Design Solutions for Seasonal Water Scarcity in the Comarca Ngäbe-Buglé

Mujeres Fuertes Consultados

Michigan Technological University

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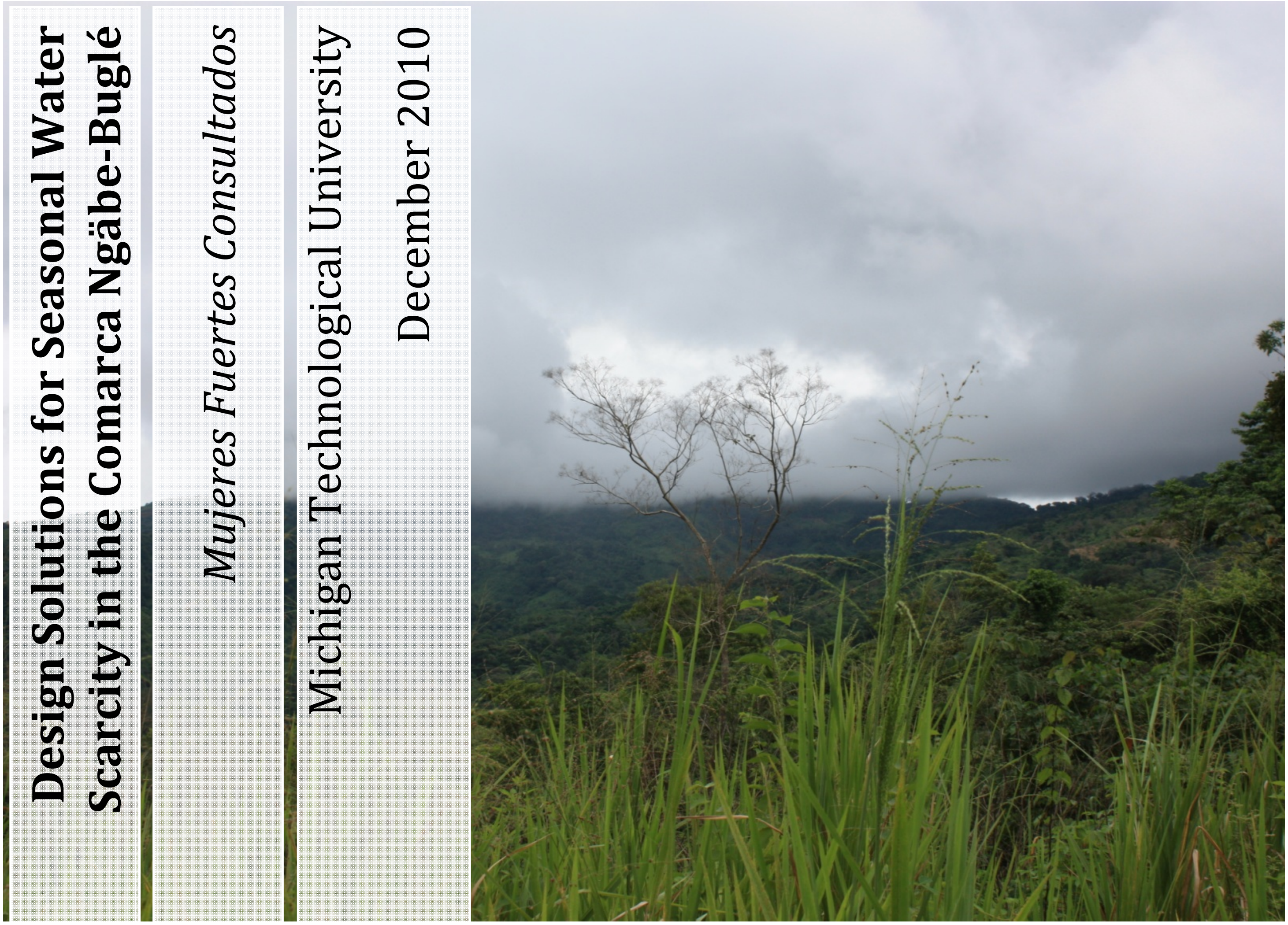

Civil and Environmental Engineering Department
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Disclaimer

This report, titled “Design Solutions for Seasonal Water Scarcity in the Comarca Ngäbe-Buglé”, represents the efforts of undergraduate students in the Civil and Environmental Engineering Department of Michigan Technological University. While students worked under the supervision and guidance of associated faculty members, the contents of this report should not be considered professional engineering.

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1.0 Executive Summary

Mujeres Fuertes Consultados has designed a water collection, storage and distribution system for an indigenous farmer in the Comarca Ngäbe-Buglé, a province of Panama, which would allow for crop production during the dry season. This farmer is currently serving as the Ngäbe counterpart to the Peace Corps volunteer that Mujeres Fuertes Consultados collaborated with. The team has also designed for the construction of rice terraces on his property.

The farmer's current method for irrigation does not provide enough water storage to allow for full crop production during the dry season, and the task of watering his crops is very labor intensive.

The system that has been designed is adaptable to other farmers in the region. Being able to irrigate in the dry season can help to alleviate famine. Farmers will also be able to sell their extra crops at local farmer's markets to earn money that can be used to buy necessities. The rice terraces were designed to be utilized in the rainy season to supplement the vegetables already being grown on the farm.

The proposed design consists of two multi-barrel storage systems, each covered by a roof to allow for rainwater collection. These will then be connected to hosing to form an irrigation system. The total cost of the system is estimated to be $312.60, and the total time for construction is estimated to be 48 days, which includes ordering materials.

2.0 Introduction

Mujeres Fuertes Consultados (MFC) is a student design group, a part of Michigan Technological University's iDesign program. The iDesign program fulfills degree requirements of a capstone design project for senior level students. The group traveled down to Panama for two weeks in August 2010 in order to talk to farmers in the Comarca Ngäbe-Buglé, an indigenous community, to gather information on their agricultural practices and identify a design project.

The team worked with a Peace Corps Volunteer, Erin Kelley, to identify the need for a rainwater collection and irrigation system to help alleviate food scarcity in the area. Erin lives and works with local farmers in Salto Dupí, a small village in the Comarca, to increase productivity on their farms. She also assists these farmers with the development of their business and entrepreneurial skills.

Farmers in the Comarca Ngäbe-Buglé are currently trying to find ways to increase crop production during the dry season (December – April). Many crops cannot tolerate the minimal amount of rainfall and high temperature during this period. This food scarcity leads to a famine season. By collecting rainfall when it is plentiful in the rainy season (May-November), water intensive crops can be irrigated through the dry season. This should alleviate some of the famine that has been experienced in the area.

MFC worked to design a rainwater collection, storage, and distribution system with a low initial cost, simple maintenance, and the ability to expand or change the system if the crops were increased or the plot shape was different. The team worked with one farmer in the Comarca, Erin's counterpart, to design a system specifically for him, but adaptable for other farmers in the region. The Peace Corps Volunteer (PCV) has received funding from an agency in the area to pay for at least one system, which will serve as a model to show the other farmers in the area that rainwater collection and storage is a viable solution for irrigating during the dry season.

Rice is a main staple in diets of people throughout the region. A few local farmers have constructed rice tanks on their property. The storage system that will be implemented to provide water during the dry season and will also be utilized for extra water during the rainy season when the farmer will be growing rice. Due to the steep slope of his farm, the farmer will need to utilize a terrace configuration.

This report describes Mujeres Fuertes Consultados' recommendations for a design solution that will help alleviate famine caused by seasonal water scarcity. Included are design analyses, cost estimates and a construction guide. Also included are the results from the August 2010 site assessment conducted in Panama.

3.0 Background

The Comarca Ngäbe-Buglé of Panama contains the largest concentration of Ngäbe-Buglé people -indigenous tribes of Panama. The Ngäbe-Buglé Comarca was formed in 1997 and has an approximate population of 169,000. Many communities in this region depend on agriculture for both sustenance and income. It has been brought to the attention of the Peace Corps volunteers in the area that the seasonal weather patterns are currently preventing farmers from fully utilizing their land throughout the entire dry season. The lack of rain during this season results in "famine months" when there are very few crops to harvest.

Erin Kelley, the Peace Corps volunteer who MFC collaborated with in Panama, lives in Salto Dupí. Salto Dupí is near the southern border of the Comarca Ngäbe-Buglé, near the Chiriquí Province. The nearest full service town, containing a hardware store, is directly south of Salto Dupí in San Felix.

The Ngäbe-Buglé Comarca is not fully recognized as an independent province by the Panamanian Government. While it is acknowledged that the Ngäbe-Buglé people own the land surface, anything under the topsoil is still owned by the Panamanian Government. Figure 1 shows the locations of all of the provinces and comarcas in Panama. The "star" shows the location of Salto Dupí in relation to some of the larger cities.

Figure 1: Comarcas and Provinces of Panamá (Image courtesy of http://allaboutPanamálife.com)

The Ngäbe-Buglé are two distinct peoples: the Ngäbe, who speak Ngäbere; and the Buglé, who speak Bugléré. The Ngäbe people the design team worked with were subsistence farmers. Some men, however, work outside the community in construction or own a store. This usually happens when the family does not own land or they are sending a child to high school.

The Ngäbe live in huts made from local wood and zinc-coated roofs. They eat rice and beans which is sometimes mixed with locally grown vegetables, such as *ñampi* (a starchy potato-like root) or spinach and tomatoes. Many raise chickens and pigs, and those with more money sometimes have cows or a horse. The women care for the home, raise the children, and make *chacaras* and *naguas*. *Chacaras* are woven shoulder bags traditionally made from Pita fibers and now more consistently made from cotton or nylon, and *naguas* are the traditional colorful dress for women and girls. The women, however, have very little authority within the family and the community. The men work the agricultural land with machetes and harvest a large variety of crops including the following: plantain, banana, orange, lemon, corn, rice, green pepper, tomato, pifa, *ñampi*, and pineapple. Most of this agricultural work is subsistence farming (Kelley, 2009).

Subsistence farming is a form of agriculture that allows the farmer to be self-sufficient. These farmers focus on growing enough food to support their family by planting various types of crops throughout the year. Instead of concentrating on a few crops and selling the surplus, they plant many varieties and consume most of the harvest. These families strive to provide for themselves as opposed to relying on other farmers and buying their goods from the market. Once they are successful in being able to feed their own family, many farmers try to expand their farms a little to allow for excess planting of a few of their crops. They then can sell these crops to obtain money for other necessities such as clothing and house wares.

Although the climate of this area is ideal for agriculture, the hydrologic cycle does not allow for crop growth throughout the entire year. During the rainy season, from May to November, the average rainfall is about 690 mm (27.2 in) per month. However, during the dry season, from December to April, there is an average rainfall of only 85.0 mm (3.35 in) per month; however, it is much lower from January through March (Etesa, 2009). Crops are unable to grow during the beginning of the year because of the low rainfall, leaving subsistence farmers without food until they are able to harvest their crops at the end of July. The months between harvesting (April-July) are known as the “famine months” because there is very little food.

The design team spent several days working on the farm of Erin’s counterpart, a subsistence farmer who lives in Nueve Esperanza, a village next to Salto Dupí. The farm is on a steep hill with two small rivers flowing around it. Both of these rivers dry to a trickle during the dry season and are located down steep paths about 300 meters from the farm. Many different types of plants are harvested on the farm. The vegetable gardens contain green peppers, mint, oregano, tomatoes, spinach, peanut, elephant ear, and green beans, and there are also two larger cornfields. Throughout the property the farmer is able to plant and harvest banana, cacao, plantain, pineapple, okra, yucca, *ñampi*, oranges, lemons, avocado, quince, lemongrass, palm, coconut, pifa, and sugar cane. The farmer is a member of a local organization called OPAMO (Organization of Agricultural Producers with Organic Methods). This community group formed about 2 years ago and has received training on fertilizers, seeds, food etc. from various institutions (Kelley, 2009). See Appendix F for a guide of crops on the farm.

Erin's counterpart has been a subsistence farmer for many years. In the past three years he has switched from farming with chemicals to organic farming techniques and relies on natural solutions to agricultural issues like insect repellent, fertilizer, and water retention. He utilizes the natural bug repellant properties of a tree in the *Tanacetum* genus of the *Asteraceae* family, the same family as sunflowers (USDA, 2010). He also has planted vetiver grass in rows across his plot of land to slow the flow of water and increase infiltration. Another storm water management method he uses is *maniflorajaro*, a ground cover related to the peanut. This plant is not harvested, but is consumed by the chickens. It prevents soil erosion and reduces storm water runoff. These storm water management techniques are incorporated into the final design for the rice tanks.

The farmer also uses several organic farming methods to increase the nutrients and organic content of his soil. Mulch is used over the entire plot to build up the organic content. Any weeds or old crops that are cut down are placed as mulch for increased water retention. He is also raising California Red Worms for his gardens in a plastic tub with composting material. He will place these worms in his gardens to aerate the soil and increase the nutrient content of the soil.

The farmer owns a 50-gallon barrel which he fills with smaller pails of rainwater collected under his roof. This only has enough storage capacity to irrigate his crops adequately for one month during the dry season. The barrel is located near the crops, down a steep slope from his house. To irrigate his crops he siphons the water from the barrel into a used fumigator backpack to individually spray them. This is a labor intensive process and an inefficient method for irrigation. MFC has created a design to allow for a more efficient collection system and a greater storage capacity.

4.0 Site Assessment

A site assessment was performed during Mujeres Fuertes Consultados' visit to the Comarca Ngäbe-Buglé in August 2010. A typical Ngäbe farm was visited and used as the design site for the project. Mujeres Fuertes Consultados completed topographic surveys to determine distances, angles, and slopes of the property and the agricultural plots that require irrigation. GPS coordinates were also taken around the entire perimeter of the property to determine the area. These points also allowed for elevations to be estimated. Soil characteristics were determined and the available area for the terraced rice paddies was measured. Rice tanks at another farm in the area were also investigated.

Mujeres Fuertes Consultados also held many conversations with the Ngäbe people in the area. From these conversations it was learned that many of the farmers in the area experience the same farming adversities: poor soil, steep slopes, and the difficulty of growing during the dry season. MFC learned that if quality crops could be grown during the dry season, there would be a market for them and the payoff would be worth it.

MFC also held a roundtable discussion with the OPAMO farmers. MFC described the technical specifications of a precipitation harvesting system and irrigation system, and the OPAMO farmers asked questions regarding the materials needed and their costs.

4.1 Irrigation System

Survey data collected in Panama was input into AutoCAD for further analysis. After these points were input, labels identifying the types of points were added to determine where the gardens were located. These were used to find a slope that specifically applied to the area where the tanks would be located for each garden. The survey points were also used to determine the size of the area where the rice will be grown. The slope and area found were then used to determine the feasibility of constructing terraces on the lower portion of the farm. Once the system was designed it was drawn in AutoCAD to provide a visual and to verify the system would fit. See Figure 2.

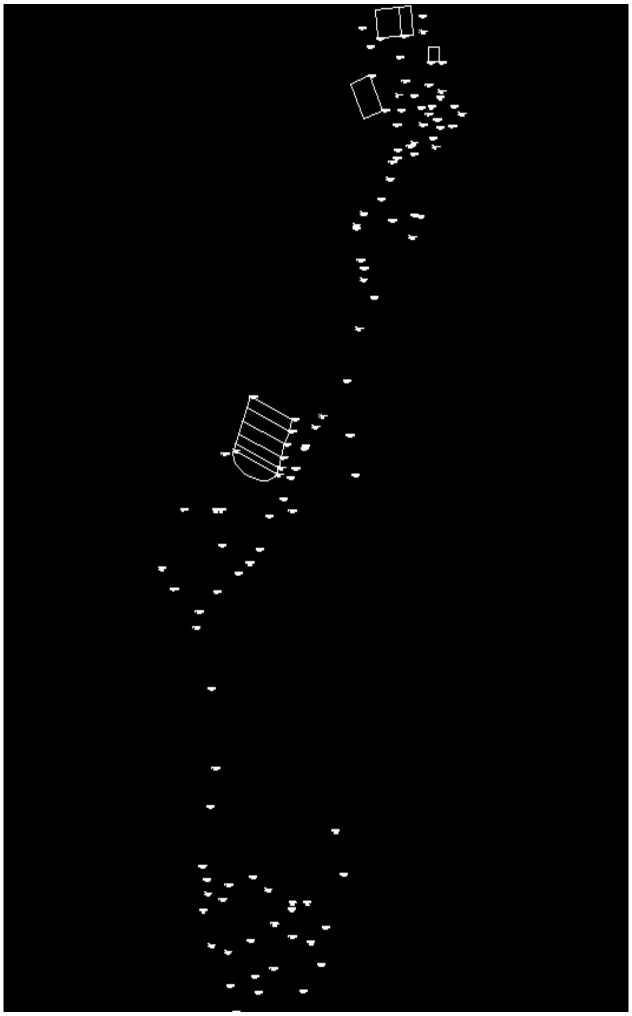

Figure 2: AutoCAD rendition of survey points on farm property

4.2 Rice Tanks

The soil characteristics, land area, and slope of the land were analyzed to evaluate the area of land where the farmer wanted to place rice paddies. During MFC's time at the farmer's property, the team studied the soil and determined that it was primarily clay. The soil felt very smooth and not gritty. If the soil was rolled into a ball, strong finger pressure was needed to be applied to break it. The in situ soil was fairly compacted and could be indented by a thumb applying pressure.

Mujeres Fuertes Consultados also visited a local farmer who was in the aquaculture business. He had several fish tanks on his property, along with a rice tank. The rice tank was dug into the ground and water was fed to it via pipes from the river nearby. MFC learned that rice seeds were first planted in a nursery bed and when they were several inches tall they would be planted in the tank. The tank was prepared by digging into the soil. Water was then added and stomped into the soil to create mud. When the excess water was drained, the rice would be planted, and then the tanks would be flooded. The tanks would remain flooded for most of the rice’s life cycle, which was about 3 months. MFC was able to participate in preparing the rice tank by stomping the mud.

5.0 Design Options and Analysis

The irrigation system designed for the Ngäbe-Buglé farmers consists of three main design components: the precipitation collection system, the rainwater storage system, and the gravity-fed drip irrigation system. Water will be collected on zinc-covered roofs that are common in the area, with the use of homemade bamboo gutters. The water will then empty into the storage system consisting of several 50-gallon polyethylene barrels connected in series with PVC piping. The water can be collected throughout the rainy season, and in the dry season the water can be released into the irrigation system. The irrigation system is composed of garden hosing with small holes punched in it.

5.1 Collection System Design

In order to allow for rainwater collection, a roof structure and gutter system has been designed.

5.1.1 Roof Structure

A bamboo frame, similar to ones already used in local construction, will be utilized to support the roofing material. The barrels will be placed beneath the roof to slow deterioration due to exposure to the sun and rain. The direction of the slope of the roof will consider the movement of the sun, and be positioned in the most advantageous way to shade the barrels for a maximum amount of time. The lifespan of the barrels will likely be decreased without protection from the elements, but they should still last well over 10 years. The structure will be placed in an open area where tree cover will not hinder precipitation collection. The storage tanks will be placed directly upslope of each garden plot to reduce excessive pressure and flow through the emitters and also to minimize the amount of hosing required.

One ten-foot length of corrugated zinc roofing will be nailed to the bamboo structure and placed perpendicular to the slope of the hill at each of the two collection locations upslope of the vegetable plots. This will minimize the amount of ground material that must be excavated to create a level area for the tanks. The corrugations in the roofing material will be placed parallel to the slope and will therefore direct the flow of water, not obstruct it. The slope of the roof should be approximately a one foot rise over the ten foot length of the roofing. This keeps the surface area available to catch precipitation as large as possible, and prevents the water from flowing into the gutter too quickly, which could lead to damage of the gutter and supports.

The structure will be made of bamboo, locally available on most farmers' land for no cost at all. Corrugated zinc roofing may be purchased from *ferreterías*, or hardware stores, in San Felix for $8 for each 10 ft by 3.5 ft section.

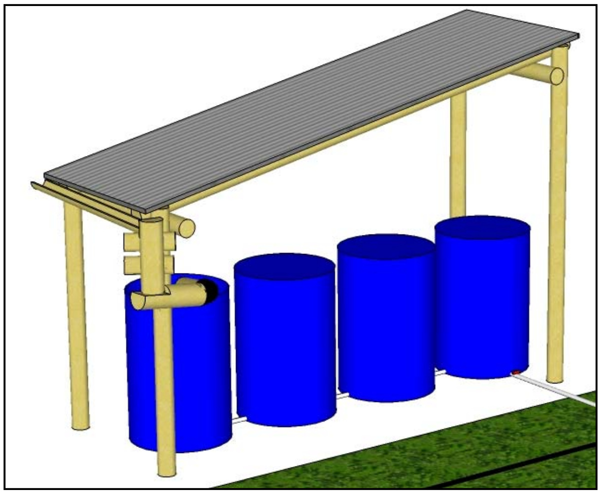

Figure 3: Roof structure design drawing

5.1.2 Gutter Design

There are several options for gutter supports. The most common design in the region is to dig two posts into the ground in front of the roof structure, each with a v-shaped notch to hold a piece of split bamboo that will serve as the gutter. Another option is for the gutter to be lashed to the bamboo girder of the structure that lies directly beneath the edge of the roof with wire or rope. The final option, as well as the least expensive, is to attach sturdy branches to the bamboo beams that run parallel to the length of the roofing, and then attach the split bamboo between a hooked portion of the branch and the beam.

A small section of screen should be placed between the end of the gutter and the downspout to avoid clogging. This should be checked and cleared periodically to avoid water backup.

The downspout will be constructed using bamboo sections and a rubber joint. A rubber joint (a piece of rubber material that can be manipulated to form elbows between bamboo sections) will connect the gutter to the first piece of bamboo and then more rubber connections can be used to connect more sections of bamboo if needed. This will create a bendable and moveable downspout. Wire and caulk can be utilized to ensure efficient connections and seals. The downspout will end when it reaches one of the 50-gallon barrels. It will be inserted into the lid of the barrel and sealed to prevent contamination of the water in the barrel.

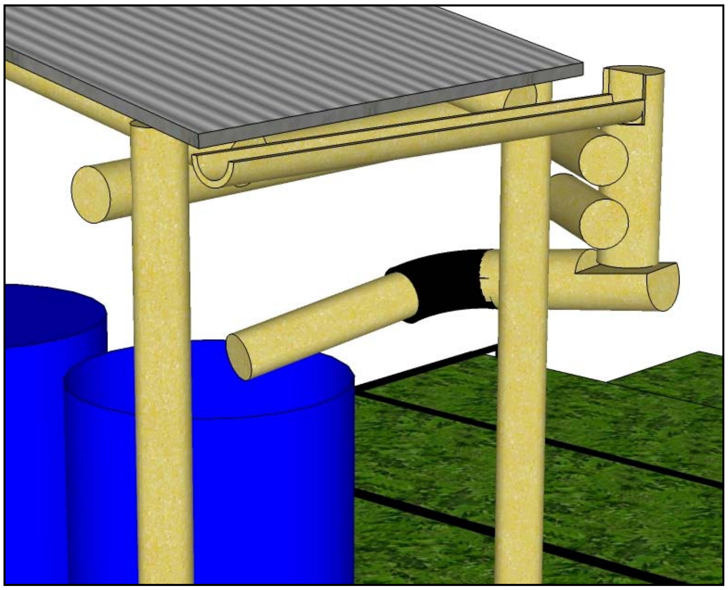

Figure 4: Gutter system design drawing; not shown are the branch supports for the gutter and the wire or lashing required to support the downspouts.

5.2 Storage System Design

Two options have been researched for possible water storage. One design option is a multi-50 gallon barrel system, and the other is a ferrocement tank.

5.2.1 Required Storage Capacity

A water budget for the upper plot was calculated in order to verify the farmer's estimation for crop water usage. A water budget for the lower plot was also calculated to determine the amount of water needed for the beans during the dry season. The Food and Agricultural Organization of the United Nations (FAO) developed a process for calculating the water budgets of various crops (Brouwer & Heibloem, 1986). The irrigation water needs (IN) for the tomatoes and spinach in the upper plot, along with the beans in the lower plot, were found using the following equation:

$$IN = ET_{crop} - Pe \qquad \text{Equation 1}$$

The amount of water that a crop needs (ET_{crop}) varies throughout its different growth stages. This is accounted for with the use of a crop factor. This factor is multiplied by the number of days in which the crop is in the particular growth stage to obtain the total amount of water needed. The effective rainfall (Pe) is calculated using one of the following equations:

$$Pe = 0.8P - 25\ if\ P > 75\ mm/month \qquad \text{Equation 2}$$

$$Pe = 0.6P - 10\ if\ P < 75\ mm/month \qquad \text{Equation 3}$$

The variable P is the actual precipitation amount on the area.

It was assumed that the mulch has 85% efficiency in preventing evaporation (Brouwer et al., 1989). It was also assumed that the crops do not occupy the entire available area of the plot and that there was some open space between the crops; therefore, only 1/15 of the total area in the upper plot and 1/7 of the lower plot were used for the calculations.

The results of the upper and lower plot water budgets may be seen in Table 1.

Table 1: Total amount of water needed for each plot during the dry season

Upper Plot	Lower Plot
Total for Dry Season (gal)	**Total for Dry Season (gal)**
173.42	*107.58*

This data verifies the farmer’s water use estimation of 5 to 10 gallons a week for about 16 weeks for the tomatoes and the spinach in the upper plot, and provides an estimate of the necessary amount for the beans in the lower plot.

5.2.2 Ferrocement Tank Design

One of the design options for water storage was a ferrocement tank. The tank is a structure consisting of a wire skeleton with a cement and sand mortar. In developing countries, this type of tank is often used for all types of water storage because they can last a long period of time, generally 25 years or more if maintained properly. With little training, the tank could be constructed with a small crew. In addition to the simple construction design and the long life, the materials can be readily found in rural regions at local hardware stores. Unlike the polyethylene barrels storage option, there is no drilling required to construct the system, which was one of the issues faced by the other design option. This tank has a minimal number of connections, making it less likely to leak than the polyethylene barrel system. Even if leaks were to arise after several years, mortar can be used to repair any cracks sustained.

For the most common type of farm in Salto Dupí, the ferrocement tank is impractical. Due to the large amount of water required to build the storage system, the tank has to be constructed during the rainy season. However, some of the materials cannot get wet before construction begins. Therefore, the cement and sand must be wrapped in waterproof material during transit up the mountain. Once the cement and sand has reached the site, it must be kept away from moisture. The large amounts of required materials are also very heavy and would require several trips up the mountain to transport the materials by hand; therefore to decrease the time that the materials would be exposed to the weather conditions, a truck would probably need to be rented to transport the materials efficiently. These logistics alone make it very difficult to construct. In addition to the logistical issues, the tank would not be mobile. Many families move to new houses several times during their life. For these types of families or farmers who move their garden plots each season, the ferrocement tank would not be practical. The typical farm has many different garden plots at different elevations. With even a modest elevation head (approximately 4-6 feet), the pressure in the hosing becomes too large for the drip function to work properly. Therefore, a separate tank would have to be placed at each plot elevation.

As farms grow, the ferrocement tank would not be easily expanded. A farmer would probably not have the money or the means to build another ferrocement tank. If expansion were needed, a polyethylene barrel would need to be attached to the system. Thus, expansion would likely be the same process no matter which initial design option was chosen.

Table 2: Cost estimate for a ferrocement tank

Material	Amount Required	Price
Sand	35 lbs sand	$34.30
Cement	10 bags (100 lbs each)	$93.15
Rebar (3/8 inch)	30 feet	$6.00
Chicken Wire	8 square meters	$40.00
Water	N/A	$0.00
Galvanized Wire	1 spool	$3.00
Faucet	1	$5.28
Piping	20 feet	$6.00
Total Price:		**$187.73**

Finally, the initial cost of a ferrocement tank may be prohibitive for many farmers. The total cost is about $190.

Figure 5: Ferrocement Tank (Water Charity, 2010)

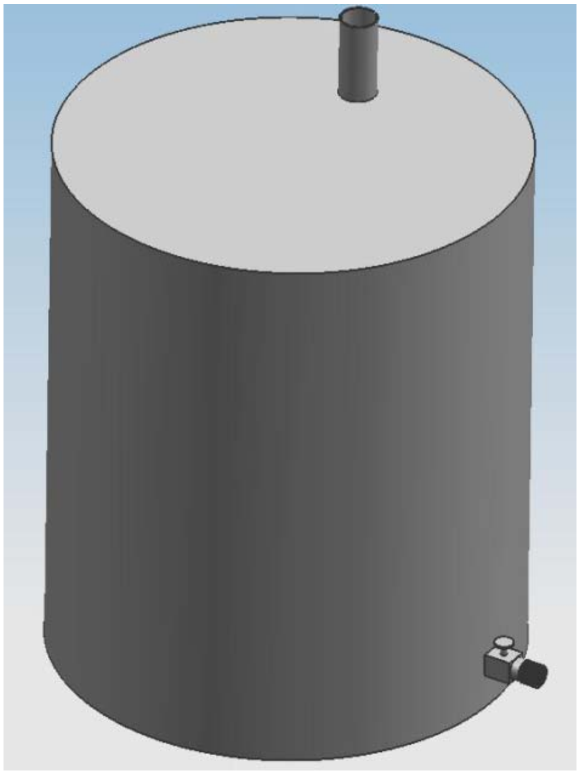

Figure 6: Ferrocement Tank AutoCAD Drawing

5.2.3 Polyethylene Barrel Design

The second option for rain water storage includes the use of 5-gallon polyethylene barrels. These barrels are readily available at the local hardware store in San Felix. In order to eliminate the need for piping between both the upper and lower plots, two separate series of these barrels will be placed directly above the upper and lower plots. The upper plot will have a 200-gallon capacity, using four barrels connected in series with 2-inch PVC piping. At the lower plot, three barrels will also be connected in series with 2-inch PVC piping to provide 150 gallons of storage. The construction guide contains a detailed outline of how these barrels can be connected together. A shut-off valve will be connected between the last barrel at each plot and its corresponding irrigation hosing. This will allow the storage system to be isolated from the irrigation system, allowing for the accumulation of water during the rainy season.

Advantages of this multi-barrel system are the ease with which its capacity can be expanded and the ease with which a similar design can be adapted to other farms in the region by simply changing the number of barrels connected in series. Another advantage of this system over the ferrocement tank design is its ease of transportation to the site. All the materials used in this design are fairly light and easily transported.

5.3 Irrigation System Design

A drip irrigation system design was chosen as a practical design solution for the study farm’s irrigation needs; this design is also adaptable for other farms in the Comarca Ngäbe-Buglé. The design team determined, through site investigation and material acquisition research, that a drip irrigation system would be the most available and economical choice. The drip irrigation system was designed using experimentally determined data and the EPA Net 2.0 computer simulation model (Rossman, 2000).

5.3.1 Experimental Analysis

A simplified version of the drip irrigation system that will be used in Panama was built to ensure that the recommended materials will be easy to construct and connect and that the flows and pressures through the system will be adequate for water to flow through the emitters. The materials used to construct the storage and hosing systems and connections were:

- Five-gallon bucket
- 50-foot vinyl 5/8-inch garden hose
- 1-inch PVC ball valve
- 1-inch PVC hose to pipe male adapter
- 1-inch threaded PVC Nipple
- Hose end cap
- Plumbers putty
- 16d and 10d nails

The first step in creating the irrigation system was to puncture holes into the hosing. Holes were made by hammering a nail into the hosing, through one side but not the other. The 16d nail was used to make holes at 12 inch intervals along the length of the hose.

Figure 7: Creating Emitter Holes in Irrigation Lines

A hole was drilled into the side of the bucket near the bottom. A power tool was used to drill a hole of the proper size. In Panama, farmers would either need to do this by hand with a knife or have it done for them in town.

A ¾” PVC slip-threaded bushing was threaded onto a ¾” PVC threaded coupling (or a reducing nipple) through the bucket. The bushing was placed inside the bucket and the coupling was placed outside. Plumbers putty was applied on both sides to create a water-tight seal. A ¾” PVC ball valve was then threaded onto the coupling. A slip barbed adapter was connected to the valve. The end of the hose was cut to eliminate the metal threading, and the end was slipped onto the barb. A hose clamp was then used to tighten the hose to the barb.

Throughout the experiment, the bucket was kept completely full at all times. The valve was turned on and the hose was allowed to fill and run until it reached steady state. Once the flow in the hosing reached a steady state, the flow rate at each of the holes was recorded.

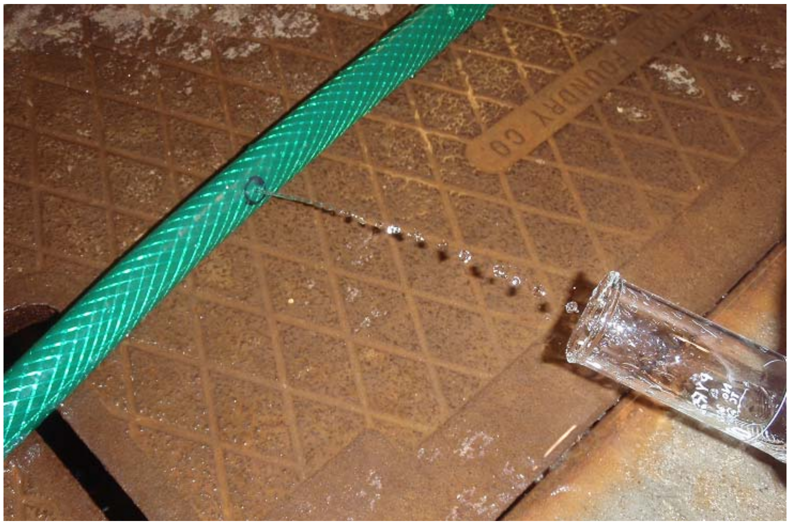

Figure 8: Flow Testing of Irrigation System

After flows through the 16d nail holes were measured, 10d nail holes were created at the midpoint between the 16d holes. These flows were then measured. The following two figures show the results from the testing.

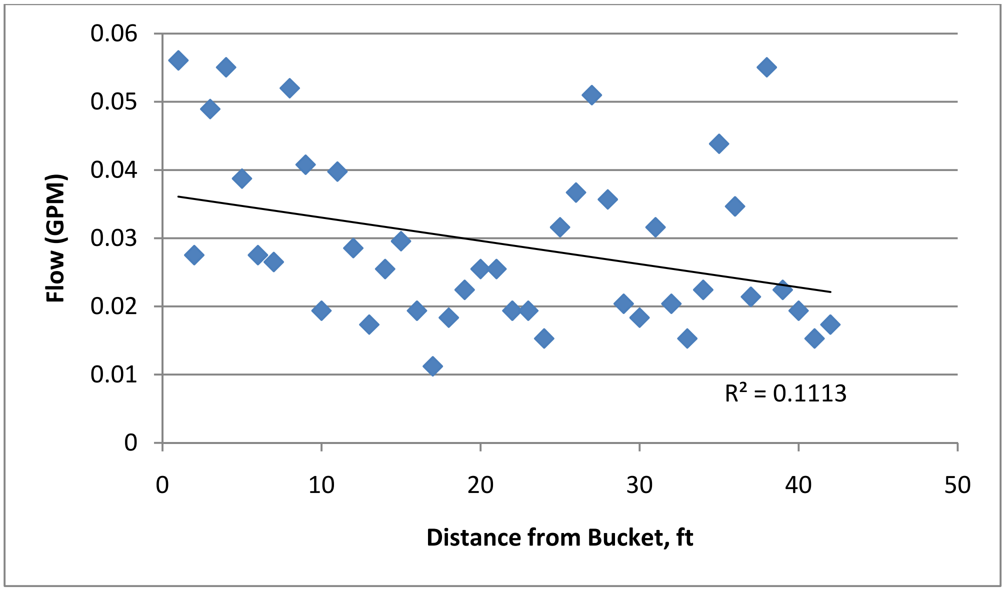

Figure 9: Flow through 16d nail holes

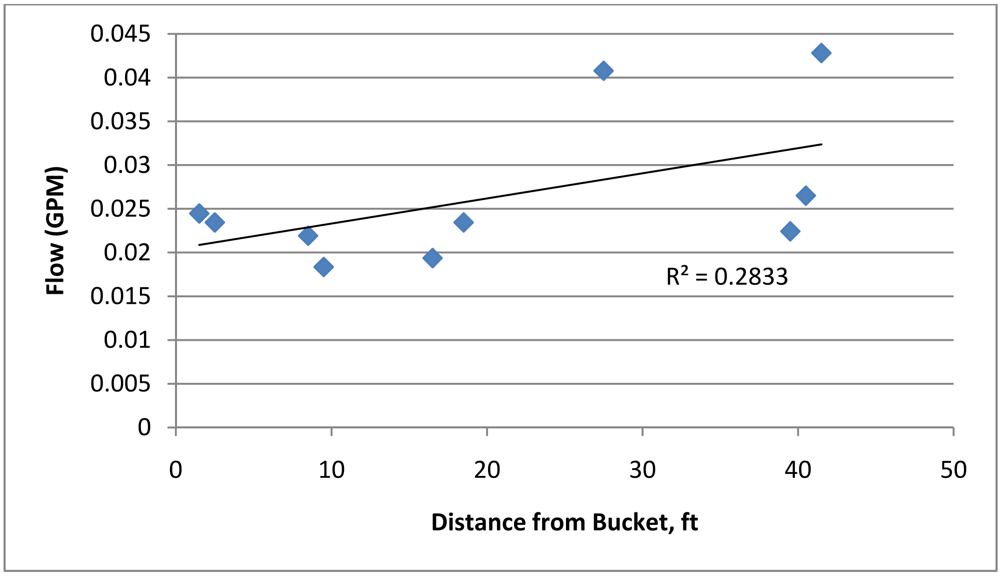

Figure 10: Flow through 10d nail holes

These plots show that the 16d nail holes delivered more variable flows than the 10d nail holes. The flows also do not show any significant trend, neither decreasing nor increasing, with distance from the bucket. The average flow through the 10d nail hole was found to be 0.026 GPM, and this was used to model the flow through the system in EPA Net 2.0.

5.3.2 Hydraulic Model Development

To model the drip irrigation system, EPA Net 2.0 was used to calculate the flows, pressures, and velocities through the emitters and the hosing. Since EPA Net 2.0 cannot determine the flow rates through the emitters while simultaneously determining the pressures, the proper emitter coefficients to be inputted into EPA Net 2.0 had to be determined experimentally.

The average experimental flow through the 10d nail-sized hole was found to be approximately 0.026 GPM. This flow roughly corresponds to values found in irrigation literature from the web. In a *Fine Gardening* article, a 16d nail-sized hole will emit 0.016 gallons per minute to irrigate an 18-inch diameter area which is equal to a depth of 1 inch of rain after an hour (Johnson, 2010). This flow is dependent on the pressure in the hosing and will change at different elevation changes. Nodes representing the emitter holes were placed 1 foot apart throughout the length of the piping.

To properly model emitters in EPA Net, an emitter coefficient (EC) needed to be calculated to describe the relationship between the flow rate and the pressure through the emitters that exit to the atmosphere. To calculate the EC, the system was run using the experimental data and the emitter coefficient was calculated using the results. Once the EC was established, the simulated system could then be experimented with: the tanks could be moved up or down the plot to show the effects of elevation change, valves could be added to demonstrate flow- or pressure-controlled flow, and partially empty tanks could be tested.

Tanks were used to represent the 50-gallon polyethylene barrels and were given a diameter of 1.9357 feet and a height of 2.833 feet. They were assumed to be full at the start of the test, and the minimum depth allowed was 0 feet (empty).

The elevations for the tanks and the nodes, along with the lengths of the vegetable plots were estimated from the AutoCAD data. One-inch PVC pipe with a Hazen-William's roughness coefficient of 130 was used to connect the tanks, and 5/8 inch pipe with a Hazen-William's roughness coefficient of 140 was used to represent the hosing in the system. This roughness coefficient is based on the Hazen-Williams roughness coefficient for plastic (Marshford, 2009).

Using all of these parameters, the system simulation was run. The resultant node (emitter) data was obtained: elevation, base demand, actual demand, and pressure. Data from the hosing was also collected: length, diameter, roughness, flow, velocity, and the friction factor. These values were used to calculate the headloss in each section of hosing. Both the Darcy-Weisbach and the Hazen-Williams headloss equations were used to calculate headloss.

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g}$$ *Eq. 4: Darcy-Weisbach Equation*

$$h_f = 0.002083 * L * \left(\frac{100}{C}\right)^{1.85} * \left(\frac{Q^{1.85}}{D^{4.8655}}\right)$$ *Eq. 5: Hazen-Williams Equation*

Where h_f = headloss due to friction [L]
f = Darcy-Weisbach friction factor
L = length [L]
D = diameter [L]
V = velocity [L/T]
g = gravitational acceleration [LT^{-2}], (32 ft/s^2)
C = Hazen-Williams roughness coefficient
Q = flow rate [L^3T^{-1}]

The Darcy-Weisbach calculation relates the friction factor of the pipe, the length of pipe, the diameter of pipe, and the velocity of flow to determine the headlosses due to friction. The Hazen-Williams formula is empirical (the equation was derived from experimental data) and relates the length and diameter of pipe to the flow through the pipe and the roughness coefficient. The headloss was found to be less than 10% of the total head and was therefore neglected.

The total head in each emitter was then calculated using the energy equation. After this, the flow rate through the hole was calculated, along with the emitter coefficient to be used in EPA Net.

$$H_i = \frac{P}{\gamma} + \frac{V^2}{2g} + h_L$$ *Eq. 6: Bernoulli Energy Equation*

Where H_i = total head [L]
h_L = head loss [L]
P = pressure $[ML^{-1}T^{-2}]$
γ = specific weight of water $[^{MT-3}]$, (62.4 lb/ft^3)
V = velocity [L/T]
g = gravitational acceleration $[LT^{-2}]$, (32.2 ft/s^2)

Based on the Bernoulli Equation, flow is related to the area that the water is flowing through, the velocity, and the pressure head.

$$Q = C_1 A\sqrt{H + \frac{\alpha V^2}{2g}}$$ *Eq. 7: Bernoulli Discharge Equation*

This can be simplified for flow through orifices using the Torricelli equation (Marshford, 2009).

$$Q = C_d * A * P^e$$ *Eq. 8: Orifice Equation*

Where C_d = coefficient of discharge
A = orifice aperture area $[L^2]$
P = fluid pressure $[ML^{-1}T^{-2}]$
e = pressure exponent $[L^3T^{-1}]/[ML^{-1}T^{-2}]^2$

Typical values for C_d are 0.62 for sharp orifices and 0.80 for tubes. For a circular aperture, the pressure exponent is typically 0.5. In this study, the diameter of the orifice is 0.0123 ft for a 10d nail hole. When performing the flow calculations, the diameter of the orifice was multiplied by 1.5 to account for area increases due to jagged edges created by pulling the nail in and out. EPA Net 2.0 applies a simple definition for the emitter coefficient based on the orifice calculation:

$$EC = \frac{Q}{P^e}$$ *Eq. 9: EPA Net 2.0 emitter coefficient calculation*

Where EC = emitter coefficient $[L^3T^{-1}L^{-1/2}]$ = 0.16 (based on experimental results and spreadsheet calculations)

Q = flow rate $[L^3T^{-1}]$

P = fluid pressure $[ML^{-1}T^{-2}]$

e = pressure exponent $[L^3T^{-1}]/[ML^{-1}T^{-2}]^2$

5.3.3 Hydraulic Model Results

The upper plot and lower plot systems were run for several trials with the experimentally calculated emitter coefficients of 0.16. Both of these systems were run with an initial base demand of 0.026 gallons per minute. The actual flows through the emitter holes were found to be 0.026 gallons per minute for the upper plot and 0.034 gallons per minute for the lower plot.

Figure 9 shows the upper plot node (emitter) pressures and pipe (hose) velocities. The node pressures ranged from 1 psi to 2.5 psi. These pressures are adequate to sustain flow through the emitters; however, clogging may occur and emitter maintenance will become necessary to keep the emitters free-flowing.

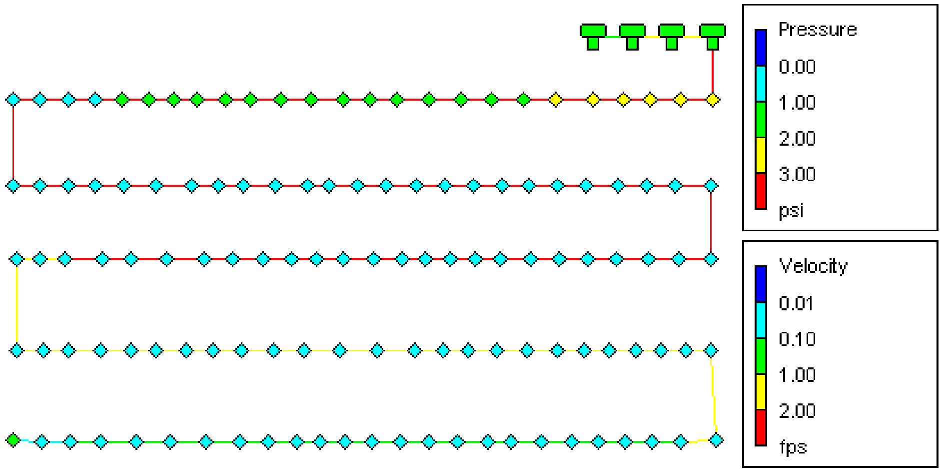

Figure 11: Upper plot EPA Net 2.0 model

Figure 10 shows the lower plot node pressures and pipe velocities. The node pressures ranged from 2.0 psi to 4.0 psi. These pressures are adequate to sustain flow through the emitters. Clogging in this section of the system will not occur as frequently; however, seasonal maintenance of the emitters will still be required.

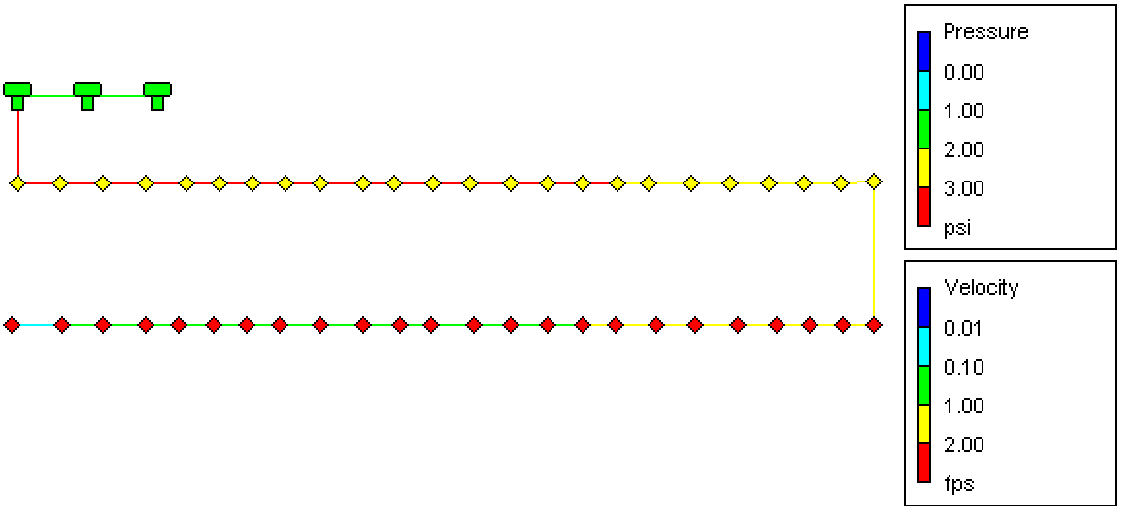

Figure 12: Lower plot EPA Net 2.0 model

See Appendix D for the detailed EPA Net 2.0 results tables and figures.

5.4 Rice Terraces

The farmer has a vacant section of land down slope of the lower bean plot where he desires to construct rice paddy terraces. This section has a total area of 2100 ft^2 (195 m^2) and a slope of 30.75^o (Figure 13).

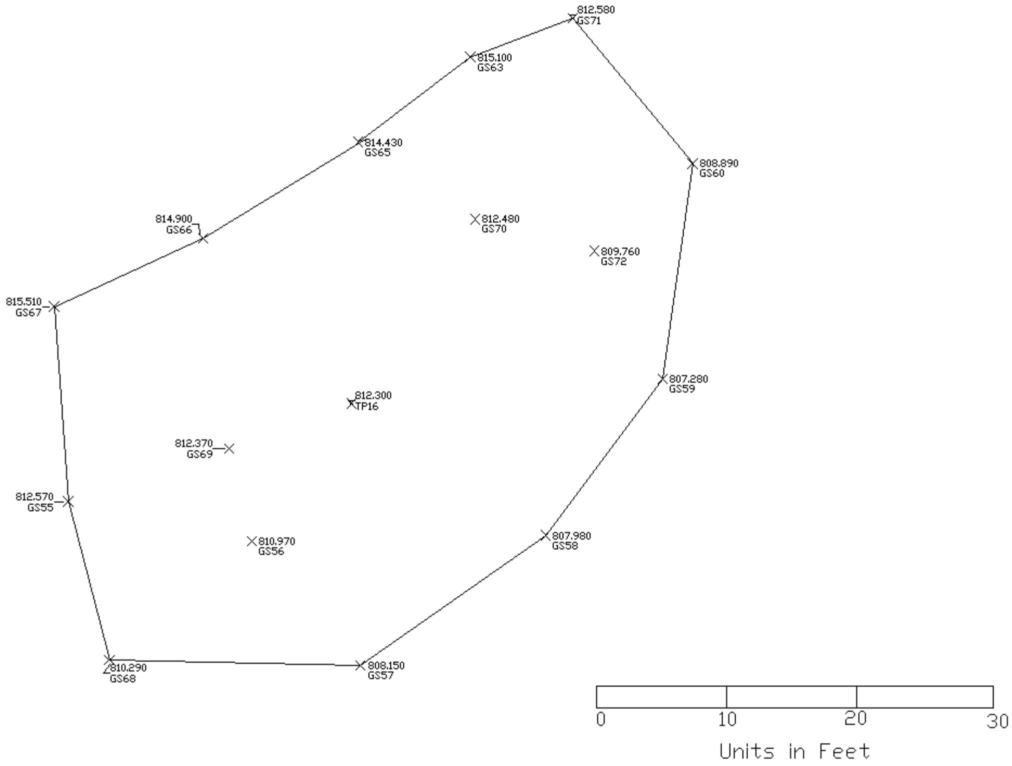

Figure 13: AutoCAD image of total area available for rice terraces

A water budget was developed and the stability of the slope was analyzed in order to determine the best dimensions for the rice terraces. It was assumed that the rice farming would begin May 1st and would continue until October 31st. This would allow for two harvests of the rice crop during the rainy season.

5.4.1 Rice Terrace Water Budget

The irrigation water need (IN) for rice paddies was found using a U.N. Food and Agricultural Organization (FAO) manual (Brouwer & Heibloem, 1986). The input equation for rice paddies varies slightly from the equation of the other crops:

$$IN = ET_{crop} + SAT + PERC + WL - Pe \qquad \textit{Eq. 10: Water Budget}$$

The amount of water that a crop needs (ET_{crop}) varies throughout its different growth stages. This is accounted for with the use of a crop factor. This value is multiplied by the number of days in which the crop is in each particular growth stage to obtain the total amount of water needed. It was assumed that 200 mm of water would completely saturate the root zone (SAT), as suggested by the FAO manual. The amount of water lost due to percolation and seepage (PERC) is 60 mm per month for heavy clay (Brouwer et al., 1989). A standing water level (WL) must be maintained at certain growth stages for rice production. This varies between 0 and 100 mm depending on the stage. Finally, the effective rainfall (Pe) is calculated using one of the following equations:

$$Pe = 0.8P - 25 \; if \; P > 75 \; mm/month \qquad \text{Eq. 11}$$

$$Pe = 0.6P - 10 \; if \; P < 75 \; mm/month \qquad \text{Eq. 12}$$

The variable P is the actual precipitation amount on the area.

Using equation 10 the following data was obtained:

Table 3: Calculated irrigation water needs for months in the rainy season

Month	Irrigation Need (mm/month)
May	-116
June	34.0
July	-19.6
August	-186
September	-33.2
October	-236

Table 2 shows that June is the only month in which supplemental water in addition to precipitation will be needed. Based on the data from the roof collection calculations in Appendix B, the system will be able to collect 485 gallons (1.84 m^3) of water from May 15th to June 30th. This quantity allows the rice paddies to have total surface area of 576 ft^2 (53.5 m^2).

For these calculations, a percolation value of 2 mm/day was used; this value was determined from the FAO Manual. However, in older versions of the manual, a percolation value of 4 mm/day was used. If this older value is used in the water budget calculations, then the rice paddies will have a total surface area of 209 ft^2 (19.4 m^2) to utilize the same volume of water. The months of July and September would also require supplemental water, along with June, under these conditions.

5.4.2 Rice Terraces Slope Stability Analysis

The stability of the slope was calculated in Slide 5.0 (Rocscience, 2009). This computer program is widely used to analyze failure planes along various slopes and determine the likelihood of failures occurring. The Spencer Method was chosen for the analysis based on its accurate and numerous calculations and lower probability of numerical instability. Material properties were then entered into the program in order to model the soil type found on the study farm. Using the USS Steel Sheet Piling Design Manual (1974), it was determined that the dry unit weight of clay is 120 lb/ft^3 and the compression strength is 2000 lb/ft^2. The frictional strength of the soil was conservatively assumed to be 0, suggesting pure clay. Based on the Mohr Circle, it may be concluded that the shear strength (cohesion) is then equivalent to 1000 lb/ft^2. It was also assumed that the slope was completely saturated. Twelve models with differing dimensions were modeled and tested. Their dimensions and safety factors may be found in Table 3.

Table 4: Terrace dimensions and safety factors of analyzed models

Height (ft)	1	1	1	1	1.5	1.5	1.5	1.5	2	2	2	2
Length (ft)	1	2	3	4	1	2	3	4	1	2	3	4
Safety factor	2.20	2.37	2.35	2.01	2.31	2.61	2.74	2.08	2.34	2.40	2.77	2.52

After assessing multiple terrace dimensions for slope stability, a dimension ratio of 2H:3L was selected. This dimension ratio was chosen to minimize excavation and allow room for crop growth and terrace reinforcement. In its last growth stage, rice can grow to be more than 3 feet high. In Figure 12, it may be seen that the least stable portion of the slope, encompassed by the green cone, still exceeded the standard minimum safety factor of 1.3. This means that the slope will be stable at these dimensions.

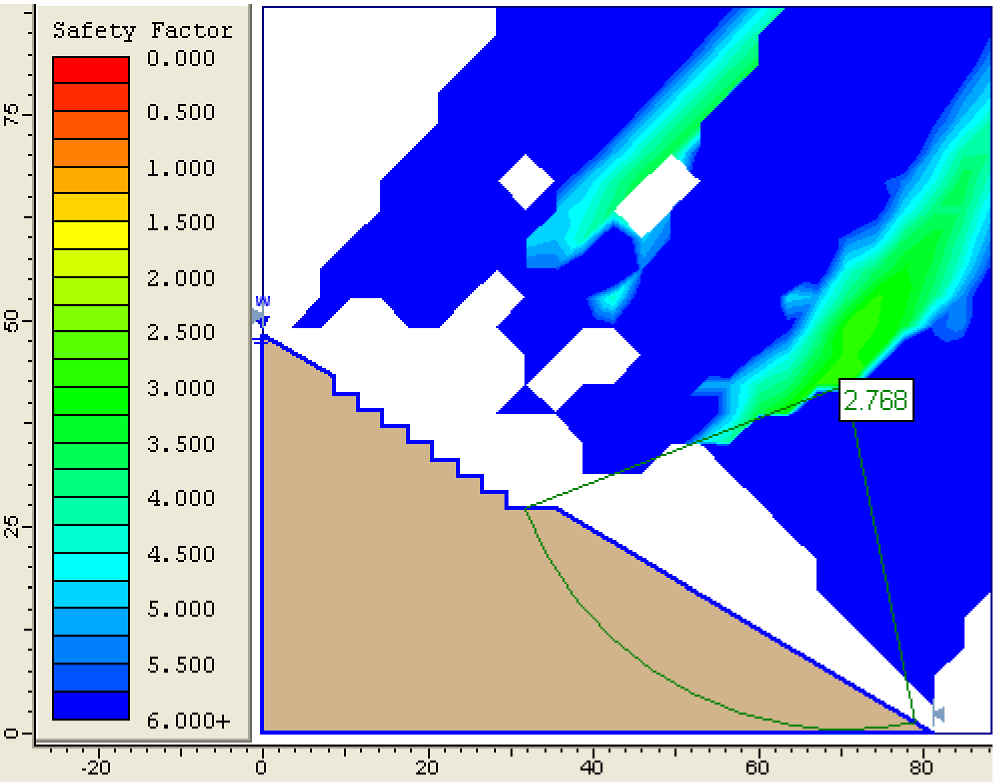

Figure 14: Slope stability for rice dimensions 2H:3L as calculated in Slide 5.0

The stability of the terraces was also analyzed. As seen in Figure 15, the chosen dimensions are very stable and will not result in a landslide under these conditions.

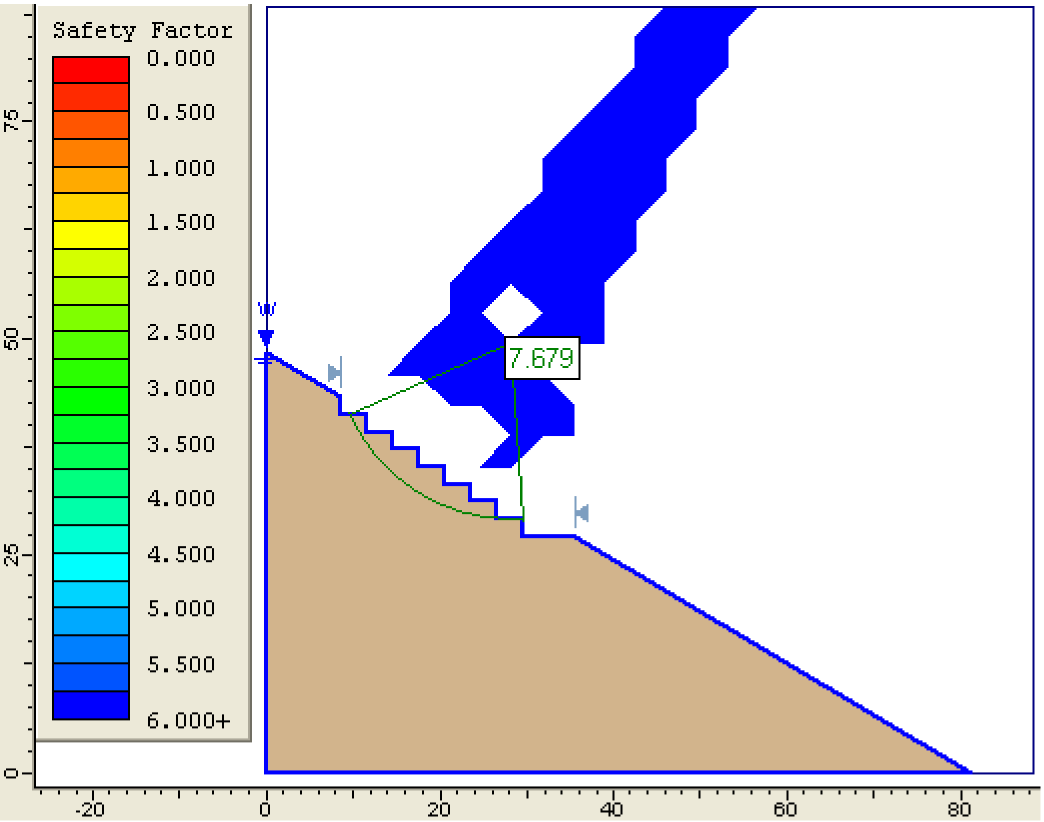

Figure 15: Terrace stability for terraces with dimensions 2H:3L as calculated in Slide 5.0

The completed rice terrace design will have 8 terraces, each with a height of 2 feet (0.61 meters), a width of 3 feet (0.91 meters), and a length of 24 feet (7.3 meters) as seen in Figure 16.

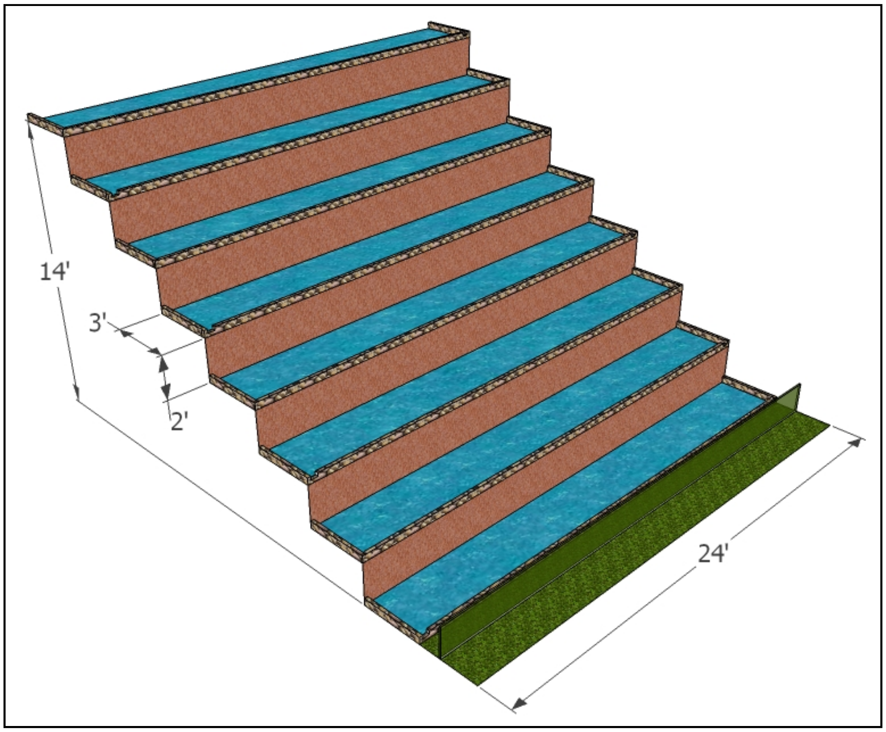

Figure 16: Rice Terrace Design

The lowest terrace will have a width of 5.9 ft (1.8 m) in order to maintain the slope of the land. Vetiver will also be planted at the bottom of this terrace to slow the flow of water and prevent soil erosion. Stone and clay will be used to build up the sides of the terraces in order to help maintain terrace stability and retain water.

6.0 Cost Estimate

While in San Felix, Mujeres Fuertes Consultados visited a *ferraterría* (hardware store) to estimate the costs for the materials for the proposed design. There were a few options for hosing, and the standard 75 feet garden hosing with a 5/8" diameter was used in the cost estimate. There were also unsorted containers of PVC connections with prices ranging from $0.35 to $0.85. A conservative estimate of the cost for the PVC connections was used. The PVC glue and plumber's putty pricing came from the Agua Contigo Consultados International Senior Design 2009 report (Endsley et al, 2009).

The project estimate does not include labor costs because it is assumed that the farmer would perform all of the labor. Also, the transportation cost is a rough assumption based on the average cost for a privately owned truck (*chiva*) from San Felix to Salto Dupí.

Table 5: Final Design Cost Estimate

	Quantity	Unit Cost	Total Cost
Zinc Roofing (3.5'x10' sheet)	2	$ 8.00	$ 16.00
Nails (box)	2	$ 2.30	$ 4.60
Rubber Sheet (12"x36" sheet)	1	$ 17.50	$ 17.50
Barrels	7	$ 25.00	$ 175.00
PVC Pipe (1" diameter) (20 ft)	1	$ 3.50	$ 3.50
PVC Threaded Nipple (1" diameter)	12	$ 0.50	$ 6.00
PVC Valve (1" diameter)	2	$ 3.50	$ 7.00
Caulk (1 tube)	1	$ 4.00	$ 4.00
Garden Hose (75')	3	$ 17.50	$ 52.50
Hose connections	3	$ 1.00	$ 3.00
Hose caps	2	$ 1.00	$ 2.00
Transportation of Materials	-	$ 40.00	$ 40.00
		Total Cost:	**$ 330.10**

7.0 Construction Scheduling

Based on experiences with farmers in the Comarca, the construction schedule for this design will differ greatly from the typical construction schedule for work done in the United States. Due to the remote location of the farm and the poor roads leading to this area, heavy machinery cannot be used. It is assumed that the farmers implementing these systems will be the ones to construct them, while also tending to other duties. For these reasons the construction durations are unique to this area.

Construction schedules were developed for both the rainfall harvesting/irrigation project and the rice terrace project. The schedules were determined separately because no interdependency exists between them. Also, the site prep and material acquisition can occur simultaneously and the total duration reflects that.

Table 6: Construction Schedule Summary

Activity	Duration (Days)
Site Prep	5
Material Acquisition	14
Roof and Gutter Construction	10
Storage System Construction	5
Irrigation System Construction	8
Rice Tank Construction	6
Total Duration	**43**

Fourteen days was chosen as a reasonable amount of time to acquire materials on the assumption that many farmers would be able to travel into San Felix at least once every few weeks. The materials may also be collected over a much longer period of time. The construction schedule also assumes work for all three sections of the design is able to be completed almost daily. All durations are rough estimates that depend highly on the farmer's other work load, the amount of people able to help, the weather, and the availability of materials.

The separate construction schedule for the rice tanks can be found in Appendix J. The critical path will depend strictly on the amount of time required to dig the terraces, undoubtedly a longer time than required to collect stones to hold the outside walls. The actual construction schedule is also dependent on the factors listed above for the irrigation system.

The time required to excavate the necessary material to create the terraces is dependent on what the farmer encounters as he digs. Assuming a general material consistency of medium clay throughout the cross section, RS Means (Reed Construction, 2010) may be used to estimate the amount of time required excavate the clay. A total volume of approximately 42 cubic yards must be removed to create the terraces. General assumptions of 1 person digging, a five-hour work day (assuming that farmers would only have this much time for this project along with their other workload), and the availability of a basic shovel were used to come to an estimation of 6 days to dig the terraces. The calculations supporting the volume and time estimates may be found in Appendix H.

8.0 Final Recommendation

The recommended design for the collection system includes zinc roofing attached to a bamboo frame. Attached to these will be a slotted bamboo gutter that will collect the rainwater that falls onto the roof and funnel it into the water storage system. The estimated cost of this system is $40.

The recommended design for the storage system is the 50-gallon polyethylene barrel system. This system was chosen because it is more adaptable and less costly than the ferrocement tank system. Also, the materials are more easily transported to the remote site. The total cost for this system is expected to be approximately $200.

The recommended design for the irrigation system requires 144 feet of garden hosing for the upper plot and 58 feet of garden hosing for the lower plot. The total hosing cost will be approximately $52.50 (based on garden hosing cost at a *ferraterría* in San Felix, Panama). A 10d nail is recommended to punch holes in the hosing at every foot, or where crops are located. A water-tight end-cap or a shut-off ball valve is recommended to plug the lower end of the hose to maintain pressure. Frequent maintenance of the emitters is also recommended to prevent clogging. The total cost for this system is estimated to be about $60.

Based on the farmer's estimation and verified by the results from the irrigation system experiment and hydraulic model analysis that each of the plots requires 10 gallons of water per week, the upper system will need to be run at steady state for about 3 minutes every week (or whenever the soil feels dry), and the lower system will need to be run at steady state for about 8 minutes every week (or whenever the soil feels dry). It is also recommended that mulch be placed over the irrigation hosing. The hosing should be thoroughly buried in the mulch to increase efficiency; evaporation will be significantly decreased and infiltration will be increased because the mulch trap water before it runs down the hill.

The recommended materials and construction methods for the irrigation system were selected under the assumption of very little funding and lack of access to proper irrigation hosing. When soaker hosing or actual drip irrigation tape is available, it is highly recommended to improve efficiency, albeit at a higher cost.

An eight-terrace rice paddy design is recommended. The terraces will be dug by the farmer to minimize the cost of construction. Each terrace will have a height of 2 feet, width of 3 feet, and length of 24 feet. The lowest terrace will have a width of 5.9 ft to maintain the natural slope. Stones and rocks should be placed along the edges of each terrace, forming a berm, to reinforce the terrace and retain the water. This may also be accomplished by forming the berm with the excavated clay. Each of the first seven terraces should then have one conduit to allow water to flow down to the next terrace. The conduits should be on alternating ends of the terraces to maintain a steady water flow. It is recommended that vetiver be planted on the lowest terrace to help prevent soil erosion, slow the water flow down the slope, and help filter the water before it leaves the terrace system.

It is recommended that water be collected in the storage barrels from May 15th to June 30th. This time period will allow for an adequate volume of water for the rice terraces for the month of June. Enough precipitation falls during the other months during the rainy season that added water is not needed. In the rare case that there is inadequate precipitation (a dry year – less than 100 mm of precipitation in March or less than 200 mm of precipitation in April), the collection time would have to be increased in order for the tanks to be filled to capacity.

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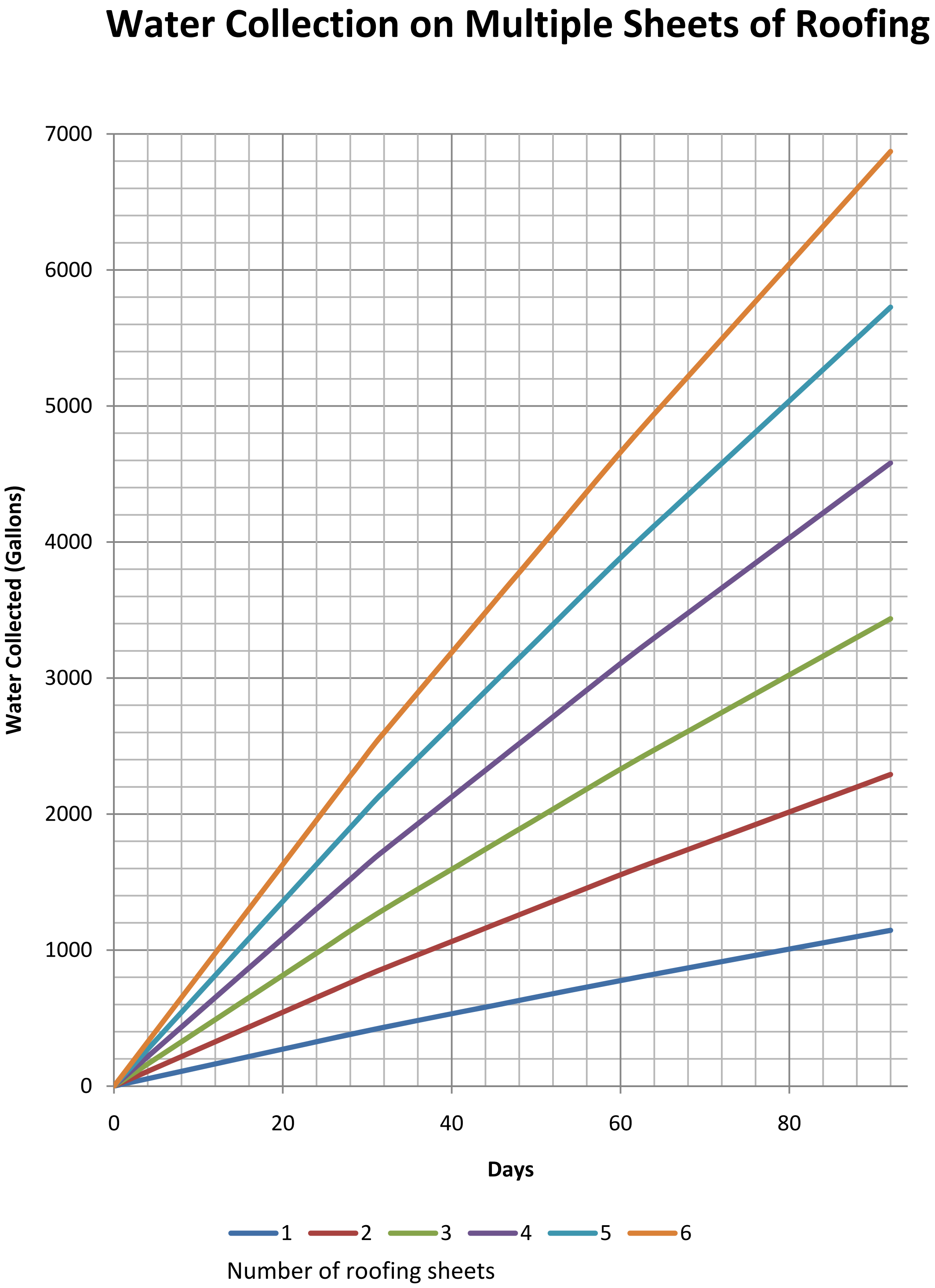
10.0 Index of Appendices

Appendix A: Rainfall Data

Quebrada Loro Rainfall Data				
Dry Season				
Month	**Average Rainfall (mm)**	**Maximum Rainfall (mm)**	**Average Rainfall (in)**	**Maximum Rainfall (in)**
December	171	583	6.71	23.0
January	29.4	91.6	1.16	3.61
February	20.1	99.5	0.791	3.92
March	62.9	328	2.48	12.9
April	142	352	5.59	13.8
Average	85.0	291	3.35	11.4
Rainy Season				
Month	**Average Rainfall (mm)**	**Maximum Rainfall (mm)**	**Average Rainfall (in)**	**Maximum Rainfall (in)**
May	639	1027	25.2	40.4
June	676	1226	26.6	48.3
July	603	953	23.7	37.5
August	726	1061	28.6	41.8
September	750	1079	29.5	42.5
October	857	1398	33.7	55.0
November	580	952	22.8	37.5
Average	690	1099	27.2	43.3

Appendix B: Water Collection on Multiple Sheets of Roofing

Calculations for determining the number of days needed to collect a given amount of rainwater for various roof sizes were performed using historical rainfall data from the town of Quebrada Loro, which is located near Salto Dupí. The number of days needed corresponds to the number of days before December 31st (the beginning of the dry season).



Appendix C: Water Budgets

Crop Factors (Kc) and Days in Growth Stages (GS)

Tomatoes

Stage	Kc	Shortest GS	Longest GS	Average GS
Initial (In)	0.45	30	35	33
Crop dev. (CD)	0.75	40	45	42
Mid-season (MS)	1.15	40	70	55
Late-season (LS)	0.8	25	30	28
Total:		135	180	158

Spinach

Stage	Kc	Shortest GS	Longest GS	Average GS
Initial	0.45	20	20	20
Crop dev.	0.6	20	30	25
Mid-season	1	15	40	27
Late-season	0.9	5	10	8
Total:		60	100	80

Beans

Stage	Kc	Shortest GS	Longest GS	Average GS
Initial	0.35	15	20	18
Crop dev.	0.7	25	30	27
Mid-season	1.1	25	30	28
Late-season	0.9	10	10	10
Total:		75	90	83

Rice

Stage	Kc	Days in GS
Nursery	0.35	31
Vegetative (Veg)	1.1	15
Reproductive (Rep)	1.05	23
Ripening (Rip)	1	23

Evapotranspiration Data and Calculations

Month	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April
T avg (°C)	27.3	26.7	26.5	26.5	26.4	26.2	26.3	26.1	26.3	26.9	27.5	27.7
p	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26	0.26	0.27	0.27	0.28
ETo	5.75624	5.88178	5.8551	5.6532	5.64032	5.41404	5.22548	5.20156	5.22548	5.50098	5.5755	5.80776

T avg – average temperature (Etesa, 2009)

p – mean daily percentage of annual daytime hours

Water Budget for Upper Plot

Tomatoes

Months	December	January	February	March	April
ETo (mm/d)	3.38	3.40	3.58	3.62	3.78
Growth Stages	In	In (2) /CD (29)	CD (13) / MS (15)	MS	MS (9) / LS (21)
Kc per growth stage	0.45	0.45/0.75	0.75/1.15	1.15	1.15/0.8
Kc per month	0.45	0.73	0.96	1.15	0.91
ET crop (mm/d)	1.52	2.48	3.45	4.17	3.42
ET crop (mm/m)	47.17	76.93	96.54	129.20	102.49
P (mm/mo)	170.50	29.40	20.10	62.90	142.00
Pe (mm/mo)	111.40	7.64	2.06	27.74	88.60
IN (mm/mo)	-64.23	69.29	94.48	101.46	13.89

Spinach

Months	December	January	February	March	April
ETo (mm/d)	3.38	3.40	3.58	3.62	3.78
Growth Stages	In (20)/CD (11)	CD (14)/ MS (17)	MS (10)/ LS (8)	In (20)/CD (11)	CD (14)/MS (16)
Kc per growth stage	0.45/0.60	0.60/1.0	1.0/0.90	0.45/0.60	0.60/1.0
Kc per month	0.50	0.82	0.29	0.50	0.81
ET crop (mm/d)	1.70	2.78	1.05	1.82	3.07
ET crop (mm/mo)	52.74	86.27	29.32	56.54	92.11
P (mm/mo)	170.50	29.40	20.10	62.90	142.00
Pe (mm/mo)	111.40	7.64	2.06	27.74	88.60
IN (mm/mo)	-58.66	78.63	27.26	28.80	3.51

Water Budget for Lower Plot

Beans

Months	December	January	February	March	April
ETo (mm/d)	3.38	3.40	3.58	3.62	3.78
Growth Stages (d)	In (18)/CD (13)	CD (14)/ MS (17)	MS (11) / LS (10)	In (18)/CD (13)	CD (14)/ MS (16)
Kc per growth stage	0.35/0.70	0.70/1.10	1.10/0.90	0.35/0.70	0.70/1.10
Kc per month	0.50	0.92	0.75	0.50	0.91
ET crop (mm/d)	1.68	3.12	2.69	1.80	3.45
ET crop (mm/mo)	52.07	96.80	75.45	55.81	103.44
P (mm/mo)	170.50	29.40	20.10	62.90	142.00
Pe (mm/mo)	111.40	7.64	2.06	27.74	88.60
IN (mm/mo)	-59.33	89.16	73.39	28.07	14.84

ETo - reference evapotranspiration (multiplied by correction factor which assumes mulch is 85% effective)

$$ETo = \left(p\left[(0.46)\left(T_{avg}\right) + 8)\right]\right) * (0.15)$$

$$ETo_{Jan} = (0.26 * [(0.46)(26.3) + 8)]) * (0.65) = 3.40 \frac{mm}{d}$$

Kc per month:

$$Kc_{month-plant} = \left(\frac{\# \; days \; in \; GS}{\# \; days \; in \; month}\right) * Kc_{GS} + \left(\frac{\# \; days \; in \; GS}{\# \; days \; in \; month}\right) * Kc_{GS} \; \ldots$$

$$Kc_{Jan-beans} = \left(\frac{14}{31}\right) * 0.70 + \left(\frac{17}{31}\right) * 1.10 = 0.92$$

ET - crop water need

$$ET \; crop = (ETo)(Kc)$$

$$ET \; crop_{\; Jan-beans} = (3.40)(0.92) = 3.12 \frac{mm}{d}$$

P - precipitation

Pe - effective rainfall

$$Pe = 0.6P - 10 \; if \; P < 75 \frac{mm}{mo}$$

$$Pe = 0.8P - 25 \; if \; P > 75 \frac{mm}{mo}$$

$$Pe_{Jan} = (0.6)(29.4) - 10 = 7.64 \frac{mm}{mo}$$

IN - irrigation need

$$IN = ET \; crop - Pe$$

$$IN_{Jan-beans} = 96.8 \frac{mm}{mo} - 7.64 \frac{mm}{mo} = 89.16 \frac{mm}{mo}$$

Water Budget for Rice Terraces						
Months	**May**	**June**	**July**	**August**	**September**	**October**
ETo (mm/day)	5.76	5.88	5.86	5.65	5.64	5.41
Growth Stages	Nursery	Veg (15)/ Rep (15)	Rep (8)/ Rip (23)	Nursery	Veg (15)/ Rep (15)	Rep (8)/ Rip (23)
Kc per growth stage	0.35	1.1/1.05	1.05/1	0.35	1.05	1.00
Kc per month	0.35	1.08	1.01	0.35	1.08	1.01
ET crop (mm/d)	2.01	6.32	5.93	1.98	6.06	5.48
ET crop (mm/mo)	60.44	189.69	177.92	59.36	181.90	164.52
SAT (mm)	200.00	200.00	200.00	200.00	200.00	200.00
PERC (mm/mo)	60.00	60.00	60.00	60.00	60.00	60.00
WL (mm)	50.00	100.00	0.00	50.00	100.00	0.00
P (mm/mo)	639.40	675.60	603.20	725.90	750.10	857.20
Pe (mm/mo)	486.52	515.48	457.56	555.72	575.08	660.76
IN (mm/mo)	-116.08	34.21	-19.64	-186.36	-33.18	-236.24

SAT – amount of water needed to completely saturate the root zone assumed 200 mm/mo
WL – standing water level

$$IN = ET_{crop} + SAT + PERC + WL - Pe$$

$$IN_{June} = 189.69\frac{mm}{mo} + 200\frac{mm}{mo} + 60\frac{mm}{mo} + 100\frac{mm}{mo} - 515.48\frac{mm}{mo} = 34.21\frac{mm}{mo}$$

Appendix D: EPA Net 2.0 Calculations and Results

EPA Net 2.0 Sample Calculations

Experimental Flow, Q = 0.026 GPM

Assuming: f = 0.027, C (EC) = 0.016, C = 140, Cd = 0.6, D = 0.0185 ft, g = 32 ft/s^2

Sample Calculations for Pipe 5 (values found in Table 7)

Darcy-Weisbach Equation

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g} = 0.027 * \frac{1\,ft}{0.625\,ft} * \frac{4.94\frac{ft^2}{s}}{2 * 32\frac{ft}{s^2}} = 0.19\,ft$$

Hazen-Williams Equation

$$h_f = 0.002083 * L * \left(\frac{100}{C}\right)^{1.85} * \left(\frac{Q^{1.85}}{D^{4.8655}}\right) = 0.002083 * 1\,ft * \left(\frac{100}{140}\right)^{1.85} * \left(\frac{0.026^{1.85}}{0.625\,ft^{4.8655}}\right) = 0.19\,ft$$

Bernoulli Energy Equation

$$H_i = \frac{P}{\gamma} + \frac{V^2}{2g} + h_L$$

Bernoulli Equation

$$Q = C_1 A\sqrt{H + \frac{\alpha V^2}{2g}}$$

Orifice Equation

$$Q = C_d * A * P^e = 0.6 * 0.000269\,ft^2 * 2.34^{0.5} = 0.00024\,GPM$$

EPA Net 2.0 Emitter Coefficient Calculation

$$EC = \frac{Q}{P^e} = \frac{0.026}{2.34^{.5}} = 0.16$$

Table 7. EPA NET 2.0 Upper Plot Node Results

Upper Plot Node Results - Actual Emitter Flow Calculations									
	Elevation	Base Demand	Demand	Head	Pressure	ΔZ	Total Head	Qcalc	Qcalc
Node ID	ft	GPM	GPM	ft	psi	ft	ft	ft3/s	GPM
Junc 5	857.17	0.026	0.05	862.61	2.36	3	8.872	0.004	0.031
Junc 6	857	0.026	0.05	862.41	2.34	3.17	8.986	0.004	0.031
Junc 7	857	0.026	0.05	862.22	2.26	3.17	8.793	0.004	0.031
Junc 8	857	0.026	0.05	862.03	2.18	3.17	8.599	0.004	0.030
Junc 9	857	0.026	0.05	861.85	2.1	3.17	8.406	0.004	0.030
Junc 10	857	0.026	0.05	861.67	2.02	3.17	8.213	0.004	0.030
Junc 11	857	0.026	0.05	861.5	1.95	3.17	8.043	0.004	0.029
Junc 12	857	0.026	0.05	861.32	1.87	3.17	7.848	0.004	0.029
Junc 13	857	0.026	0.05	861.15	1.8	3.17	7.678	0.004	0.029
Junc 14	857	0.026	0.05	860.99	1.73	3.17	7.509	0.004	0.028
Junc 15	857	0.026	0.05	860.83	1.66	3.17	7.340	0.003	0.028
Junc 16	857	0.026	0.05	860.67	1.59	3.17	7.171	0.003	0.028
Junc 17	857	0.026	0.05	860.51	1.52	3.17	7.001	0.003	0.027
Junc 18	857	0.026	0.05	860.36	1.46	3.17	6.855	0.003	0.027
Junc 19	857	0.026	0.04	860.21	1.39	3.17	6.686	0.003	0.027
Junc 20	857	0.026	0.04	860.06	1.33	3.17	6.541	0.003	0.026
Junc 21	857	0.026	0.04	859.92	1.26	3.17	6.372	0.003	0.026
Junc 22	857	0.026	0.04	859.78	1.2	3.17	6.226	0.003	0.026
Junc 23	857	0.026	0.04	859.64	1.14	3.17	6.082	0.003	0.026
Junc 24	857	0.026	0.04	859.5	1.09	3.17	5.959	0.003	0.025
Junc 25	857	0.026	0.04	859.37	1.03	3.17	5.815	0.003	0.025
Junc 26	857	0.026	0.04	859.24	0.97	3.17	5.669	0.003	0.025
Junc 27	857	0.026	0.04	859.11	0.92	3.17	5.548	0.003	0.024
Junc 28	856.99	0.026	0.04	858.99	0.87	3.18	5.437	0.003	0.024
Junc 29	855.5	0.026	0.03	855.93	0.19	4.67	5.343	0.003	0.024
Junc 30	855.8	0.026	0.03	856	0.09	4.37	4.805	0.003	0.023
Junc 31	855.8	0.026	0.03	856.07	0.12	4.37	4.870	0.003	0.023
Junc 32	855.8	0.026	0.03	856.15	0.15	4.37	4.935	0.003	0.023
Junc 33	855.8	0.026	0.03	856.22	0.18	4.37	4.999	0.003	0.023
Junc 34	855.8	0.026	0.03	856.3	0.22	4.37	5.087	0.003	0.023
Junc 35	855.8	0.026	0.03	856.38	0.25	4.37	5.152	0.003	0.023
Junc 36	855.8	0.026	0.03	856.46	0.29	4.37	5.240	0.003	0.024
Junc 37	855.8	0.026	0.04	856.55	0.32	4.37	5.306	0.003	0.024
Junc 38	855.8	0.026	0.04	856.63	0.36	4.37	5.394	0.003	0.024
Junc 39	855.8	0.026	0.04	856.72	0.4	4.37	5.483	0.003	0.024
Junc 40	855.8	0.026	0.04	856.81	0.44	4.37	5.571	0.003	0.024
Junc 41	855.8	0.026	0.04	856.9	0.48	4.37	5.660	0.003	0.025
Junc 42	856	0.026	0.04	856.99	0.43	4.17	5.340	0.003	0.024
Junc 43	856	0.026	0.04	857.09	0.47	4.17	5.429	0.003	0.024
Junc 44	856	0.026	0.04	857.18	0.51	4.17	5.519	0.003	0.024
Junc 45	856	0.026	0.04	857.28	0.55	4.17	5.607	0.003	0.025
Junc 46	856	0.026	0.04	857.38	0.6	4.17	5.720	0.003	0.025
Junc 47	856	0.026	0.04	857.48	0.64	4.17	5.809	0.003	0.025
Junc 48	856	0.026	0.04	857.59	0.69	4.17	5.922	0.003	0.025
Junc 49	856	0.026	0.04	857.7	0.74	4.17	6.034	0.003	0.025
Junc 50	856	0.026	0.04	857.81	0.78	4.17	6.124	0.003	0.026
Junc 51	856	0.026	0.04	857.92	0.83	4.17	6.236	0.003	0.026
Junc 52	856	0.026	0.04	858.03	0.88	4.17	6.350	0.003	0.026
Junc 53	854.3	0.026	0.04	855.51	0.52	5.87	7.211	0.003	0.028
Junc 54	854	0.026	0.04	855.44	0.62	6.17	7.740	0.004	0.029
Junc 55	854	0.026	0.04	855.37	0.6	6.17	7.690	0.004	0.029

Upper Plot Node Results - Actual Emitter Flow Calculations (continued)

	Elevation	Base Demand	Demand	Head	Pressure	ΔZ	Total Head	Qcalc	Qcalc
Node ID	ft	GPM	GPM	ft	psi	ft	ft	ft3/s	GPM
Junc 57	854	0.026	0.04	855.25	0.54	6.17	7.5441	0.0035	0.0284
Junc 58	854	0.026	0.04	855.18	0.51	6.17	7.4710	0.0035	0.0283
Junc 59	854	0.026	0.04	855.13	0.49	6.17	7.4211	0.0035	0.0282
Junc 60	854	0.026	0.04	855.07	0.46	6.17	7.3481	0.0035	0.0281
Junc 61	854	0.026	0.04	855.01	0.44	6.17	7.2984	0.0035	0.0280
Junc 62	854	0.026	0.04	854.96	0.41	6.17	7.2255	0.0035	0.0278
Junc 63	854	0.026	0.04	854.9	0.39	6.17	7.1758	0.0035	0.0277
Junc 64	854	0.026	0.04	854.85	0.37	6.17	7.1270	0.0034	0.0276
Junc 65	854	0.026	0.04	854.8	0.35	6.17	7.0775	0.0034	0.0275
Junc 66	854	0.026	0.04	854.75	0.33	6.17	7.0280	0.0034	0.0274
Junc 67	854	0.026	0.03	854.7	0.31	6.17	6.9785	0.0034	0.0273
Junc 68	854	0.026	0.03	854.66	0.29	6.17	6.9298	0.0034	0.0272
Junc 69	854	0.026	0.03	854.61	0.27	6.17	6.8805	0.0034	0.0271
Junc 70	854	0.026	0.03	854.57	0.25	6.17	6.8312	0.0034	0.0271
Junc 71	854	0.026	0.03	854.53	0.23	6.17	6.7826	0.0034	0.0270
Junc 72	854	0.026	0.03	854.49	0.21	6.17	6.7334	0.0033	0.0269
Junc 73	854	0.026	0.03	854.45	0.19	6.17	6.6849	0.0033	0.0268
Junc 74	854	0.026	0.03	854.41	0.18	6.17	6.6590	0.0033	0.0267
Junc 75	854	0.026	0.03	854.37	0.16	6.17	6.6105	0.0033	0.0266
Junc 76	854	0.026	0.03	854.34	0.15	6.17	6.5847	0.0033	0.0266
Junc 77	853	0.026	0.03	853.59	0.25	7.17	7.8150	0.0036	0.0289
Junc 78	853.2	0.026	0.03	853.6	0.17	6.97	7.4267	0.0035	0.0282
Junc 79	853.2	0.026	0.03	853.61	0.18	6.97	7.4481	0.0035	0.0282
Junc 80	853.2	0.026	0.03	853.62	0.18	6.97	7.4457	0.0035	0.0282
Junc 81	853.2	0.026	0.03	853.64	0.19	6.97	7.4671	0.0035	0.0283
Junc 82	853.2	0.026	0.03	853.65	0.2	6.97	7.4880	0.0035	0.0283
Junc 83	853.2	0.026	0.03	853.67	0.2	6.97	7.4857	0.0035	0.0283
Junc 84	853.2	0.026	0.03	853.68	0.21	6.97	7.5072	0.0035	0.0284
Junc 85	853.2	0.026	0.03	853.7	0.22	6.97	7.5283	0.0035	0.0284
Junc 86	853.2	0.026	0.03	853.72	0.22	6.97	7.5267	0.0035	0.0284
Junc 87	853.3	0.026	0.03	853.74	0.19	6.87	7.3549	0.0035	0.0281
Junc 88	853.3	0.026	0.03	853.76	0.2	6.87	7.3765	0.0035	0.0281
Junc 89	853.3	0.026	0.03	853.78	0.21	6.87	7.3977	0.0035	0.0281
Junc 90	853.3	0.026	0.03	853.8	0.22	6.87	7.4195	0.0035	0.0282
Junc 91	853.4	0.026	0.03	853.82	0.18	6.77	7.2246	0.0035	0.0278
Junc 92	853.4	0.026	0.03	853.84	0.19	6.77	7.2464	0.0035	0.0279
Junc 93	853.4	0.026	0.03	853.87	0.2	6.77	7.2678	0.0035	0.0279
Junc 94	853.4	0.026	0.03	853.89	0.21	6.77	7.2897	0.0035	0.0279
Junc 95	853.4	0.026	0.03	853.92	0.22	6.77	7.3112	0.0035	0.0280
Junc 96	853.4	0.026	0.03	853.95	0.24	6.77	7.3563	0.0035	0.0281
Junc 97	853.4	0.026	0.03	853.97	0.25	6.77	7.3779	0.0035	0.0281
Junc 98	853.4	0.026	0.03	854	0.26	6.77	7.3999	0.0035	0.0282
Junc 99	853.4	0.026	0.03	854.03	0.27	6.77	7.4215	0.0035	0.0282
Junc 100	853.4	0.026	0.03	854.06	0.29	6.77	7.4668	0.0035	0.0283
Junc 101	852	0.026	0.04	853.52	0.66	8.17	9.7250	0.0040	0.0323
Junc 102	852	0.026	0.04	853.51	0.65	8.17	9.7003	0.0040	0.0322
Junc 103	852	0.026	0.04	853.5	0.65	8.17	9.6993	0.0040	0.0322
Junc 104	852	0.026	0.04	853.49	0.65	8.17	9.6979	0.0040	0.0322
Junc 105	852	0.026	0.04	853.48	0.64	8.17	9.6737	0.0040	0.0322

Upper Plot Node Results - Actual Emitter Flow Calculations (continued)

	Elevation	Base Demand	Demand	Head	Pressure	ΔZ	Total Head	Qcalc	Qcalc
Node ID	ft	GPM	GPM	ft	psi	ft	ft	ft3/s	GPM
Junc 106	852	0.026	0.04	853.48	0.64	8.17	9.672391	0.004013	0.032188
Junc 107	852	0.026	0.04	853.47	0.64	8.17	9.671153	0.004012	0.032186
Junc 108	852	0.026	0.04	853.46	0.63	8.17	9.64674	0.004007	0.032145
Junc 109	852	0.026	0.04	853.46	0.63	8.17	9.645326	0.004007	0.032143
Junc 110	851.5	0.026	0.04	853.45	0.85	8.67	10.65522	0.004212	0.033784
Junc 111	851.5	0.026	0.04	853.45	0.84	8.67	10.63097	0.004207	0.033745
Junc 112	851.5	0.026	0.04	853.44	0.84	8.67	10.62999	0.004207	0.033744
Junc 113	851.5	0.026	0.04	853.44	0.84	8.67	10.62907	0.004207	0.033742
Junc 114	851.5	0.026	0.04	853.44	0.84	8.67	10.62819	0.004206	0.033741
Junc 115	851.5	0.026	0.04	853.44	0.84	8.67	10.62737	0.004206	0.033739
Junc 116	851.5	0.026	0.04	853.43	0.84	8.67	10.62659	0.004206	0.033738
Junc 117	851.5	0.026	0.04	853.43	0.84	8.67	10.62569	0.004206	0.033737
Junc 118	851.5	0.026	0.04	853.43	0.84	8.67	10.62503	0.004206	0.033736
Junc 119	851.5	0.026	0.04	853.43	0.84	8.67	10.62442	0.004206	0.033735
Junc 120	851.5	0.026	0.04	853.43	0.84	8.67	10.62386	0.004205	0.033734
Junc 121	851.5	0.026	0.04	853.43	0.84	8.67	10.62322	0.004205	0.033733
Junc 122	851.5	0.026	0.04	853.43	0.84	8.67	10.62277	0.004205	0.033732
Junc 123	851.5	0.026	0.04	853.43	0.84	8.67	10.62237	0.004205	0.033731
Junc 124	851.5	0.026	0.04	853.43	0.84	8.67	10.62202	0.004205	0.033731
Junc 129	856.98	0.026	0.04	858.87	0.82	3.19	5.095205	0.002912	0.023362
Junc 130	856	0.026	0.04	858.15	0.93	4.17	6.330452	0.003246	0.02604
Junc 131	853.5	0.026	0.04	854.3	0.35	6.67	7.483167	0.00353	0.028312
Junc 132	853.4	0.026	0.03	854.1	0.3	6.77	7.466901	0.003526	0.028281
Junc 133	851	0.026	0.04	853.43	1.05	9.17	11.60873	0.004396	0.035263
average									0.028161

Table 8. EPA NET 2.0 Upper Plot Pipe Results

Upper Plot Pipe Results - Headloss Calculations								
	Length	Diameter	Roughness	Flow	Velocity	Friction Factor	Headloss, using darcy-weisbach	Headloss using Hazen Williams
Link ID	ft	in		GPM	fps		ft	ft
Pipe 4	2	0.625	140	4.78	5	0.027	0.4050	0.3976
Pipe 5	1	0.625	140	4.73	4.94	0.027	0.1977	0.1950
Pipe 6	1	0.625	140	4.68	4.89	0.027	0.1937	0.1912
Pipe 7	1	0.625	140	4.63	4.84	0.027	0.1897	0.1874
Pipe 8	1	0.625	140	4.58	4.79	0.027	0.1858	0.1837
Pipe 9	1	0.625	140	4.53	4.74	0.027	0.1820	0.1800
Pipe 10	1	0.625	140	4.48	4.69	0.027	0.1782	0.1763
Pipe 11	1	0.625	140	4.43	4.63	0.027	0.1736	0.1727
Pipe 12	1	0.625	140	4.38	4.58	0.027	0.1699	0.1691
Pipe 13	1	0.625	140	4.34	4.53	0.027	0.1662	0.1663
Pipe 14	1	0.625	140	4.29	4.49	0.027	0.1633	0.1628
Pipe 15	1	0.625	140	4.24	4.44	0.027	0.1597	0.1593
Pipe 16	1	0.625	140	4.2	4.39	0.027	0.1561	0.1565
Pipe 17	1	0.625	140	4.15	4.34	0.027	0.1526	0.1531
Pipe 18	1	0.625	140	4.11	4.29	0.027	0.1491	0.1504
Pipe 19	1	0.625	140	4.06	4.25	0.027	0.1463	0.1470
Pipe 20	1	0.625	140	4.02	4.2	0.027	0.1429	0.1443
Pipe 21	1	0.625	140	3.97	4.15	0.027	0.1395	0.1410
Pipe 22	1	0.625	140	3.93	4.11	0.027	0.1368	0.1384
Pipe 23	1	0.625	140	3.89	4.06	0.027	0.1335	0.1358
Pipe 24	1	0.625	140	3.84	4.02	0.028	0.1357	0.1326
Pipe 25	1	0.625	140	3.8	3.97	0.028	0.1324	0.1300
Pipe 26	1	0.625	140	3.76	3.93	0.028	0.1297	0.1275
Pipe 27	1	0.625	140	3.72	3.89	0.028	0.1271	0.1250
Pipe 28	1	0.625	140	3.68	3.85	0.028	0.1245	0.1226
Pipe 29	6	0.625	140	3.64	3.8	0.028	0.7278	0.7206
Pipe 30	1	0.625	140	3.59	3.76	0.028	0.1188	0.1171
Pipe 31	1	0.625	140	3.55	3.72	0.028	0.1162	0.1147
Pipe 32	1	0.625	140	3.51	3.67	0.028	0.1131	0.1123
Pipe 33	1	0.625	140	3.47	3.63	0.028	0.1107	0.1099
Pipe 34	1	0.625	140	3.43	3.59	0.028	0.1083	0.1076
Pipe 35	1	0.625	140	3.39	3.55	0.028	0.1059	0.1053
Pipe 36	1	0.625	140	3.36	3.51	0.028	0.1035	0.1036
Pipe 37	1	0.625	140	3.32	3.47	0.028	0.1011	0.1013
Pipe 38	1	0.625	140	3.28	3.43	0.028	0.0988	0.0991
Pipe 39	1	0.625	140	3.24	3.39	0.028	0.0965	0.0968
Pipe 40	1	0.625	140	3.2	3.35	0.028	0.0943	0.0946
Pipe 41	1	0.625	140	3.17	3.31	0.028	0.0920	0.0930
Pipe 42	1	0.625	140	3.13	3.27	0.028	0.0898	0.0908
Pipe 43	1	0.625	140	3.09	3.24	0.028	0.0882	0.0887
Pipe 44	1	0.625	140	3.06	3.2	0.028	0.0860	0.0871
Pipe 45	1	0.625	140	3.02	3.16	0.028	0.0839	0.0850
Pipe 46	1	0.625	140	2.99	3.12	0.029	0.0847	0.0835
Pipe 47	1	0.625	140	2.95	3.09	0.029	0.0831	0.0814
Pipe 48	1	0.625	140	2.92	3.05	0.029	0.0809	0.0799
Pipe 49	1	0.625	140	2.89	3.02	0.029	0.0793	0.0784
Pipe 50	1	0.625	140	2.85	2.98	0.029	0.0773	0.0764
Pipe 51	1	0.625	140	2.82	2.95	0.029	0.0757	0.0749
Pipe 52	1	0.625	140	2.79	2.92	0.029	0.0742	0.0734
Pipe 53	1	0.625	140	2.76	2.88	0.029	0.0722	0.0720

Upper Plot Pipe Results - Headloss Calculations (continued)

	Length	Diameter	Roughness	Flow	Velocity	Friction Factor	Headloss, using darcy-weisbach	Headloss using Hazen Williams
Link ID	ft	in		GPM	fps		ft	ft
Pipe 54	6	0.625	140	2.73	2.85	0.029	0.4240	0.4232
Pipe 55	1	0.625	140	2.69	2.81	0.029	0.0687	0.0686
Pipe 56	1	0.625	140	2.65	2.77	0.029	0.0668	0.0668
Pipe 57	1	0.625	140	2.61	2.73	0.029	0.0648	0.0649
Pipe 58	1	0.625	140	2.57	2.69	0.029	0.0630	0.0631
Pipe 59	1	0.625	140	2.54	2.65	0.029	0.0611	0.0617
Pipe 60	1	0.625	140	2.5	2.61	0.029	0.0593	0.0599
Pipe 61	1	0.625	140	2.46	2.57	0.029	0.0575	0.0582
Pipe 62	1	0.625	140	2.42	2.53	0.029	0.0557	0.0564
Pipe 63	1	0.625	140	2.39	2.5	0.03	0.0563	0.0551
Pipe 64	1	0.625	140	2.35	2.46	0.03	0.0545	0.0535
Pipe 65	1	0.625	140	2.31	2.42	0.03	0.0527	0.0518
Pipe 66	1	0.625	140	2.28	2.38	0.03	0.0510	0.0505
Pipe 67	1	0.625	140	2.24	2.35	0.03	0.0497	0.0489
Pipe 68	1	0.625	140	2.21	2.31	0.03	0.0480	0.0477
Pipe 69	1	0.625	140	2.17	2.27	0.03	0.0464	0.0461
Pipe 70	1	0.625	140	2.14	2.24	0.03	0.0452	0.0450
Pipe 71	1	0.625	140	2.1	2.2	0.03	0.0436	0.0434
Pipe 72	1	0.625	140	2.07	2.17	0.03	0.0424	0.0423
Pipe 73	1	0.625	140	2.04	2.13	0.03	0.0408	0.0411
Pipe 74	1	0.625	140	2	2.1	0.03	0.0397	0.0397
Pipe 75	1	0.625	140	1.97	2.06	0.03	0.0382	0.0386
Pipe 76	1	0.625	140	1.94	2.03	0.03	0.0371	0.0375
Pipe 77	1	0.625	140	1.91	1.99	0.031	0.0368	0.0364
Pipe 78	1	0.625	140	1.87	1.96	0.031	0.0357	0.0350
Pipe 79	6	0.625	140	1.84	1.92	0.031	0.2057	0.2040
Pipe 80	1	0.625	140	1.8	1.89	0.031	0.0332	0.0326
Pipe 81	1	0.625	140	1.77	1.85	0.031	0.0318	0.0316
Pipe 82	1	0.625	140	1.73	1.81	0.031	0.0305	0.0303
Pipe 83	1	0.625	140	1.7	1.78	0.031	0.0295	0.0294
Pipe 84	1	0.625	140	1.67	1.74	0.031	0.0282	0.0284
Pipe 85	1	0.625	140	1.63	1.71	0.031	0.0272	0.0272
Pipe 86	1	0.625	140	1.6	1.67	0.031	0.0259	0.0262
Pipe 87	1	0.625	140	1.57	1.64	0.031	0.0250	0.0253
Pipe 88	1	0.625	140	1.53	1.6	0.031	0.0238	0.0242
Pipe 89	1	0.625	140	1.5	1.57	0.032	0.0237	0.0233
Pipe 90	1	0.625	140	1.47	1.53	0.032	0.0225	0.0224

Upper Plot Pipe Results - Headloss Calculations (continued)

	Length	Diameter	Roughness	Flow	Velocity	Friction Factor	Headloss, using darcy-weisbach	Headloss using Hazen Williams
Link ID	ft	in		GPM	fps		ft	ft
Pipe 91	1	0.625	140	1.43	1.5	0.032	0.0216	0.0213
Pipe 92	1	0.625	140	1.4	1.46	0.032	0.0205	0.0205
Pipe 93	1	0.625	140	1.37	1.43	0.032	0.0196	0.0197
Pipe 94	1	0.625	140	1.33	1.39	0.032	0.0185	0.0186
Pipe 95	1	0.625	140	1.3	1.36	0.032	0.0178	0.0179
Pipe 96	1	0.625	140	1.27	1.32	0.032	0.0167	0.0171
Pipe 97	1	0.625	140	1.23	1.29	0.032	0.0160	0.0161
Pipe 98	1	0.625	140	1.2	1.25	0.033	0.0155	0.0154
Pipe 99	1	0.625	140	1.17	1.22	0.033	0.0147	0.0147
Pipe 100	1	0.625	140	1.13	1.19	0.033	0.0140	0.0138
Pipe 101	1	0.625	140	1.1	1.15	0.033	0.0131	0.0131
Pipe 102	1	0.625	140	1.07	1.12	0.033	0.0124	0.0125
Pipe 103	1	0.625	140	1.04	1.08	0.033	0.0115	0.0118
Pipe 104	6	0.625	140	1	1.05	0.034	0.0675	0.0660
Pipe 105	1	0.625	140	0.96	1.01	0.034	0.0104	0.0102
Pipe 106	1	0.625	140	0.92	0.97	0.034	0.0096	0.0094
Pipe 107	1	0.625	140	0.88	0.93	0.034	0.0088	0.0087
Pipe 108	1	0.625	140	0.85	0.88	0.034	0.0079	0.0081
Pipe 109	1	0.625	140	0.81	0.84	0.035	0.0074	0.0075
Pipe 110	1	0.625	140	0.77	0.8	0.035	0.0067	0.0068
Pipe 111	1	0.625	140	0.73	0.76	0.035	0.0061	0.0061
Pipe 112	1	0.625	140	0.69	0.72	0.035	0.0054	0.0055
Pipe 113	1	0.625	140	0.65	0.68	0.036	0.0050	0.0050
Pipe 114	1	0.625	140	0.61	0.64	0.036	0.0044	0.0044
Pipe 115	1	0.625	140	0.57	0.6	0.036	0.0039	0.0039
Pipe 116	1	0.625	140	0.53	0.55	0.037	0.0034	0.0034
Pipe 117	1	0.625	140	0.49	0.51	0.037	0.0029	0.0029
Pipe 118	1	0.625	140	0.45	0.47	0.038	0.0025	0.0025
Pipe 119	1	0.625	140	0.41	0.43	0.038	0.0021	0.0021
Pipe 120	1	0.625	140	0.37	0.38	0.039	0.0017	0.0017
Pipe 121	1	0.625	140	0.33	0.34	0.04	0.0014	0.0014
Pipe 122	1	0.625	140	0.29	0.3	0.039	0.0011	0.0011
Pipe 123	1	0.625	140	0.25	0.26	0.043	0.0009	0.0008
Pipe 124	1	0.625	140	0.2	0.21	0.04	0.0005	0.0006
Pipe 125	1	0.625	140	0.16	0.17	0.049	0.0004	0.0004
Pipe 126	1	0.625	140	0.12	0.13	0.037	0.0002	0.0002
Pipe 127	1	0.625	140	0.08	0.09	0.054	0.0001	0.0001
Pipe 128	1	0.625	140	0.04	0.04	0.104	0.0000	0.0000

Table 9. EPA NET 2.0 Lower Plot Node Results

Lower Plot Node Results - Actual Emitter Flow Calculations									
	Elevation	Base Demand	Demand	Head	Pressure	ΔZ	Total Head	Qcalc	Qcalc
Node ID	ft	GPM	GPM	ft	psi	ft	ft	ft3/s	GPM
Junc 128	820.25	0.026	0.05	825.96	2.47	3.1	8.7294	0.0038	0.0306
Junc 134	820	0.026	0.05	825.9	2.56	3.35	9.1758	0.0039	0.0314
Junc 135	820	0.026	0.05	825.84	2.53	3.35	9.1048	0.0039	0.0312
Junc 136	820	0.026	0.05	825.79	2.51	3.35	9.0562	0.0039	0.0311
Junc 137	820	0.026	0.05	825.73	2.48	3.35	8.9846	0.0039	0.0310
Junc 138	820	0.026	0.05	825.68	2.46	3.35	8.9362	0.0039	0.0309
Junc 139	820	0.026	0.05	825.64	2.44	3.35	8.8878	0.0038	0.0309
Junc 140	820	0.026	0.05	825.59	2.42	3.35	8.8389	0.0038	0.0308
Junc 141	820	0.026	0.05	825.54	2.4	3.35	8.7907	0.0038	0.0307
Junc 142	820	0.026	0.05	825.5	2.38	3.35	8.7426	0.0038	0.0306
Junc 143	820	0.026	0.05	825.46	2.37	3.35	8.7163	0.0038	0.0306
Junc 144	820	0.026	0.05	825.42	2.35	3.35	8.6684	0.0038	0.0305
Junc 145	820	0.026	0.05	825.38	2.33	3.35	8.6206	0.0038	0.0304
Junc 146	820	0.026	0.05	825.35	2.32	3.35	8.5952	0.0038	0.0303
Junc 147	820	0.026	0.05	825.32	2.3	3.35	8.5469	0.0038	0.0303
Junc 148	820	0.026	0.05	825.28	2.29	3.35	8.5217	0.0038	0.0302
Junc 149	820	0.026	0.05	825.25	2.28	3.35	8.4965	0.0038	0.0302
Junc 150	820	0.026	0.05	825.22	2.26	3.35	8.4491	0.0038	0.0301
Junc 151	820	0.026	0.05	825.2	2.25	3.35	8.4236	0.0037	0.0300
Junc 152	820	0.026	0.05	825.17	2.24	3.35	8.3987	0.0037	0.0300
Junc 153	820	0.026	0.05	825.15	2.23	3.35	8.3739	0.0037	0.0299
Junc 154	820	0.026	0.05	825.13	2.22	3.35	8.3491	0.0037	0.0299
Junc 155	820	0.026	0.05	825.1	2.21	3.35	8.3245	0.0037	0.0299
Junc 156	819.5	0.026	0.05	825.08	2.42	3.85	9.2914	0.0039	0.0315
Junc 157	817	0.026	0.06	824.9	3.42	6.35	14.0248	0.0048	0.0388
Junc 158	817	0.026	0.06	824.88	3.42	6.35	14.0228	0.0048	0.0388
Junc 159	817	0.026	0.06	824.87	3.41	6.35	13.9981	0.0048	0.0387
Junc 160	817	0.026	0.06	824.85	3.4	6.35	13.9735	0.0048	0.0387
Junc 161	817	0.026	0.06	824.84	3.4	6.35	13.9714	0.0048	0.0387
Junc 162	817	0.026	0.06	824.83	3.39	6.35	13.9470	0.0048	0.0387
Junc 163	817	0.026	0.06	824.82	3.39	6.35	13.9454	0.0048	0.0386
Junc 164	817	0.026	0.06	824.81	3.38	6.35	13.9213	0.0048	0.0386
Junc 165	817	0.026	0.06	824.8	3.38	6.35	13.9196	0.0048	0.0386
Junc 166	817	0.026	0.06	824.79	3.38	6.35	13.9180	0.0048	0.0386
Junc 167	817	0.026	0.06	824.78	3.37	6.35	13.8942	0.0048	0.0386
Junc 168	817	0.026	0.06	824.78	3.37	6.35	13.8931	0.0048	0.0386
Junc 169	817	0.026	0.06	824.77	3.37	6.35	13.8918	0.0048	0.0386
Junc 170	817	0.026	0.06	824.77	3.37	6.35	13.8907	0.0048	0.0386
Junc 171	817	0.026	0.06	824.77	3.36	6.35	13.8673	0.0048	0.0385
Junc 172	817	0.026	0.06	824.76	3.36	6.35	13.8663	0.0048	0.0385
Junc 173	817	0.026	0.06	824.76	3.36	6.35	13.8657	0.0048	0.0385
Junc 174	817	0.026	0.06	824.76	3.36	6.35	13.8650	0.0048	0.0385
Junc 175	817	0.026	0.06	824.76	3.36	6.35	13.8644	0.0048	0.0385
Junc 176	817	0.026	0.06	824.76	3.36	6.35	13.8639	0.0048	0.0385
Junc 177	817	0.026	0.06	824.75	3.36	6.35	13.8635	0.0048	0.0385
Junc 178	817	0.026	0.06	824.75	3.36	6.35	13.8633	0.0048	0.0385
Junc 179	817	0.026	0.06	824.75	3.36	6.35	13.8631	0.0048	0.0385
Junc 180	816	0.026	0.06	824.75	3.79	7.35	15.8245	0.0051	0.0412
average									0.0346

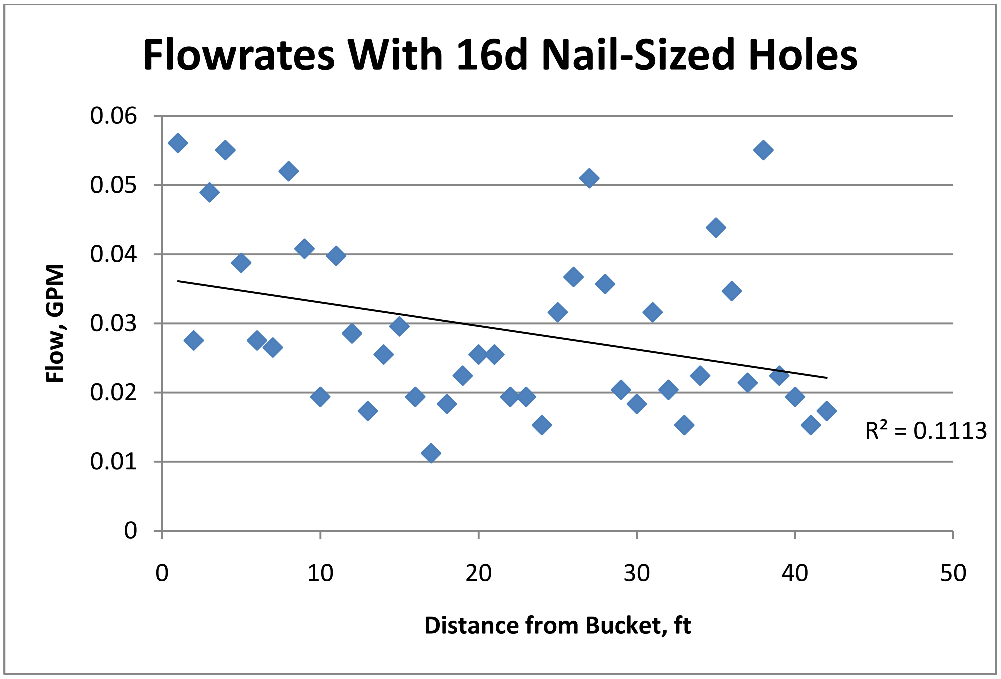
Table 10. EPA NET 2.0 Lower Plot Pipe Results

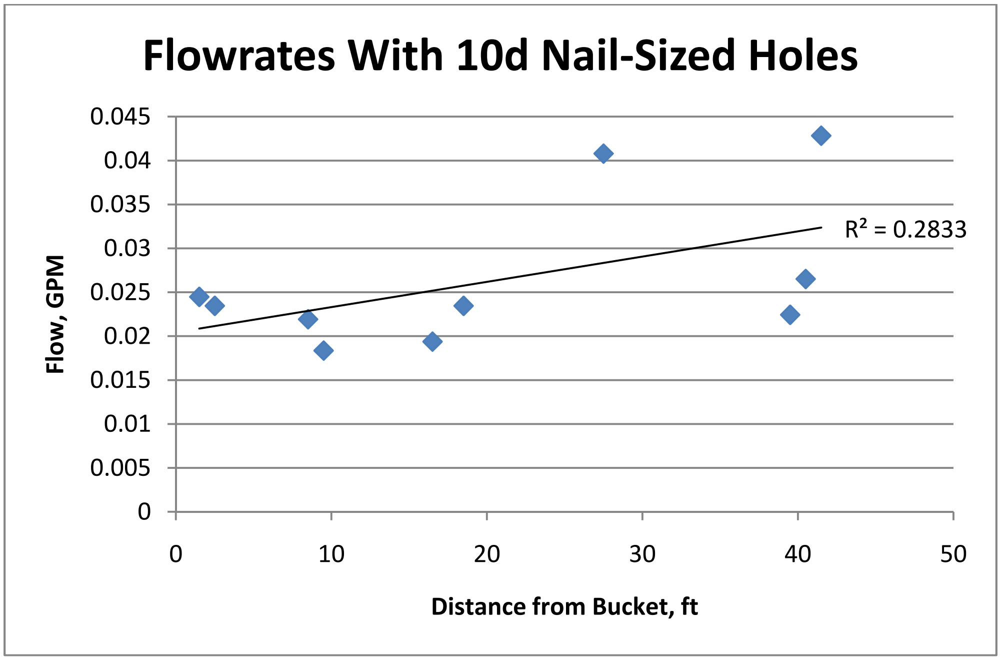
Lower Plot Pipe Results - Headloss Calculations								
	Length	Diameter	Roughness	Flow	Velocity	Friction Factor	Headloss, using darcy-weisbach	Headloss using Hazen Williams
Link ID	ft	in		GPM	fps		ft	ft
Pipe 132	1	0.625	140	2.49	2.61	0.029	0.05926527	0.059493151
Pipe 133	1	0.625	140	2.44	2.55	0.029	0.05657175	0.057301944
Pipe 134	1	0.625	140	2.39	2.5	0.03	0.05625	0.055148575
Pipe 135	1	0.625	140	2.34	2.45	0.03	0.0540225	0.053033161
Pipe 136	1	0.625	140	2.29	2.39	0.03	0.0514089	0.050955823
Pipe 137	1	0.625	140	2.24	2.34	0.03	0.0492804	0.048916684
Pipe 138	1	0.625	140	2.19	2.29	0.03	0.0471969	0.046915872
Pipe 139	1	0.625	140	2.14	2.23	0.03	0.0447561	0.044953515
Pipe 140	1	0.625	140	2.09	2.18	0.03	0.0427716	0.043029749
Pipe 141	1	0.625	140	2.03	2.13	0.03	0.0408321	0.04077236
Pipe 142	1	0.625	140	1.98	2.07	0.03	0.0385641	0.038933978
Pipe 143	1	0.625	140	1.93	2.02	0.03	0.0367236	0.037134639
Pipe 144	1	0.625	140	1.88	1.97	0.031	0.03609237	0.035374491
Pipe 145	1	0.625	140	1.83	1.92	0.031	0.03428352	0.03365369
Pipe 146	1	0.625	140	1.78	1.86	0.031	0.03217428	0.031972396
Pipe 147	1	0.625	140	1.73	1.81	0.031	0.03046773	0.030330772
Pipe 148	1	0.625	140	1.68	1.76	0.031	0.02880768	0.02872899
Pipe 149	1	0.625	140	1.63	1.71	0.031	0.02719413	0.027167223
Pipe 150	1	0.625	140	1.58	1.65	0.031	0.02531925	0.025645655
Pipe 151	1	0.625	140	1.53	1.6	0.032	0.024576	0.024164473
Pipe 152	1	0.625	140	1.48	1.55	0.032	0.023064	0.022723873
Pipe 153	1	0.625	140	1.43	1.5	0.032	0.0216	0.021324058
Pipe 154	1	0.625	140	1.38	1.45	0.032	0.020184	0.019965238
Pipe 155	9.81	0.625	140	1.33	1.39	0.032	0.18195745	0.182933281
Pipe 156	1	0.625	140	1.28	1.33	0.032	0.01698144	0.017371472
Pipe 157	1	0.625	140	1.22	1.28	0.033	0.01622016	0.015895122
Pipe 158	1	0.625	140	1.16	1.22	0.033	0.01473516	0.01447923
Pipe 159	1	0.625	140	1.11	1.16	0.033	0.01332144	0.013345833
Pipe 160	1	0.625	140	1.05	1.1	0.033	0.011979	0.012041993
Pipe 161	1	0.625	140	1	1.04	0.034	0.01103232	0.011002672
Pipe 162	1	0.625	140	0.94	0.99	0.034	0.00999702	0.009812614
Pipe 163	1	0.625	140	0.89	0.93	0.034	0.00882198	0.008868899
Pipe 164	1	0.625	140	0.83	0.87	0.035	0.00794745	0.007794579
Pipe 165	1	0.625	140	0.78	0.81	0.035	0.00688905	0.006948214
Pipe 166	1	0.625	140	0.72	0.75	0.035	0.00590625	0.005991883
Pipe 167	1	0.625	140	0.67	0.7	0.035	0.005145	0.005244892
Pipe 168	1	0.625	140	0.61	0.64	0.036	0.00442368	0.004409186
Pipe 169	1	0.625	140	0.56	0.58	0.037	0.00373404	0.003763969
Pipe 170	1	0.625	140	0.5	0.52	0.037	0.00300144	0.003052057
Pipe 171	1	0.625	140	0.44	0.46	0.038	0.00241224	0.002409271
Pipe 172	1	0.625	140	0.39	0.41	0.04	0.0020172	0.001927382
Pipe 173	1	0.625	140	0.33	0.35	0.039	0.00143325	0.001414976
Pipe 174	1	0.625	140	0.28	0.29	0.041	0.00103443	0.001044096
Pipe 175	1	0.625	140	0.22	0.23	0.041	0.00065067	0.000668313
Pipe 176	1	0.625	140	0.17	0.18	0.047	0.00045684	0.00041479
Pipe 177	1	0.625	140	0.11	0.12	0.044	0.00019008	0.000185385
Pipe 178	1	0.625	140	0.03	0.03	0	0	1.67561E-05

Appendix E: Irrigation Experimental Data

Flowrates Using 16d Nail-Sized Holes		
Emitter	Flowrate, Q	Flowrate, Q
ft from bucket	mL/15 sec	GPM
1	55	0.0561
2	27	0.0275
3	48	0.0489
4	54	0.0551
5	38	0.0387
6	27	0.0275
7	26	0.0265
8	51	0.0520
9	40	0.0408
10	19	0.0194
11	39	0.0398
12	28	0.0285
13	17	0.0173
14	25	0.0255
15	29	0.0296
16	19	0.0194
17	11	0.0112
18	18	0.0184
19	22	0.0224
20	25	0.0255
21	25	0.0255
22	19	0.0194
23	19	0.0194
24	15	0.0153
25	31	0.0316
26	36	0.0367
27	50	0.0510
28	35	0.0357
29	20	0.0204
30	18	0.0184
31	31	0.0205
32	20	0.0199
33	15	0.0193
34	22	0.0186
35	43	0.0180
36	34	0.0174
37	21	0.0168
38	54	0.0162
39	22	0.0155
40	19	0.0149
41	15	0.0143
42	17	0.0137

Flowrates Using 10d Nail-Sized Holes		
Emitter	**Flowrate, Q**	**Flowrate, Q**
ft from bucket	**mL/15 sec**	**GPM**
1.5	24	0.02447
2.5	23	0.02345
8.5	21.5	0.02192
9.5	18	0.01835
16.5	19	0.01937
18.5	23	0.02345
27.5	40	0.04078
41.5	42	0.04282
40.5	26	0.02651
39.5	22	0.02243


Flowrates With 16d Nail-Sized Holes
Flow, GPM
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
Distance from Bucket, ft
R² = 0.1113


Flowrates With 10d Nail-Sized Holes
Flow, GPM
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10
20
30
40
50
Distance from Bucket, ft
R² = 0.2833

Appendix F: Harvestable Plants

Appendix G: Water Collection and Storage Design Drawings

Appendix H: Rice Tank Design Drawings

Appendix I: Rice Tank Excavation Calculations

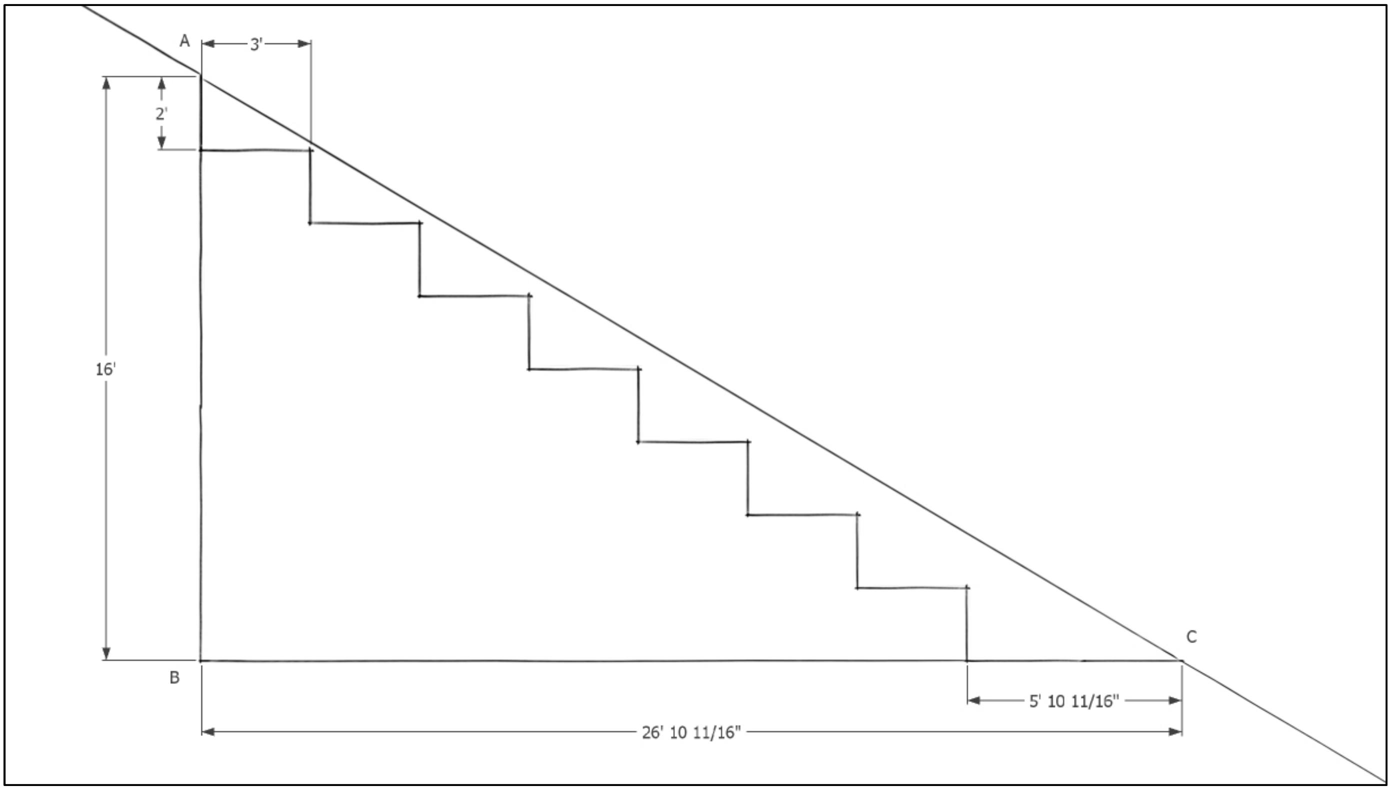


Figure 17: Rice Tank Dimensions

Each terrace has a depth of 24’
Determine area of material to be cut:

$$A_{ABC} = \frac{(16')(26.89')}{2} = 215.12\ \text{ft}^2$$

$$A_{KEEP} = \frac{(14')(21')}{2} + \frac{7\left((3')(2')\right)}{2} = 168\ \text{ft}^2$$

$A_{CUT} = A_{ABC} - A_{KEEP} = 215.12\ \text{ft}^2 - 168\ \text{ft}^2 = 47.12\ \text{ft}^2$

$V_{CUT} = d * A_{CUT} = (24')(47.12\ \text{ft}^2) = 1130.88\ \text{ft}^3 = 41.89\ \text{yd}^3$

From RS Means 31.23.16.16 0030

For medium clay, 1 cubic yard may be excavated by hand in 3.33 hrs with a crew of 5 people.

$$1\ \text{person} * \frac{3.33\ \text{hours}}{5\ \text{people} * 1\ \text{cubic yard}} = 0.666\ \text{hours/ cubic yard}$$

Total time required to remove material:

41.89 cubic yards * 0.666 hours/ cubic yard = 27.89 hours

Considering a 5 hour work day

27.89 hours * 1 day/5 hours = 5.578 days ~ 6 days

Appendix J: Construction Schedule

Construction Schedule Explanations

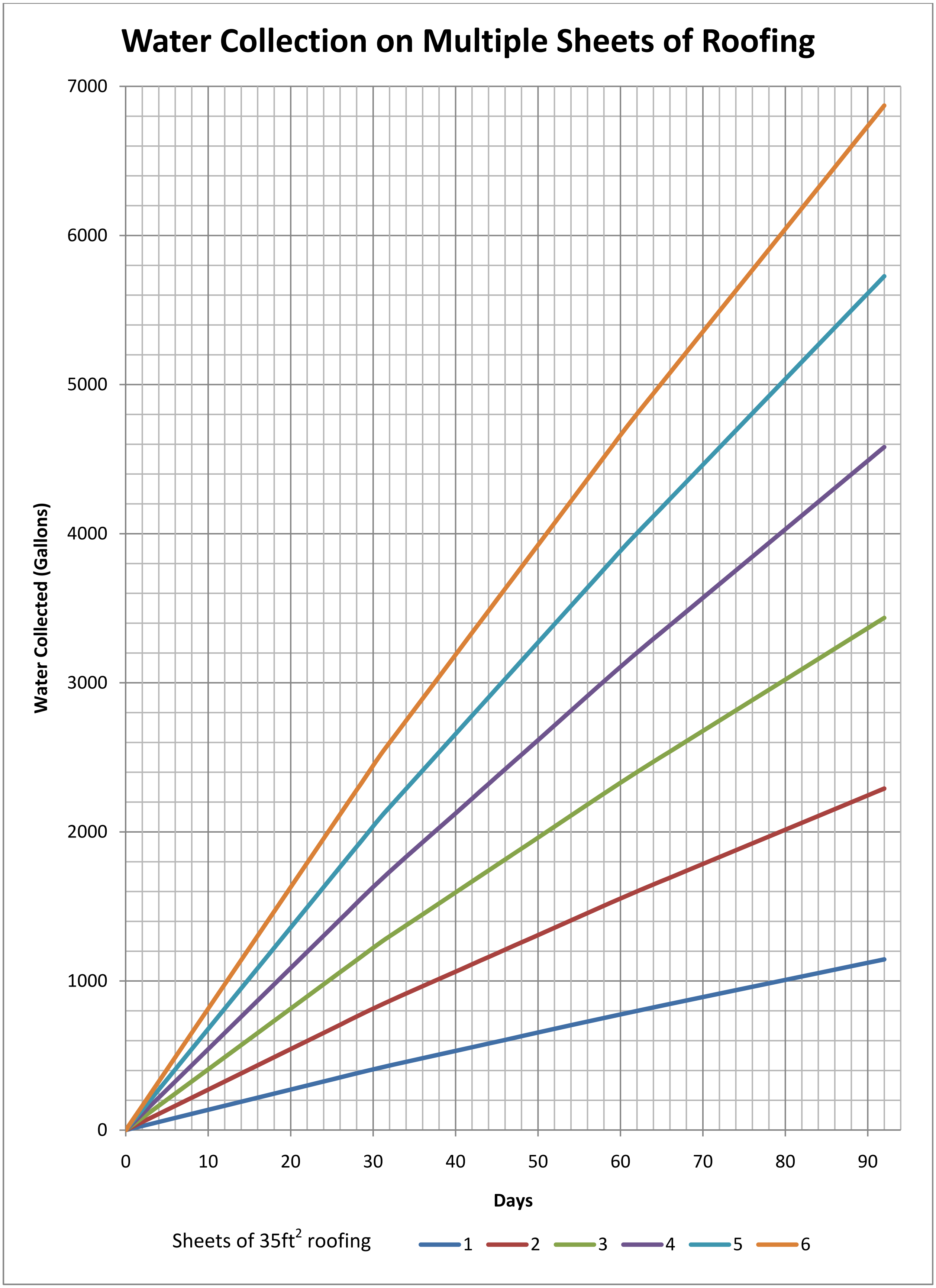
The flowchart of the construction schedule for the rainwater collection, storage, and irrigation system is located in this Appendix. The separate components of the design are depicted by color to better visualize the work to be completed. Orange boxes indicate an activity that is part of the collection system construction, blue boxes indicate storage system construction, and green boxes indicate distribution system construction.

Across the top of each procedure box, the early start, duration, and early finish of the project is shown. The bottom half of the box depicts the late start, slack, and late finish. The late start is the latest possible day to begin the project that will not affect the critical path. If the task is delayed further than the late start, that task will become part of the critical path of the entire project. Slack (or float) is the number of days a task may be delayed without delaying the project finish.

The critical path (outlined in red) shows the tasks for which no delay may occur to complete the project in the shortest possible amount of time. The available slack for all activities on the critical path is zero. The irrigation system design's critical path follows the distribution system construction, including the process of making holes in the garden hose.

The construction schedule for the rice terraces is also shown. This schedule utilized a 5-hour workday because it was assumed that the farmer digging the terraces and constructing them would have other daily farm duties to attend to during the other daylight hours.

Appendix K: Construction Guide


Water Collection on Multiple Sheets of Roofing
Water Collected (Gallons)
0
1000
2000
3000
4000
5000
6000
7000
0
10
20
30
40
50
60
70
80
90
Days
Sheets of 35ft² roofing
1
2
3
4
5
6