	191
13		0	191	191	100	91	91
14	0.5209	191	282	282	100	182	182
15	0.5209	191	373	300	100	200	200
16		0	200	200	100	100	100
17	0.5209	191	291	291	100	191	191
18		0	191	191	100	91	91
19	0.5209	191	282	282	100	182	182
20		0	182	182	100	82	82
21	0.5209	191	273	273	100	173	173
22	0.5209	191	364	300	100	200	200
23		0	200	200	100	100	100
24	0.5209	191	291	291	100	191	191
25	0.5209	191	382	300	100	200	200
26		0	200	200	100	100	100
27	0.5209	191	291	291	100	191	191
28	0.5209	191	382	300	100	200	200
29	0.5209	191	391	300	100	200	200
30		0	200	200	100	100	100

Table 21: Storage Analysis for Structure B during September. Daily demand set to 100 gallons/day

SEPTEMBER	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallon)
1	0.2736	100	200	200	100	100	100
2	0.2736	100	201	201	100	101	101
3		0	101	101	100	1	1
4	0.2736	100	101	101	100	1	1
5	0.2736	100	101	101	100	1	1
6		0	1	1	100	-99	0
7	0.2736	100	100	100	100	0	0
8		0	0	0	100	-100	0
9	0.2736	100	100	100	100	0	0
10		0	0	0	100	-100	0
11		0	0	0	100	-100	0
12		0	0	0	100	-100	0
13		0	0	0	100	-100	0
14		0	0	0	100	-100	0
15	0.2736	100	100	100	100	0	0
16		0	0	0	100	-100	0
17	0.2736	100	100	100	100	0	0
18	0.2736	100	101	101	100	1	1
19	0.2736	100	101	101	100	1	1
20		0	1	1	100	-99	0
21	0.2736	100	100	100	100	0	0
22		0	0	0	100	-100	0
23	0.2736	100	100	100	100	0	0
24	0.2736	100	101	101	100	1	1
25	0.2736	100	101	101	100	1	1
26		0	1	1	100	-99	0
27	0.2736	100	100	100	100	0	0
28	0.2736	100	101	101	100	1	1
29		0	1	1	100	-99	0
30	0.2736	100	100	100	100	0	0

Table 22: Storage Analysis for Structure B during October. Daily demand set to 100 gallons/day

OCTOBER	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.3486	128	128	128	100	28	28
2	0.3486	128	156	156	100	56	56
3		0	56	56	100	-44	0
4	0.3486	128	128	128	100	28	28
5	0.3486	128	156	156	100	56	56
6		0	56	56	100	-44	0
7	0.3486	128	128	128	100	28	28
8		0	28	28	100	-72	0
9	0.3486	128	128	128	100	28	28
10		0	28	28	100	-72	0
11	0.3486	128	128	128	100	28	28
12	0.3486	128	156	156	100	56	56
13		0	56	56	100	-44	0
14	0.3486	128	128	128	100	28	28
15	0.3486	128	156	156	100	56	56
16		0	56	56	100	-44	0
17	0.3486	128	128	128	100	28	28
18		0	28	28	100	-72	0
19	0.3486	128	128	128	100	28	28
20		0	28	28	100	-72	0
21	0.3486	128	128	128	100	28	28
22		0	28	28	100	-72	0
23	0.3486	128	128	128	100	28	28
24		0	28	28	100	-72	0
25	0.3486	128	128	128	100	28	28
26		0	28	28	100	-72	0
27	0.3486	128	128	128	100	28	28
28	0.3486	128	156	156	100	56	56
29	0.3486	128	183	183	100	83	83
30	0.3486	128	211	211	100	111	111

Table 23: Storage Analysis for Structure B during November. Daily demand set to 100 gallons/day

NOVEMBER	Rain (inches)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallon)
1	0.6444	236	347	300	100	200	200
2	0.6444	236	436	300	100	200	200
3		0	200	200	100	100	100
4	0.6444	236	336	300	100	200	200
5	0.6444	236	436	300	100	200	200
6		0	200	200	100	100	100
7	0.6444	236	336	300	100	200	200
8	0.6444	236	436	300	100	200	200
9		0	200	200	100	100	100
10		0	100	100	100	0	0
11		0	0	0	100	-100	0
12	0.6444	236	236	236	100	136	136
13	0.6444	236	372	300	100	200	200
14	0.6444	236	436	300	100	200	200
15		0	200	200	100	100	100
16	0.6444	236	336	300	100	200	200
17	0.6444	236	436	300	100	200	200
18	0.6444	236	436	300	100	200	200
19		0	200	200	100	100	100
20		0	100	100	100	0	0
21	0.6444	236	236	236	100	136	136
22	0.6444	236	372	300	100	200	200
23		0	200	200	100	100	100
24	0.6444	236	336	300	100	200	200
25		0	200	200	100	100	100
26	0.6444	236	336	300	100	200	200
27		0	200	200	100	100	100
28	0.6444	236	336	300	100	200	200
29	0.6444	236	436	300	100	200	200
30		0	200	200	100	100	100

Table 24: Storage Analysis for Structure B during December. Daily demand set to 100 gallons/day

DECEMBER	Rain (inch)	Collection (gallons)	Storage + collection (gallons)	Available supply adjustment for tank size (gallons)	Demand (gallons)	Supply - Demand (gallons)	Storage (gallons)
1	0.6844	251	351	300	100	200	200
2	0.6844	251	451	300	100	200	200
3		0	200	200	100	100	100
4	0.6844	251	351	300	100	200	200
5	0.6844	251	451	300	100	200	200
6		0	200	200	100	100	100
7	0.6844	251	351	300	100	200	200
8		0	200	200	100	100	100
9	0.6844	251	351	300	100	200	200
10	0.6844	251	451	300	100	200	200
11		0	200	200	100	100	100
12	0.6844	251	351	300	100	200	200
13		0	200	200	100	100	100
14	0.6844	251	351	300	100	200	200
15	0.6844	251	451	300	100	200	200
16	0.6844	251	451	300	100	200	200
17		0	200	200	100	100	100
18	0.6844	251	351	300	100	200	200
19	0.6844	251	451	300	100	200	200
20	0.6844	251	451	300	100	200	200
21		0	200	200	100	100	100
22	0.6844	251	351	300	100	200	200
23		0	200	200	100	100	100
24	0.6844	251	351	300	100	200	200
25	0.6844	251	451	300	100	200	200
26		0	200	200	100	100	100
27	0.6844	251	351	300	100	200	200
28	0.6844	251	451	300	100	200	200
29		0	200	200	100	100	100
30	0.6844	251	351	300	100	200	200

Appendix G

Alternatives Analysis

Failure Modes and Effects Analysis (FMEA) Framework

Table 1: FMEA Framework for Ram Pump System

System Group	Part Name	Failure Mode(s)	Item Causing	Local Effect	End Effect	Probability (1-10)	Severity (1-4)	Risk Priority Number (Probability*Severity)	Detection Method, Provisions, and Remarks
Collection System	Diversion wall	Sliding failure	Soil friction overcome	Reduced river intake	Reduced delievery flowrate into supply tank	1	3	3	Can easily be prevented by anchoring and riprap
		Dislodging	Flowrate of river or large debris	Reduced river intake	Reduced delievery flowrate into supply tank	3	2	6	Can easily be replaced or resituated
	Filters	Clogging	Debris	Reduced river intake	Not meeting water demand	7	1	7	Easily avoided or rapidly fixed if does occur
Pump	Ram Pump	Check Valve Issue	Check Valve Mechanism	Stoppage of pressurizing chamber	Complete Stoppage of System	4	4	16	Replaceable component but would take time
		Clogging or low intake flowrate	Debris or Flowrate	Reduction in pressurizing chamber	Possible reduction to complete system shutdown.	4	3	12	Detachable to clean out and is unlikely to occur
		Foundation Failure	Erosion	Tilting of Ram Pump	Loss of efficency - failure	1	3	3	Increased
	Pipe Network	Dislodging	Human or Animal disturbance.	Broken Pipe or connection	Disturbance of supply momentarly	6	2	12	Easily avoided or rapidly fixed if does occur
Supply Tank	Tank	Cracking	Weathering	Leakage	Reduction of Storage	2	2	4	Visual Inspection
Filtration	5 Micron Mesh Filter	Clogging	Debris and particles larger than 5 Micron	Poor water treatment	Lowered quality of distributed water	4	2	8	Preventtion by routine cleaning and maintenance of the filter
Distrubution Network	Pipe Network	Loose pipes	Pressure	Leaking Water	Reduction of Flow	5	2	10	Reduced flow at the tap
							Average	8	

Table 2: FMEA Framework for Rainwater Harvesting Systems

System Group	Part Name	Failure Mode(s)	Item Causing	Local Effect	End Effect	Probability (1-10)	Severity (1-4)	Risk Priority Number (Probability*Severity)	Detection Method, Provisions or Remarks
Collection system	Gutters	Clogging	Heavy debris	Reduced flow to filter and tank	Lowered water supply	6	4	24	Can be prevented by periodic cleaning of the gutters
		Cracks	Time and heavy rain	Reduced flow to filter and tank	Lowered water supply	3	1	3	Proper Maintenance and timely replacement
	Roof	Large Rocks and Debris	Debris: leaves, insects, dust	Extra debris in filtration	Water not fit for drinking	4	3	12	Timely cleaning of the roofs
Filtration	Mesh Filter	Over flow	Heavy Rain	Water not properly filtered	Lowered water supply	4	1	4	N/A; only reduces collection
		Clogging	Heavy debris	Water not properly filtered	Lowered water supply	1	2	2	Filter should be cleaned periodically
	First Flush	Cracked pipe	Time and heavy rain	Collected water not delivered to tank	Lowered water supply	2	1	2	Replace the pipe
		Interior ball gets stuck	Malfunction of the rubber ball	Small partilces enter storage tank	Water not fit for drinking	1	2	2	Unscrew the assembly and remove the ball and reassemble it
Disinfection	In Line Chlorinator	Clogging	Poor mixing of Chlorine tablets and high flowrates	The chlorine tablet will not dissolve completely	Inconsistent Chlorination of the water	3	3	9	Unscrew and clean the chlorinator
Storage	Plastic Tank	Leakage	Cracking of the plastic	Loss of water availability	Water Demand might not be met completely	1	1	1	Use plastic sealant to cover the crack (Example: Flex Seal)
		Particle Build up in the bottom	Filtration system malfunction	Loss of water availability	Water Demand might not be met completely	1	3	3	Timely cleaning of the storage tank and filtration system
							Average	6	

Appendix H

Rainwater Harvesting 3D Model views

Figure 1: Structure B Front View

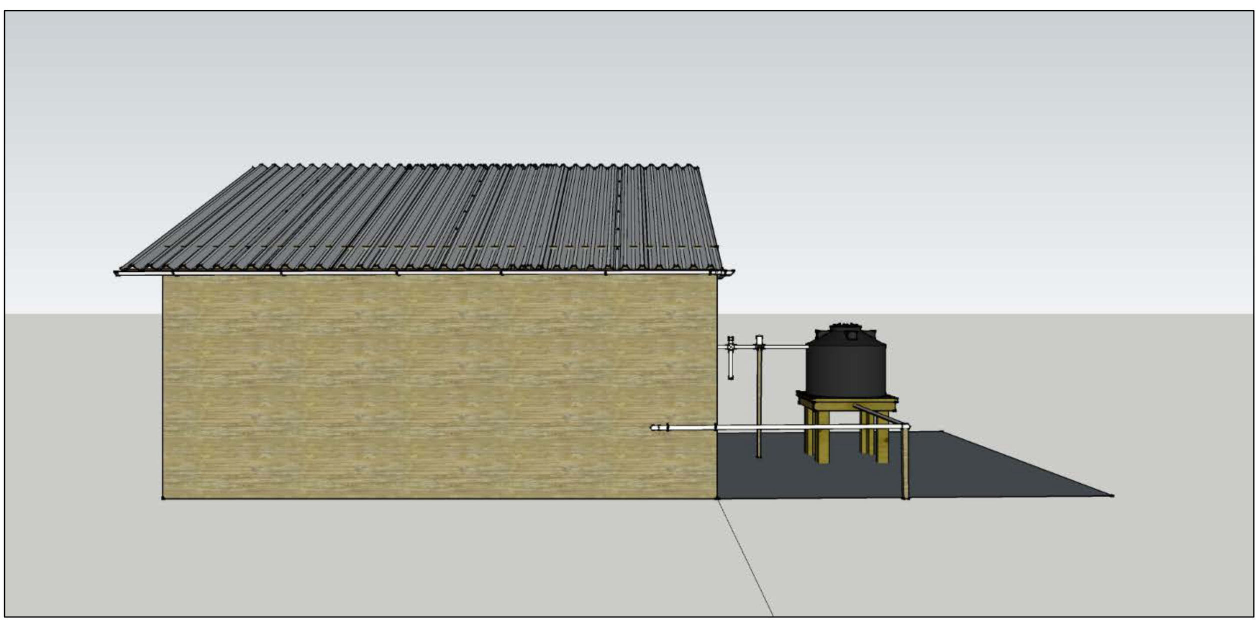


Figure 2: Structure B Left View

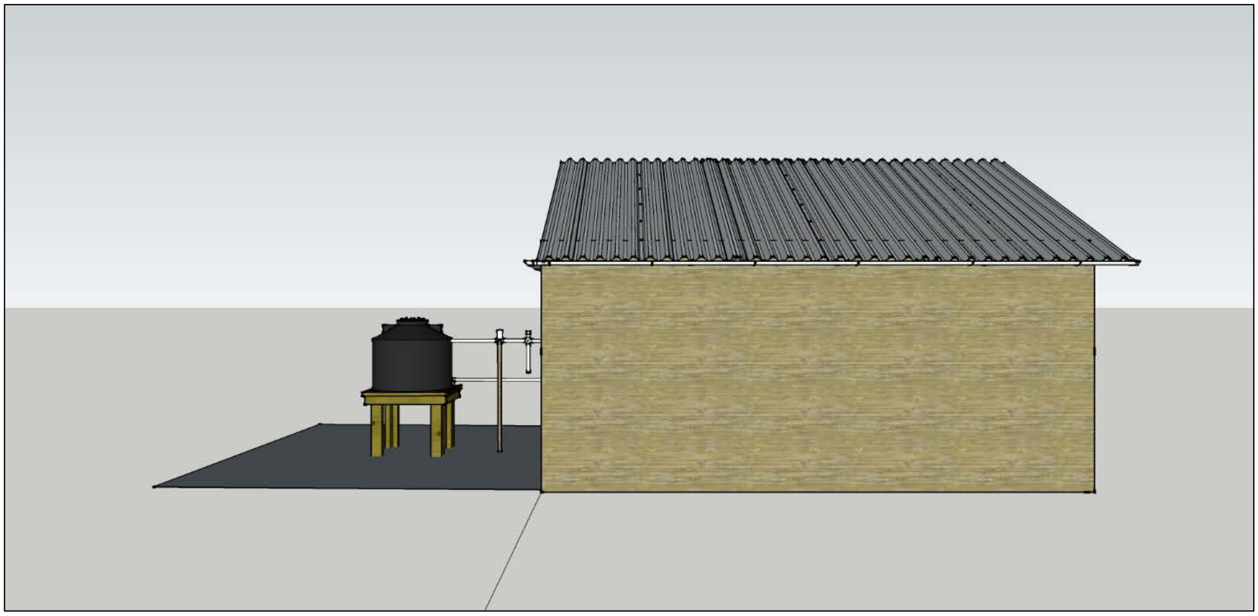


Figure 3: Structure B Right View

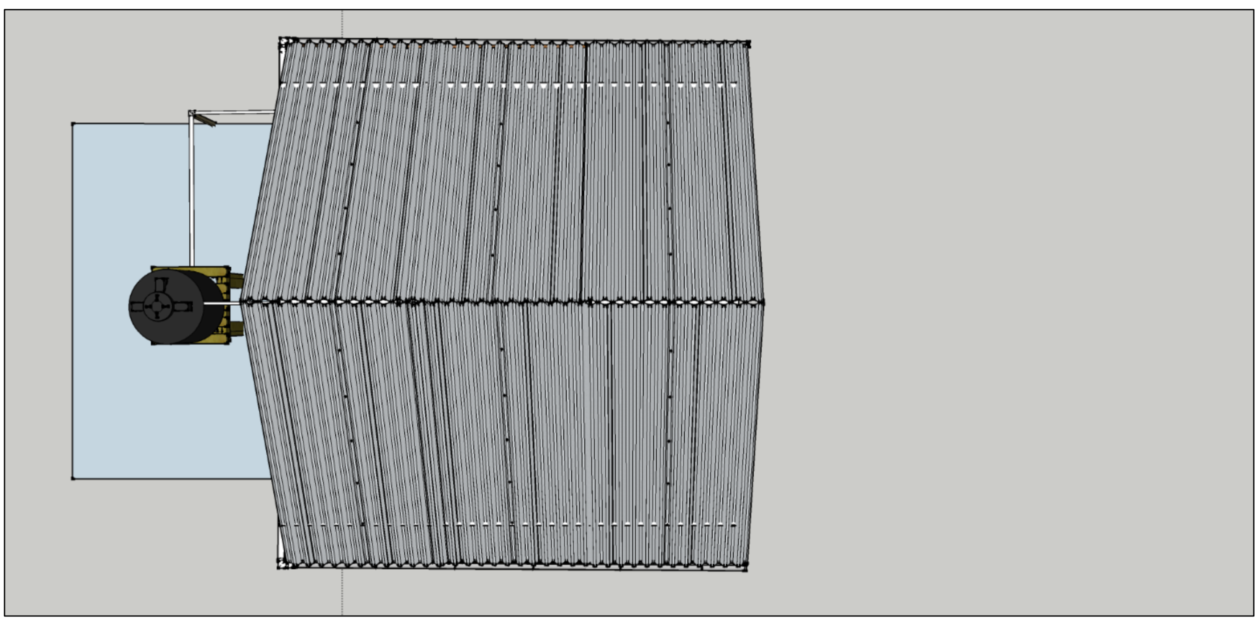


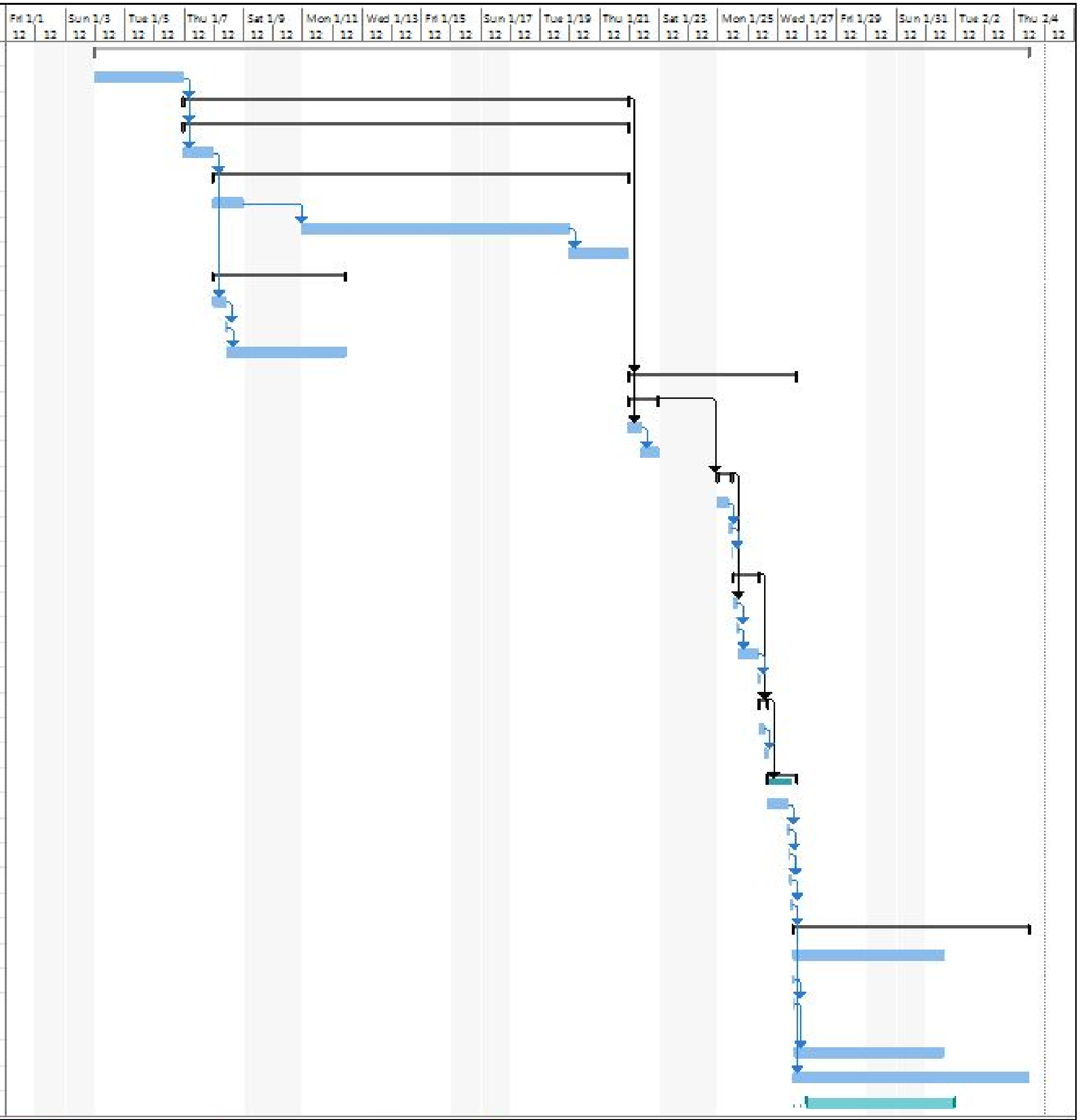
Figure 4: Structure B Top View

Appendix I

Construction Schedule

Rainwater Harvesting Systems Construction Schedule

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
0		iDesign Project	23.5 days	Mon 1/4/16	Thu 2/4/16	
1		Initiate Project	3 days	Mon 1/4/16	Wed 1/6/16	
2		Preliminary Steps	11 days	Thu 1/7/16	Thu 1/21/16	1
3		Purchase & Order Project Resources	11 days	Thu 1/7/16	Thu 1/21/16	1
4		Shopping & Purchasing in Almirante	1 day	Thu 1/7/16	Thu 1/7/16	1
5		Ordering locally unavailable material	10 days	Fri 1/8/16	Thu 1/21/16	4
6		Order Online	1 day	Fri 1/8/16	Fri 1/8/16	
7		Shipping to Pickup Location	7 days	Mon 1/11/16	Tue 1/19/16	6
8		Transport to Quebrada Pinzon	2 days	Wed 1/20/16	Thu 1/21/16	7
9		Site Planning	2.38 days	Fri 1/8/16	Tue 1/12/16	
10		Preparing PVC Gutter Pipes	2 hrs	Fri 1/8/16	Fri 1/8/16	4
11		Marking System Layout	1 hr	Fri 1/8/16	Fri 1/8/16	10
12		Wooden Stand Material Preperation	2 days	Fri 1/8/16	Tue 1/12/16	11
13		Construction	3.94 days	Fri 1/22/16	Wed 1/27/16	2
14		Gutter Installation	1 day	Fri 1/22/16	Fri 1/22/16	
15		Cleaning Roofs	2 hrs	Fri 1/22/16	Fri 1/22/16	2
16		Installing Gutter Supports & Gutters	6 hrs	Fri 1/22/16	Fri 1/22/16	15
17		Filtration System	0.5 days	Mon 1/25/16	Mon 1/25/16	14
18		Install Mesh Self Cleaning Filter	0.5 hrs	Mon 1/25/16	Mon 1/25/16	
19		Inline Chlorinator Hookup	3 hrs	Mon 1/25/16	Mon 1/25/16	18
20		Attach First Flush System	0.5 hrs	Mon 1/25/16	Mon 1/25/16	19
21		Erection of Tank Stand	0.69 days	Mon 1/25/16	Tue 1/26/16	
22		Dig Pile Holes	2.5 hrs	Mon 1/25/16	Mon 1/25/16	17
23		Place & Level Columns	1 hr	Mon 1/25/16	Mon 1/25/16	22
24		Connect Tank Platform to Columns	1 hr	Mon 1/25/16	Tue 1/26/16	23
25		Test Stability	1 hr	Tue 1/26/16	Tue 1/26/16	24
26		Tank Placement	0.75 days	Tue 1/26/16	Tue 1/26/16	21
27		Lifting Tank onto Stand	3 hrs	Tue 1/26/16	Tue 1/26/16	
28		Securing Tank	3 hrs	Tue 1/26/16	Tue 1/26/16	27
29		System Connection	1 day	Tue 1/26/16	Wed 1/27/16	26
30		Connect Gutter System to Mesh Filter	1 hr	Tue 1/26/16	Wed 1/27/16	
31		Connect Mesh Filter to First Flush System	1 hr	Wed 1/27/16	Wed 1/27/16	30
32		Connect First Flush to Inline Chlorinator	1 hr	Wed 1/27/16	Wed 1/27/16	31
33		Connect Inline Chlorinator to Tank	1 hr	Wed 1/27/16	Wed 1/27/16	32
34		1 Gallon Test	0.5 hrs	Wed 1/27/16	Wed 1/27/16	33
35		Initation of System Function	6 days	Wed 1/27/16	Thu 2/4/16	34
36		Education of maintance & saftey concerns	6 days	Wed 1/27/16	Thu 2/4/16	
37		Filter Systems	0.5 hrs	Wed 1/27/16	Wed 1/27/16	
38		Regular Inspection of Tank Stand & Failure Causes	1 hr	Wed 1/27/16	Wed 1/27/16	37
39		Chlorination Process	3 days	Wed 1/27/16	Mon 2/1/16	38
40		Allow Tank to Fill	6 days	Wed 1/27/16	Thu 2/4/16	34
41		Conclusion of Construction Project	3 days	Wed 1/27/16	Mon 2/1/16	36



Project: iDesign Project
Date: Tue 11/17/15

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