Improving Accessibility
To Potable Water in Yuu, Ecuador

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Submitted: December 14, 2012

Disclaimer

Team Pipe Bueno consists of engineering students working on an international senior design project at Michigan Technological University in Houghton, MI. While the students worked under the supervision and guidance of associate faculty members, the contents of this report should not be considered professional engineering.

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Executive Summary

In May of 2012, four students formed the very first senior design team from Michigan Tech to ever go to Ecuador: Team Pipe Bueno. Team Pipe Bueno would eventually be charged with providing a small community in the Amazonian region of Ecuador with access to potable water.

The Shuar community of Yuu, Ecuador is located approximately eight hours outside of the capital city Quito. Its 120 residents are comprised mainly of farmers, artists, and families that are attempting to send their children to university. Most of the community members are farmers and construction workers who work in nearby towns. Approximately three years ago, the federal Ecuadorian government built this community a water distribution system complete with pump, tank, and PVC piping down the length of the community. This system was poorly engineered, however, and so it never distributed so much as a drop of water to any of the families. Currently, the community gathers some water at their homes, or else they trek up to five kilometers into the jungle to access springs.

Upon arriving and discovering the community's desire for easy access to potable water, the team collected several data sets. Ranging from surveying roads to interviewing families about water consumption, from water quality to available water flow, Team Pipe Bueno collected as much information as possible about the community and their water sources.

After returning to the United States, it was Team Pipe Bueno's first intention to design an entirely new distribution system for this community. Approximately halfway through this design, the team realized that designing something that had already failed in this community was not in Yuu's best interests. After re-evaluation of a rain water collection system and requesting some precipitation data from Ecuadorian partners, Team Pipe Bueno created a much more sustainable and practical solution: rain water collection systems that will be built at each individual home.

The final design utilizing rain water collection provides a sustainable solution to Yuu's concerns about access to water at their homes. Team Pipe Bueno intends to involve the community members in the construction process, ensuring that they will be able to build these systems for future homes and also feel personal ownership of their system. Additionally, this design is much more cost effective, at approximately $324 (U.S.dollars) for each of the thirty-eight homes total in the community. This system will provide every member of the community with at least enough water needed for consumption every day of the year.

Team Pipe Bueno’s purpose in reaching out to this community was to help them gain access to potable water. This design does just that, and also allows for adjustments to be made as needed by the community.

Introduction

The community of Yuu is located in the Amazonia region in eastern Ecuador, approximately seven hours from the capital city Quito. Yuu is a Shuar community established approximately ten years ago. Shuar and Spanish are the prominent languages spoken. The community boundaries span approximately one mile in length, and are located half way between two larger cities Puyo and Macas along a major highway.

Families attempt to send their children to universities in hopes that they will return well-educated and able to contribute to the community. Boys and girls attend school daily, where they are taught by professors within the community. The main sources of income are farming, arts, and construction (and other jobs) in Puyo or Quito. Yuu has a handful of skilled individuals who have acquired construction and carpentry knowledge from external jobs. This is reflected in the quality of their newer houses and the school, which are built of concrete instead of wood. Due to the relatively low income the community receives, most families try to limit the amount of children they have in order to provide them with the money they need to live and attend at a university.

Although some basic needs of living are met such as electricity, people in Yuu struggle to find adequate water during the dry season. Based on the needs and desires of Yuu, Team Pipe Bueno is designing a system that allows the community to receive potable water year-round. Currently, the approximate 120 residents of Yuu are utilizing water from various groundwater sources, surface water sources and rain collection. They do not use any form of treatment before consumption. Many of these sources show signs of contamination and become scarce during the dry season. During the dry season the community is left with insufficient water leaving them with two options: drinking contaminated stagnant water or walking for miles in harsh terrain to obtain water. These stagnant sources are eutrophic and the visible quality is poor. Some of these sources are utilized as bathing areas although it is common for fungus to grow on the bathers' skin.

Many communities throughout Ecuador have received government help for obtaining potable water. According to a survey held in 2004, "In rural areas, 38 percent of the systems have collapsed and 20 percent are seriously impaired"[1]. However, major system failures have occurred since the implementation of these water systems. The community of Yuu falls within the 38 percent of the systems that have collapsed. Approximately three years ago, the federal Ecuadorian government constructed a water distribution system complete with pump, tank, and PVC piping down the length of the community. According to the Yuu community, it never worked as intended, failing to distribute water. There are many possible reasons to explain why this occurred. The water source used had a low flow and was almost non-existent during the dry season. Proper education of the maintenance and upkeep of the system was not received by the community. Another large problem that Team Pipe Bueno identified was that the pump was not efficient for the large elevation change of ninety meter from the pump the tank. On the pump, it stated that the pump was efficient up to twenty-four meters which was less than required.

An important aspect of this project is to ensure that the system designed is sustainable and that the community is educated on maintenance and upkeep of the system. It is ideal that the system will be reliable and last for many generations. The community does not have a specific budget, although they do not receive much yearly income; therefore, designing an economical system is critical. Investigation of the past system is important to ensure that the future system will not have the same qualities that led to failure of the past system.

Methods

Surveying

While traveling to Yuu, Ecuador, some of the main data that was to be collected was the layout of the community and corresponding topographical data. To begin developing the layout of the town, a full profile of the road was surveyed using a sight level. Along with the survey data, GPS points were taken along the centerline of the road every hundred feet. After developing the outline of the road that passed through the community, data points were taken at the corners of each house with the GPS, as were the dimensions of each home.

After returning from Ecuador the data collected was compiled into spreadsheets and sorted and organized to facilitate further analysis. Once the data was organized and formatted, it was imported into AutoCAD©, and a master layout of the community was developed. The AutoCAD© drawing consisted mostly of the GPS data points but was verified through the use of the manual survey data. The AutoCAD© drawing with locations and elevations provided a solid base for the development of the layout for a water distribution system.

Population Demographics

When designing a water system, it is important to know the typical per capita water consumption and the number of residents in the community. Team Pipe Bueno spent the first couple days getting to know the community and the social dynamics and structure. With the communication and culture barriers it was difficult to obtain exact data. The team went house to house asking basic questions in order to estimate how many people live at each house, their daily water consumption, and their current water sources. The GPS coordinates, dimensions, and characteristics were also recorded for each house. The typical household size was 5-6, but it ranged from 1-15 people with an approximate 120 people living in the community. This data was gathered from each of the thirty-eight households that are currently in Yuu.

Turbidity

The residents of Yuu had several water sources they used for drinking, cleaning, and washing. These sources included small groundwater springs, surface water ponds, rain barrels, and smaller standing springs. The water quality was tested in order to determine the overall safety of these water sources and to determine whether the water they were using was potable.

Potential water sources for the town of Yuu were also tested for water quality. Certain sites may be conveniently located, but have non-potable water. Water filtration was a consideration of the project, but the cleaner the water sources the better. Ultimately, the water quality data collected was considered, but not used in the final design of the project.

Clay is the dominant soil type encountered in Yuu. Because of the large quantities of rainfall, significant volumes of clay particles run off into standing water sources, contaminating them in the process. Most water sources were notably milky in composition; therefore, it was important to test the turbidity of each water source. For each water source (groundwater and surface water), five turbidity measurements were conducted. These measurements were averaged to account for variability encountered during testing. The methodology can be found in Appendix A.

Measurements in flowing water sources were taken upstream of any other activity present in the area (walking, dogs, other data collection tasks). Even stepping in a stream source with one foot could significantly stir up particulate in the source. Therefore, taking upstream samples was essential to ensure that the water was uncontaminated from external forces. This practice was also applied to the groundwater spring sources, to ensure accurate measurements.

Because of the location of Yuu, associated soil properties, and topography, it was no surprise that each surface water source had very high turbidity levels. Most houses were at a higher elevation than most of the surface water sources, and also had various amount of livestock. Latrines were assumed to exist at similar elevations. Because frequent rainfall events occur, clay, feces, and other material may drain into the surface water sources, as indicated by high NTU measurements in certain sources such as the wash ponds. Measurements ranged from 2 NTUs in flowing surface water to over 30 NTUs in sources such as wash ponds where water is not flowing; however, testing did not occur during rainfall events, which would result in higher NTU measurements due to the runoff of clay and particulate. The groundwater sources were generally <5 NTU. This is expected due to the large amount of filtration of the water as it percolated down to lower elevations.

Although turbidity analysis alone cannot determine potable water quality, it is an important indicator of the general quality of the water source. A turbid water source may be a result of lack of proper drainage or poor location selection of latrines. The livestock and latrine locations give evidence of a possible correlation between the turbidity and coliform levels; as turbidity increases, so do coliform and pathogens, but this theory has not been proven. It is therefore recommended that the community cease to utilize these surface water sources unless emergency use is require. The turbidity of the water will be an important parameter in the future, if filtration of surface water is pursued by the community.

Water Quality

The total coliform count is often used as an indicator of the overall water quality. The total coliform count was tested in current water sources, water from storage containers in households, and sources that were being considered for the main source of a distribution system. The materials used for this test were 200 3M™ Petrifilm™ *E. Coli.*/Coliform Count Plates, 200 1 mL pipets, and a spreader. Collection methods and details are explained in Appendix B.

For each current water source, five samples were taken. Fifteen samples were tested for the potential water sources. Three samples were tested from water gathered from storage within the house. Samples from each source were isolated by two thick plastic cards to minimize contamination. Groups of samples were held together using a rubber band and then inserted into a plastic bag. The results concluded that none of their current sources meet the EPA standards (discussed in Appendix B). The average total coliform count and the average *Escherichia coli* count for possible water sources and currently used water sources were found to be 143, 8, 120, and 2 respectively. Water tested from storage devices varied depending on the house and location (see Tables 1-3 for detailed results).

Flow Analysis

Flow data was collected to determine which sources would suffice for the community. The flow was found using the float method (by dropping a twig or leaf into the source and recording the time it took to reach the designated length). A minimum of ten trials were performed at each source. The length was chosen by the longest stretch that had relatively uniform width and depth. The width and depth were recorded to obtain an approximate cross sectional area. The flow was then found by multiplying the area and the velocity of the source. Team Pipe Bueno concluded that the flow from the water source used for the old distribution system (source 1) and another creek nearby, (source 2) would not be sufficient to supply the community year round due to the low flow and the seasonal variations.

The third source (source 3) was much larger than the first two. Team Pipe Bueno theorized that a possible reservoir may be constructed, and therefore a river bed analysis was performed. The team used this data to create a model of the river bed shown in Appendix C. This process also provided a more accurate manner of calculating the cross-sectional area, making the flow data calculated more reliable. This model will assist in determining the best location to construct a reservoir. The velocity of the river was found using the same methods above. The flow was then determined by multiplying the velocity with the volume (taken from the model) and then divided by the length used to determine the velocity. It was concluded that this source would be adequate to meet the community’s water needs, having a flow of 1,221,000 liters/day.

Preliminary Design

There exist multiple proposed design solutions to the water issues Yuu faces. One design option is to develop an entirely new piping distribution system. In order to scale this system correctly, a map of the community and the proposed water source was created in AutoCAD©. The water distribution model was then developed in EPANET 2.0©, overlain on this drawing.

The system would include damming a consistent and clean water source which lies approximately 3,000 lateral feet from the town and 1,500 feet vertical feet below. This water source was considered the optimal location based on flow data, local geography, and water quality analysis. Water would be consolidated behind a concrete dam that would need to be constructed on-site. No water treatment system would be installed at this time. This reservoir will service the entire community. Directly following this reservoir would be a tank and a pump. The overall head that needs to be provided by this pump would be sufficient for 3,000 lateral feet of pipe and 1,500 feet of vertical head in order to reach another storage tank closer to the community. This tank is located at a higher elevation than most of the houses in Yuu, and the water would then distributed by gravity. For the three houses that are higher than this tank, another pump would need to be installed right after the tank in order to reach these homes. The piping material selected is two inch PVC, for two reasons. One is to minimize head losses, and the other is that it is the smallest available piping from a nearby distributor in Puyo. It is proposed that the pipe should be buried at least one foot down when crossing the house property lines. This is to ensure the pipe is not exposed to sunlight, human traffic, and horse traffic (which are used for travel). Water will be accessed at each house via a spigot, but the system will not be built to accommodate bathrooms or showers. The pipes will run downhill on each side of the road, using the culverts that are currently in place in the highway to skip certain sections where homes are not present. The houses and buildings located near the top of the town, which include the school and church, would also have their own access points. The proposed layout is given in Appendix D.

The chosen design must conform to economic constraints, and some sacrifices may need to be made in order to develop a sustainable, affordable system. Therefore a cost analysis of this system has been prepared and presented in Appendix E. While on-site, Team Pipe Bueno visited local pipe distributors in Puyo, Ecuador and received piping prices. The piping comes in ten foot sections, so there are the appropriate numbers of connections for this. The approximate cost for piping for the entire community is $7,000, and there is an additional cost of $2,800 for pipe connections and tees. Team Pipe Bueno included a twenty percent overhead to cost to cover any miscellaneous materials and basic construction tools that may need to be purchased on site. For example, there were no shovels or adequate tools for this type of job observed anywhere while in Yuu, so these may need to be purchased. Additionally, pipes are typically connected with some kind of silicon adhesive, so this too will need to be purchased. Finally, Team Pipe Bueno priced the two pumps that would be needed for this project. The price of the first pump is approximately $9,000 and the second pump is approximately $4,000. These prices reflect the size needed to cover their respective heads and also include an incurred cost of having a specialist come to Yuu and install them. The grand total for a system of this size is approximately $25,000.

In addition to cost, there are several other factors that need to be considered when designing a new piping distribution system for this community. The community has previously had a piping system installed, and it never worked, due in part to poor engineering design, but also due to inevitable human error. While there is power in the community, the proposed pump location would be deep into the jungle. In such a remote location, power would not be an option and the system would rely on diesel fuel, just as in the previous system. The education of the community would be crucial to the maintenance and sustainability of the piped network system. In the community, multiple people would have to be educated on how to repair any issues that could possibly occur to the piping system. If the community is not prepared and ready to fix these problems, it could lead to a large portion or the whole community being without water for an extended period of time. In a community that is desperate for clean drinking water, this would present a major problem. It would be necessary to educate more than one person who would be capable and competent enough to fix these larger issues. If the pump fails because the desired source does not have adequate flow year round, it will be difficult for members of the community to solve this problem. All of these issues leave too much potential for failure.

Final Design

Precipitation

Because of Yuu’s remote location in the Amazon region of Ecuador, it presented a challenge to collect rain water data that would be reliable and representative of the actual location of the community. After extensive research data was found for a city nearby called Puyo, approximately 30 miles away. This data is assumed to be representative of the rainfall in Yuu, since it is the closest data collection site available. The data was obtained from the National Oceanic and Atmospheric Administration National Climate Data Center (NOAA NCDC) database and contained daily precipitation data from 2008 thru 2012. This data was given to us by our Escuela Politecnica Univercial (EPN) partners in Quito, Ecuador. Although this resource contained a large amount of useful data, there were gaps in the data, up to several months at a time. It was decided to use the data from 2011 because it was the most complete, and the few days that did not have any precipitation data could be assumed to have zero precipitation. This data was compiled and is represented in Appendix F. Some of the data are highlighted in yellow. These data points represent days that had no collection reported, and so the assumed value was zero. This is represented in the adjusted precipitation values in Appendix G. However, it was likely there was some precipitation on those days because there were also days that had recorded values of zero precipitation, but not very many (only eleven for the year).

This data was then used to determine the volume of water that could be theoretically collected every day for each house. Sample calculations are given in Appendix H. Reliability is calculated using individual roof surface area and amount of water needed per home based upon the number of occupants and an assumed consumption of fifty liters per person per day. The roof material throughout most of the community was not easily identified but was a metal and this was taken into consideration when calculating potential collection.

Analyzing the precipitation data gathered, first there was a need to decide what conclusions were desired and what specifically needed to be calculated as an outcome of this analysis. It was determined that a daily amount of water that would be available for a specific tank size to each household. An Excel© spreadsheet was developed using the precipitation data, roof area of the homes, and water consumption per capita. This spreadsheet calculates a running total of daily amounts of water available.

The first step in developing this spreadsheet was to calculate the roof area for each specific home by using the measurements taken while in Ecuador. After calculating the roof area, the amount of water that could potentially be collected can be calculated corresponding to the daily precipitation data. Each daily precipitation value was converted into feet and then multiplied it by the individual house area, which was then converted to liters. This is then multiplied by a safety factor of 0.7 (70%) to account for the fact that not all of the water will be collected on any given day. After the potential amount of water collected was calculated, next an upper limit based on tank size could then be factored in. The tank size limited the amount of water collected to a value that was pre-determined by the team as a sufficient size. With a constant tank size, roof area, and consumption the team was able to put together an equation, shown in Appendix I, that would show a constant daily total that varied depending on the amount of precipitation.

Tank Sizing

After deciding that the rainwater harvesting system would consist of identical tanks for each individual house, the size of the tank became a critical design decision in order to supply every house their specific amount of water needed. After the excel spreadsheet was developed to calculate the frequency of the amount of water each person in the household was receiving some of the constant variable were modified so that they could be inputted individually depending on what was desired. The new spread sheet still calculated the frequency of water per person in the household but used the input data of the variables of tank size, population, roof area, and conserve percentage. The spreadsheet was ultimately used to evaluate the tradeoffs between the size of the tank and the water supply reliability. The conserve (ration) percentage was a new parameter that was added to reduce the daily consumption from fifty liters per day per person to twenty liters per day per person in times when the tank storage dropped below the specified level. For the calculations of tank size, the conserve percentage was assumed to be 40%. With this new spreadsheet, after the four parameters are entered, a table is output displaying the reliability of the chosen tank size with the specified household size and roof area. A minimum tank size was found that would provide a sufficient amount of water to that particular family every day of the year. Once the minimum tank size was found for each house, a uniform tank size was chosen for the entire community that would provide a sufficient amount of water to every house and still be reasonably sized for construction. This led to over designing of the tank size for the majority of the houses throughout the community. Even though the majority of households will not need this large of a tank, the design for every home to have the same size tank was pursued. An example of the Excel© spreadsheet and calculations can be seen in Appendix J. A summary of the Excel© spreadsheet can be viewed below.

Table 1: Tank Sizes for 100% Reliability

			100% Reliability	
House	# of people	Roof Area	Tank Size (L)	
R0	1	1116.00	650.00	
R1	1	728.00	650.00	
R2	5	1320.00	3300.00	
R3	8	1170.00	5500.00	
R4	3	1102.00	2000.00	
R5	4	1296.00	2500.00	
R7	4	1476.00	2500.00	
R8	3	1760.00	1900.00	
R9	7	1440.00	4500.00	
R11	7	1530.00	4700.00	
R12	2	924.00	1300.00	
R13	8	2457.00	5000.00	
R14	4	1116.00	2500.00	
R15	5	1440.00	3300.00	
L0	1	1584.00	650.00	
L1	6	1521.00	3800.00	
L2	5	1521.00	3300.00	
L3	8	1581.00	5400.00	
L4	3	1581.00	2000.00	
L5	4	1386.00	2500.00	
L6	3	1287.00	2000.00	
L7	1	1209.00	650.00	
L9	15	1584.00	5500.00	94.5%
L10	5	1404.00	3300.00	
L11	8	1170.00	5500.00	
L12a/b	6	1287.00	4000.00	
		Max Volume =	5500.00	

System Components

Gutter

A proper gutter system is needed to ensure adequate collection of rainfall from the roof. The major components include not only the gutter itself, but also the gutter hangers. Although manufactured gutters and gutter hangers exist, the costs of these materials are quite high on a per house basis. Gutter hangers made of wood were selected for mounting the gutters to the roof. Wood is a locally available material, as well as a cheap material to work with. It will consist of two pieces; one piece connects to the rafters on the roof, and the other piece secures the gutter in place. The roof overhangs the gutter slightly so that the water loss off the roof is kept to a minimum. The gutters will have a downward slope towards the storage tank of at least 1.5%.

It was decided that six inch PVC pipe cut in half would be a suitable alternative for the gutters. Multiple reasons support this decision. One major factor was availability of materials. It was confirmed that PVC pipe was available in the nearest city, Puyo. By cutting the pipe in half, the cost per linear foot of the pipe is halved. Manufactured gutters were quite expensive per linear foot and there was no confirmation that such a product as this was readily available in Puyo. The PVC sections are approximately three meters in length. Because most houses in Yuu had lengths greater than three meters, PVC joints must be used to connect the pipes.

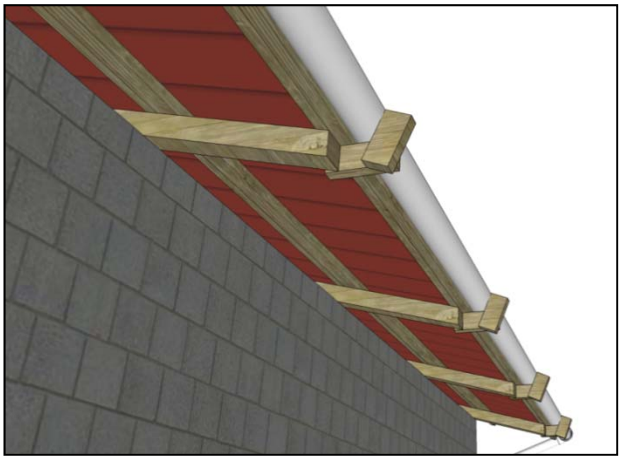

Figure 1: Gutter Hanger Design

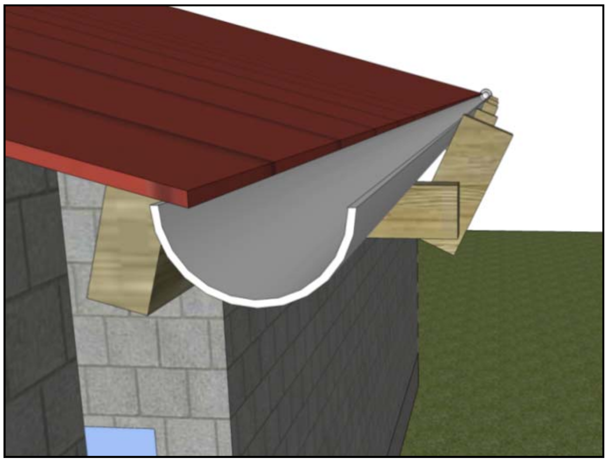

Figure 2: Gutter Orientation

Water Quality

One major goal of designing a system such as this is to ensure that the water remains potable while in storage since sediment, feces, and other particulates can build up on the roof in times of drought. When a storm occurs, these contaminants would be washed into the storage tank (if no controls are used). This will accelerate the growth of pathogens within the storage tank, which can result in sickness if the water is consumed. The filtration apparatus that was designed consists of two parts; a coarse and fine screen filtration section (hereby referred to as the funnel section), followed by a first flush device. The funnel section is designed to remove large objects such as leaves and twigs (which can be a nutrient source for bacteria in the storage tank), as well as to prevent mosquitos from entering the tank. The section consists of a plastic funnel with notches cut in the sides, so that the pipes coming from each gutter sit in the funnel instead of just resting on top. The funnel will have wire mesh in one layer, and a finer mesh in the layer below. Very fine screens were considered to not be needed, since water must flow through the screens at a reasonable rate, so that no water is lost over the sides of the funnel. A very fine screen could contribute to excessive overflow, which is undesirable.

A ball style first flush device complements the screen section. The purpose of this device is to remove the first inflow of water to the storage tank when a storm begins. As a storm begins, the precipitation that hits the roof first will dislodge and carry pollutants which flow into the first flush device. As the storm progresses, the runoff water is initially diverted into a vertical section of pipe. A ball rises with the water level in the first flush device. When the first flush device is filled completely, the ball seals off a hole at the top, and the rest of the runoff can continue into the storage tank.

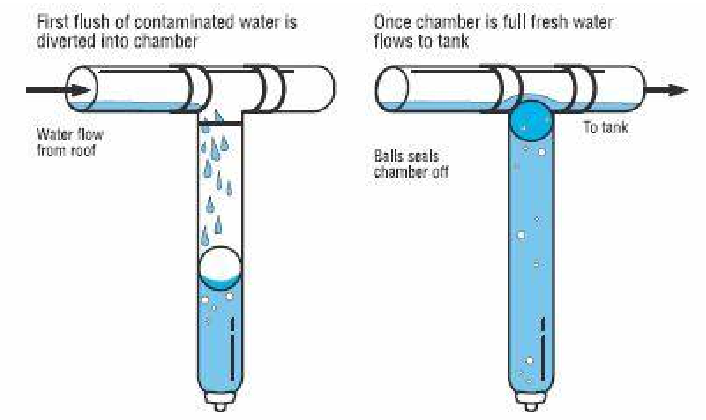

Figure 3: Ball Style First Flush Device [2]

It can be assumed that the volume of water in the first flush device contains most of the contaminants from the roof; therefore this water is slowly dripped on the ground and wasted. If water is dripped onto the ground too fast, the first-flush device may not fill, and clean water will be diverted into the first flush device rather than the storage tank. The slow dripping is to ensure that clean water flows into the storage tank, and is not wasted in the first flush device, while providing the capacity to capture the first-flush volume in the next rainfall event.

The filtration apparatus is attached directly to the storage tank; therefore a support form is needed in order to suspend the pipe segment. A simple support structure made out of wood that resembles a two pronged fork, will be held in the ground with a small portion of concrete. The 90° elbow that connects the screen funnel to the first flush device is supported in the middle of the fork, effectively reducing deflection of the pipe section and stresses exerted on the pipe connections.

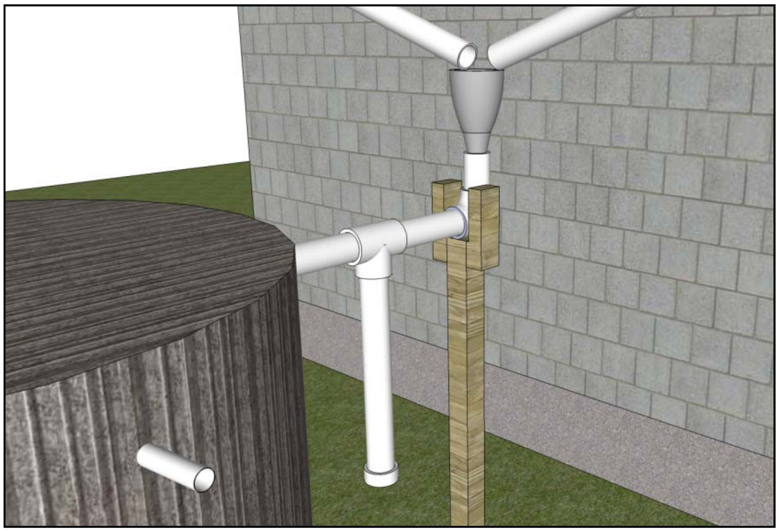

Figure 4: Filtration Apparatus. (Notches in funnel screen not shown)

Storage Tank

Two major options for storing the rainwater were considered; purchasing polyethylene (PE) barrels or constructing a storage tank. The former was expensive (approximately $264.00 USD) and had a limited storage capacity (approximately 2500L). The latter was chosen as a more reasonable solution, utilizing a tank construction style known as Ferro cement. A Ferro cement tank is relatively easy to build, consisting of a concrete base with concrete walls reinforced with chicken wire and rebar. A mix ratio of 1, 3, and 0.5 by volume (cement, sand, and water) results in a mixture similar to a plaster. This plaster is spread onto the chicken wire and rebar in layers to form the tank wall. The tank will include the inlet from the filtration apparatus (at the top of the tank), a screened overflow pipe, a spigot, and a plug at the bottom of the tank.   The screen overflow pipe is to ensure excess water can escape the tank and not backup into the filtration apparatus. The plug at the bottom of the tank ensures complete drainage for tank cleaning.

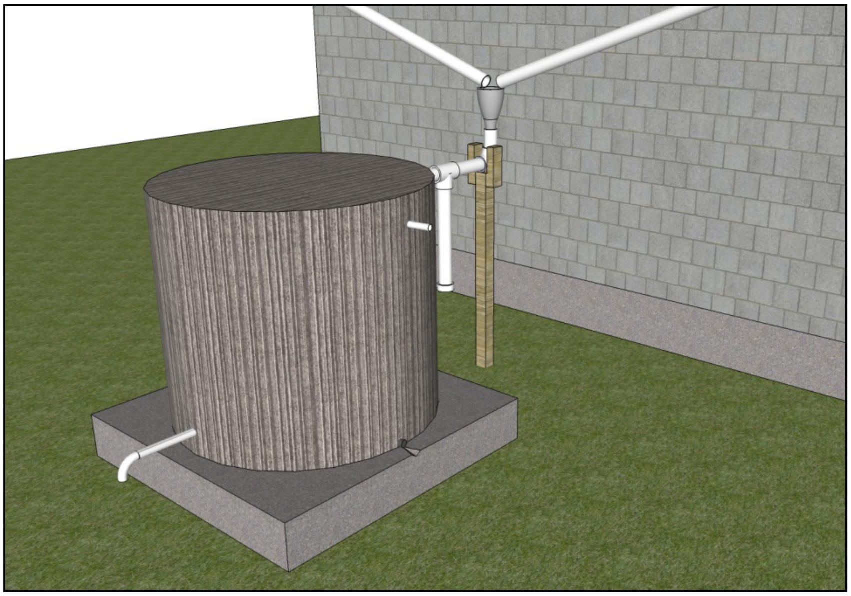

Figure 5: Ferro cement storage tank with associated components. (Spigot valve and cover not shown)

The spigot is where the resident can access the stored water, and is located approximately 6 inches above the bottom of the tank. This results in a quantity of dead space in the tank (water that cannot be accessed). This is important because the filtration apparatus cannot guarantee 100% sediment removal; therefore sediment will most likely build up in the tank. In order to clean the tank, an access cover will be installed in the top of the tank.

Cost Estimate

A cost estimate was developed for the entire community (38 houses). Although the materials needed for each house vary, average values for a generic house was used.

A cost estimate on a per house basis was developed. A per house cost estimate has inherent uses in reporting an estimate of how much a system will cost. However, most of the houses are unique in dimensions and location conditions. The population estimate was a difficult task that resulted in extremely vague estimates of residents in each household. Therefore, the actual cost per house will fluctuate greatly depending on variables such as house dimensions, number of residents, and roof configuration.

Many of the houses deviated from the “generic house”. Therefore, there may be more length of gutter needed for a given house, which will increase costs. Because there was no building standard for the older houses, the orientation of the roof may vary greatly from house to house. More material may be needed for gutter hangers if the roof rafters are short. These are all issues that may only be properly assessed on-site.

Construction Schedule

After developing all the necessary components for the design of the rainwater harvesting system, a construction schedule was developed. It was assumed that each household would be constructing their own gutters, filtration system, and tank. While ordering and shipping information may vary depending on the supplier and availability of supplies, some rough estimates were used in the construction schedule for these events. Overall, construction of an individual household rainwater harvesting system will take approximately four weeks, depending on the ordering and shipping timeframes. A detailed outline of the construction schedule can be found in Appendix K.

Table 2: Construction Outline (Detailed version in Appendix K)

Activity	**Activity Number**	**Activity Duration** (Days - 8 hours)	**Predecessors**	**Successors**
Site Cleaning and Preparation	1	3	-	10
Order and Receive Pipe	2	7	-	13, 16
Order and Receive Wood	3	7	-	7
Order and Receive Concrete	4	7	-	11
Order and Receive Building Materials	5	7	-	7, 8, 14, 15, 16
Order and Receive First Flush Device	6	14	-	9, 14
Assemble Gutter Hangers	7	0.5	3, 5	9
Install Wire Mesh for Tank	8	0.25	5	11
Install Gutter Hangers	9	0.5	7	10
Install Gutters	10	0.25	1, 13, 9	12, 17
Pour Concrete for Tank	11	1	4, 8	12
Concrete Curing	12	7	11	20
Assemble Gutters	13	0.25	2	10
Assemble First Flush	14	0.25	6, 5	18
Assemble Screening Device	15	0.125	5	19
Assemble Piping	16	0.25	2, 5	17
Install Piping	17	0.125	16, 10	19, 20
Install First Flush	18	0.0625	14, 19	20
Install Screening Device	19	0.0625	17, 15	18, 20
Connect Piping to Tank	20	0.0625	12, 17, 18, 19	-

🟥 = Critical Path

Social Aspects

When first designing the water distribution system for the community of Yuu, there were many issues dealing with the social aspects of having a water system supplying the entire community. One of the biggest issues was the ownership of the community water distribution system when constructing and implementing. The water distribution system would be designed to be maintained and manage by the community as a whole to limit the social aspects that affected the system. But with a community system it was not clear in the design process if the problem of ownership was properly addressed. Once the design changed from a community water distribution system to an individual home rainwater collection system the issue of ownership eliminated. But new concerns developed dealing with tank sizes through the design process. Fairness was a concern if one family had a larger tank than another. Justifying to the community that need for a larger tank for a certain family which had more people in their household became an issue. To then limit this concern, jealousy throughout the community was taken in to consideration when designing the tank size. The most effective way to solve this issue is to give every household the same size tank, while still making sure that every household could collect and store enough water to satisfy their individual demands.

Concerns

Although the rainfall harvesting system is designed to be sustainable, it is not without concern. A standard system was designed for the “generic” house, but approximately half of the houses in the community did not share these generally standard dimensions and construction technique. It is projected that there must be improvisation in regards to the gutter hangers, gutters, and supports based on material availability and recycling of old material. Small deviations from the design may not be a major issue, but the efficiency of the system could be compromised if large deviations from the rainfall harvesting design are implemented.

Funding

At this time, it is unknown who the financial burden will be incurred upon. The cost per house of a system is generally not too expensive. Although the cost may turn into a community matter, it is more likely that each family will be responsible for the costs of their own system. This will reduce conflicts in intercommunity relationships on the issue of “fairness”; some families may require a larger tank than 5500L, which will increase the cost of the system. By placing most, if not all of the financial burden on each individual family, it will allow for variation of tank size based on need, not on “fairness”.

Recommendations

No system can be sustained without proper maintenance. Without system upkeep, the water may become contaminated with bacteria or mosquito larvae, or the ability of the system to collect an adequate amount of water may be compromised. The storage tank must be decontaminated at least bi-annually. The stored water must be drained from the tank in order for cleaning to occur. When cleaning, it is of upmost importance that nothing foreign enters the tank (such as animal feces, which is abundant near the houses). The filtration cone must be cleaned off manually in order to prevent clogging. The gutters may need to be frequently cleaned out from objects such as plant material. Communicating the proper technique in regards to these matters as well as the inherent consequences from system neglect will be incredibly important to ensure a long system life for the future, until more advanced water systems can be implemented.

It is recommended that the owner/residents of each house build their own system, rather than an appointed construction team in the community (However, additional help will most likely be needed for the Ferro cement tank construction). This will encourage ownership of the systems, with a motivation to upkeep these systems deriving from a personal stake in each system. Weekly inspection should occur to ensure the system is functioning properly. By building their own systems, the residents will have some knowledge of how the system functions, allowing them to make any repairs that are needed in the future. A system is only useful if it functions, and establishing ownership is a key parameter to ensure an adequate supply of potable water for Yuu.

To further the longevity of the system, children should not be allowed to play near the tank, nor should the tank or pipes be used to hang objects from (such as clothes). These issues can result in broken gutters and pipes. Animals must be restricted from the area, especially near the funnel in the filtration apparatus. In short, the system should not be touched or disturbed unless maintenance or cleaning needs to be conducted. The components should not be used for anything else other than their intended purposes.

It is important to communicate that these systems are easy to repair. Previously when the piping system failed, the pipe was repurposed for other uses. This left repair of the system generally impossible. If the materials in a failed rainwater harvesting system are repurposed, then the entire system will need repairs much sooner in the future for that household. It is recommended that in the case of system failure, the materials not be repurposed, as any problems may be a very simple problem. Problems include: clogged inflow pipes, clogged screens, a clogged spigot, improper orientation of gutters, leakage in gutters or pipes, etc. These are all basic problems that can be easily addressed in a reasonable amount of time.

Acknowledgement

Team Pipe Bueno would like to thank Dr. David Watkins, who served as a crucial mentor and advisor throughout the design process. They would also like to thank Dr. Kurt Paterson for accompanying the team to Ecuador and providing guidance and documentation of the trip.

Team Pipe Bueno would also like to thank their university partners in Ecuador. Students and faculty members from the Escuela Politecnica Internacional in Quito, Ecuador provided valuable help in understanding language and background information and also in understanding community dynamics while on-site. Student volunteers took time out of their studies and busy lives to accompany Team Pipe Bueno to Yuu and helped find suitable lodging in Puyo. Additionally, EPN faculty members provided crucial precipitation data for the rain water collection system design, and have been very helpful in answering questions via email after Team Pipe Bueno returned to the United States.

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List of Appendices

Appendix A

Methodology for Turbidity

The methodology of turbidity was as follows

1. Fill 1 ml vial completely and screw the cap on
2. Place filled vial into portable turbidometer
3. Allow turbidometer to measure turbidity level [Nephelometric Turbidity Units (NTU)]
4. Remove vial from turbidometer and discard water sample
5. Rinse vial

Appendix B

Water Quality

Methods for Coliform Testing

1. Place the Petrifilm plate on a level surface.
2. Using new pipet, collect 1 mL of the water.
3. Lift the film layer of the Petrifilm plate and release the 1mL of water on the center of the bottom plate and discard the pipet.
4. Carefully, roll the top film down, avoiding trapping air which caused bubbles.
5. Once the film is covering the bottom, the sample should naturally spread throughout the plate. Gently apply pressure on the spreader (using the flat side and lining it up with the inoculum) to ensure even spreading of the sample.
6. Lift the spreader and leave the petrifilm plate for a minute to let the gel solidify.
7. Using human incubation, explained below, the samples were incubated for 48 hours.
8. After incubation was complete, the total coliform (pink) and the *E. Coli.* (blue) were counted.

It is recommended that the samples be incubated between 34-36 degrees Celsius, approximately human body temperature. Since there was no incubation system available, the plastic bags containing samples were attached to the team members' bodies day and night in order to incubate the samples. As the samples incubated, the top film trapped gas that is produced by the lactose fermenting coliforms and *E. Coli.* (~95% of all coliform produce gas) indicated by the formation of blue and pink colonies. The number of total coliform and *E. Coli.* for each sample was counted and recorded. The petrifilm plates were discarded with the pipettes into sealed bags.

According to the EPA standards in the United States (less than 5% of samples of the minimum 40 samples tested are allowed to test positive for total coliform), none of the water samples tested were considered acceptable for consumption. Stagnant surface water had the highest amount of total coliform, while the water tested from inside the house varied depending on the house, and the ground water sources and rivers had the lowest counts.

Table 3: Summation of Water Quality Data, taken from possible water sources.

Source	Trial	TC	EC
Pump	1	3	0
	2	2	0
	3	3	0
	4	2	0
	5	6	0
	6	3	0
	7	2	0
	8	5	0
	9	1	0
	10	3	0
	Average	3	0
Outfall Pump	1	2	0
	2	1	0
	3	1	0
	4	6	0
	5	1	0
	6	1	0
	7	5	0
	8	2	0
	9	4	0
	10	3	0
	Average	2.6	0
Source 1	1	344	8
	2	368	6
	3	336	4
	4	248	0
	5	376	1
	6	296	6
	7	376	4
	8	352	13
	9	298	1
	10	352	2
	11	328	2
	12	288	5
	13	352	16
	14	336	9
	15	360	4
	Average	334	5.4
Source 2	1	200	0
	2	168	1
	3	240	0
	4	210	1
	5	362	4
	6	264	1
	7	270	0
	8	208	0
	9	168	1
	10	216	1
	Average	230.6	0.9
Total Average		143	8

Table 2: Summation of Water Quality Data, taken from currently used water sources.

Source	Trial	TC	EC
Spring A	A1	44	0
	A2	56	0
	A3	92	0
	A4	96	2
	A5	56	0
	Average	68.8	0.4
Spring B	B1	42	0
	B2	27	0
	B3	35	0
	B4	29	1
	B5	38	1
	Average	34.2	0.4
Spring C	C1	1	0
	C2	1	0
	C3	0	0
	C4	0	0
	C5	1	0
	Average	0.6	0
Spring D	D1	280	2
	D2	160	1
	D3	248	1
	D4	280	0
	D5	264	3
	Average	246.4	1.4
Spring E	E1	176	4
	E2	136	1
	E3	140	1
	E4	160	4
	E5	200	2
	Average	162.4	2.4
Spring F	F1	71	5
	F2	38	5
	F3	90	3
	F4	73	8
	F5	66	3
	Average	67.6	4.8
Spring G	G1	330	2
	G2	264	2
	G3	288	3
	G4	312	0
	G5	178	0
	Average	274.4	1.4
Pond L4-6B	1	101	3
	2	113	4
	3	78	11
	4	152	6
	5	100	9
	Average	108.8	6.6
Armandos	1	TMTC	TMTC
	2	TMTC	TMTC
	3	TMTC	TMTC
	4	TMTC	TMTC
	5	TMTC	TMTC
	Average	TMTC	TMTC
Total Average		120	2

Table 3: Summation of Water Quality Data, taken from water storage.

Source	Trial	TC	EC
R4 inside cup	1	TMTC	0
	2	TMTC	0
	3	TMTC	0
	average	TMTC	0
R5 inside cup	1	104	0
	2	118	0
	3	80	0
	average	101	0
R6 Tank	1	328	0
	2	388	0
	3	256	0
	average	324	0
R6 inside storage	1	304	0
	2	424	0
	3	344	0
	average	357	0
R11 inside pot	1	47	0
	2	41	0
	3	53	0
	average	47	0
R0 cup inside	1	87	0
	2	91	0
	3	96	0
	average	91	0
R1 Tank	1	15	0
	2	29	0
	3	19	0
	average	21	0
R11 Tank	1	63	0
	2	45	0
	3	51	0
	average	53	0
R2 Tank	1	63	0
	2	45	0
	3	51	0
	average	53	0
L5 bucket	1	31	3
	2	52	3
	average	41.5	3

L7 inside	1	TMTC	0
	2	TMTC	0
	3	TMTC	1
	average	TMTC	0.33
sph (pipe bucket?)	1	7	0
	2	6	0
	3	24	3
	4	1	10
	5	2	0
	average	8	2.6
R3 bucket	1	232	0
	2	162	0
	3	248	0
	average	214	0
R13 Inside storage	1	TMTC	30
	2	TMTC	25
	average	0	27.5
L9 20 liter	1	70	0
	2	60	1
	3	66	0
	average	TMTC	0.33
L9 gallon bucket	1	TMTC	8
	2	TMTC	5
	3	TMTC	4
	average	TMTC	5.7
L11/L11K	1	75	10
	2	68	9
	3	79	4
	average	74	7.7

**TMTC- This value represents ‘Too many to count’. This value was used if there were clearly over 300 colonies present after the 48 hours of incubation.*

**The Total average values excluded TMTC*

**Source column- this column represents the source name appointed by Team Pipe Bueno (example R4 represents the fourth house on the right side of the road).*

**TC- Total Coliform count.*

**EC- Escherichia coli count.*

Appendix C

Streambed Model

Excel river bed analysis

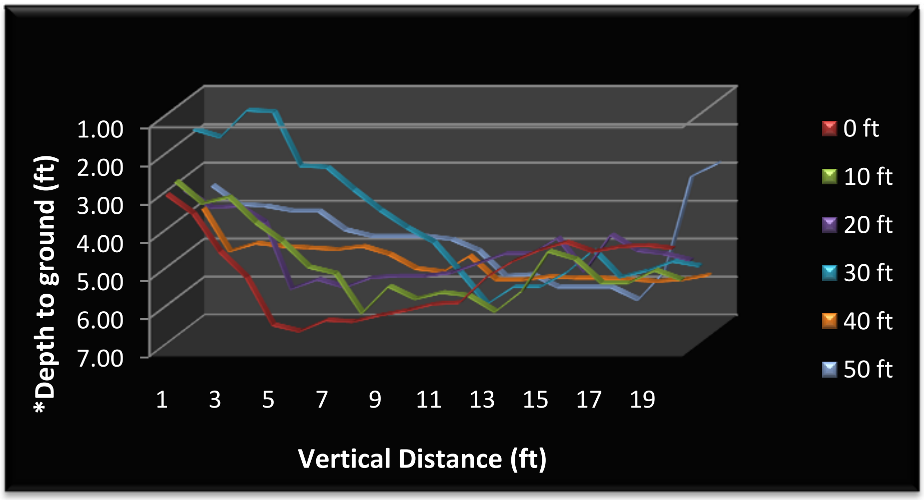


Figure 6: Excel river bed analysis at site 1

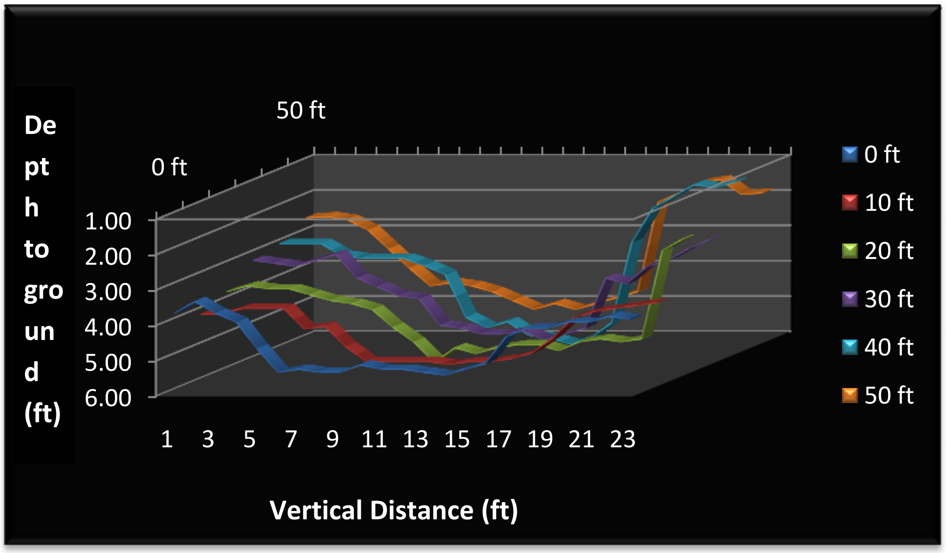


Figure 7: Excel river bed analysis at site 2

**The y axis of Figure 1 represents the depth from a reference height (64 inches was used) to the ground. When water was reached along the vertical distance, it was recorded in order to know where the water level was.*

Two team members stood on either side of the river holding a tape measure perpendicular to the river. Another member of the team acted as a reference height and measured the distance from the reference point to the ground. This measurement was recorded at each foot across perpendicular to the river. This process was repeated 5 times at intervals of 10 ft. parallel to the river.

Streambed Model at site 2 using Google Sketch

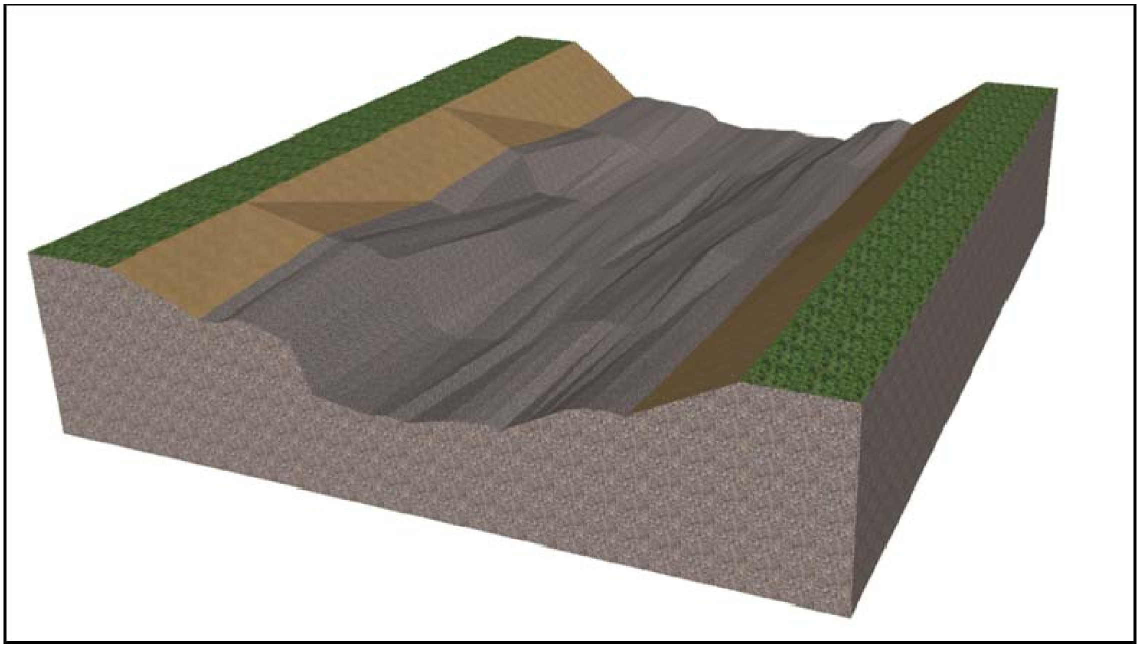
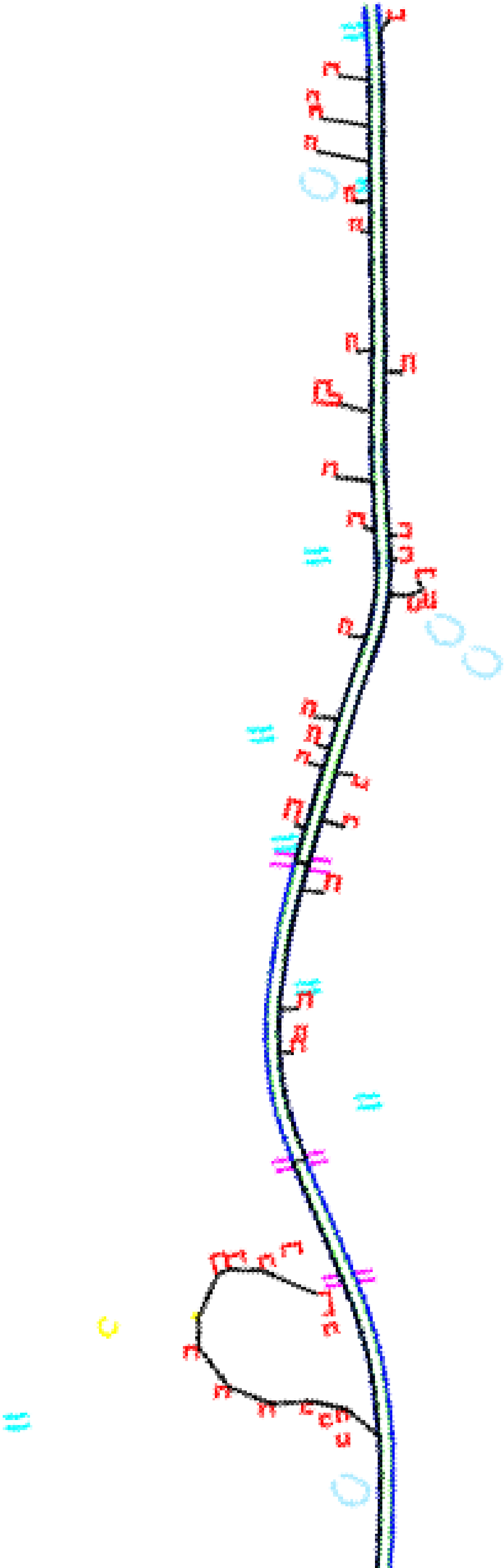


Figure 8: Streambed Model at site 2

A streambed model was created in Google Sketch. Site 2 was the only site modeled since Team Pipe Bueno thought it was the best option for building reservoir.

Appendix D

Piping Distribution System



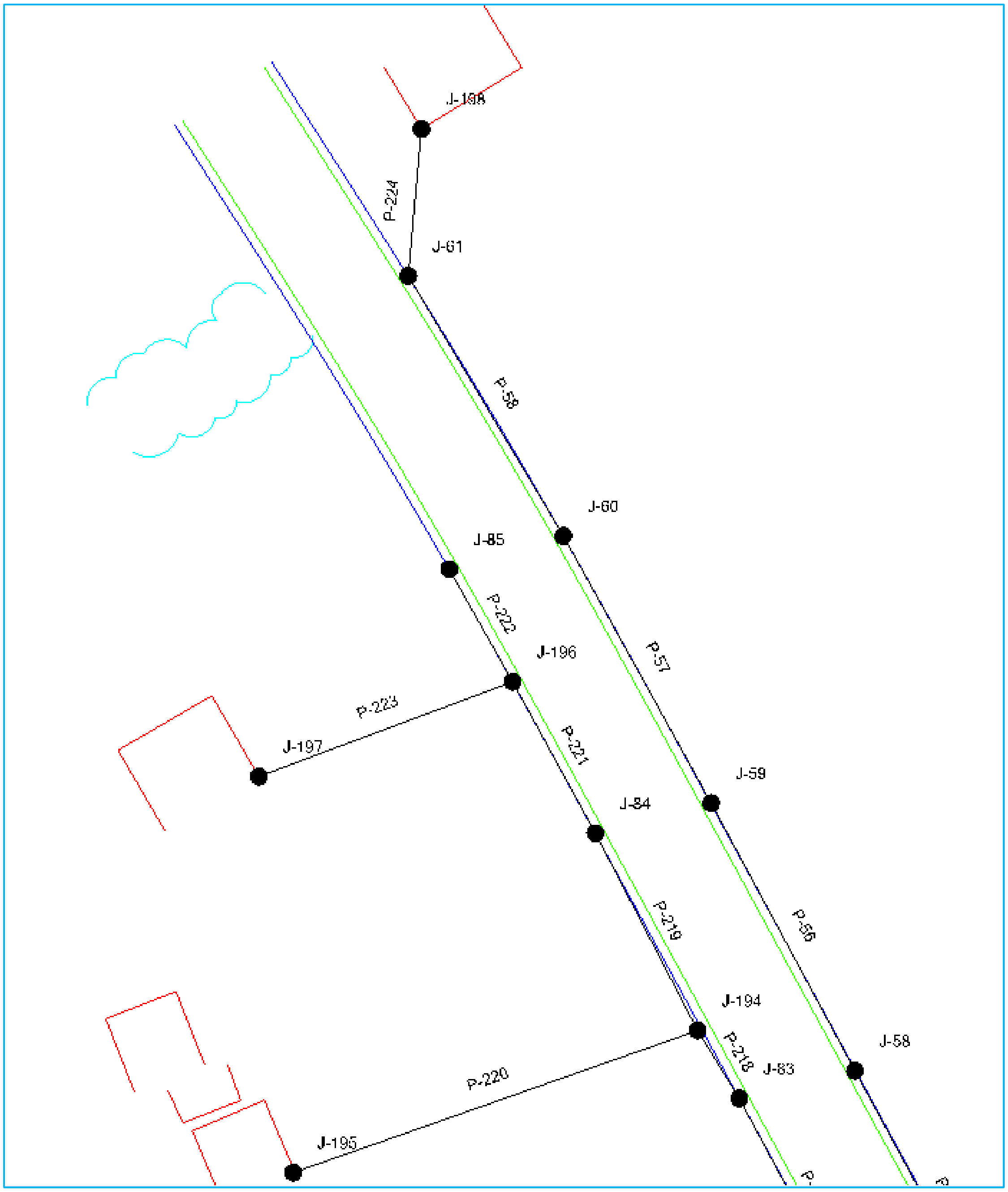
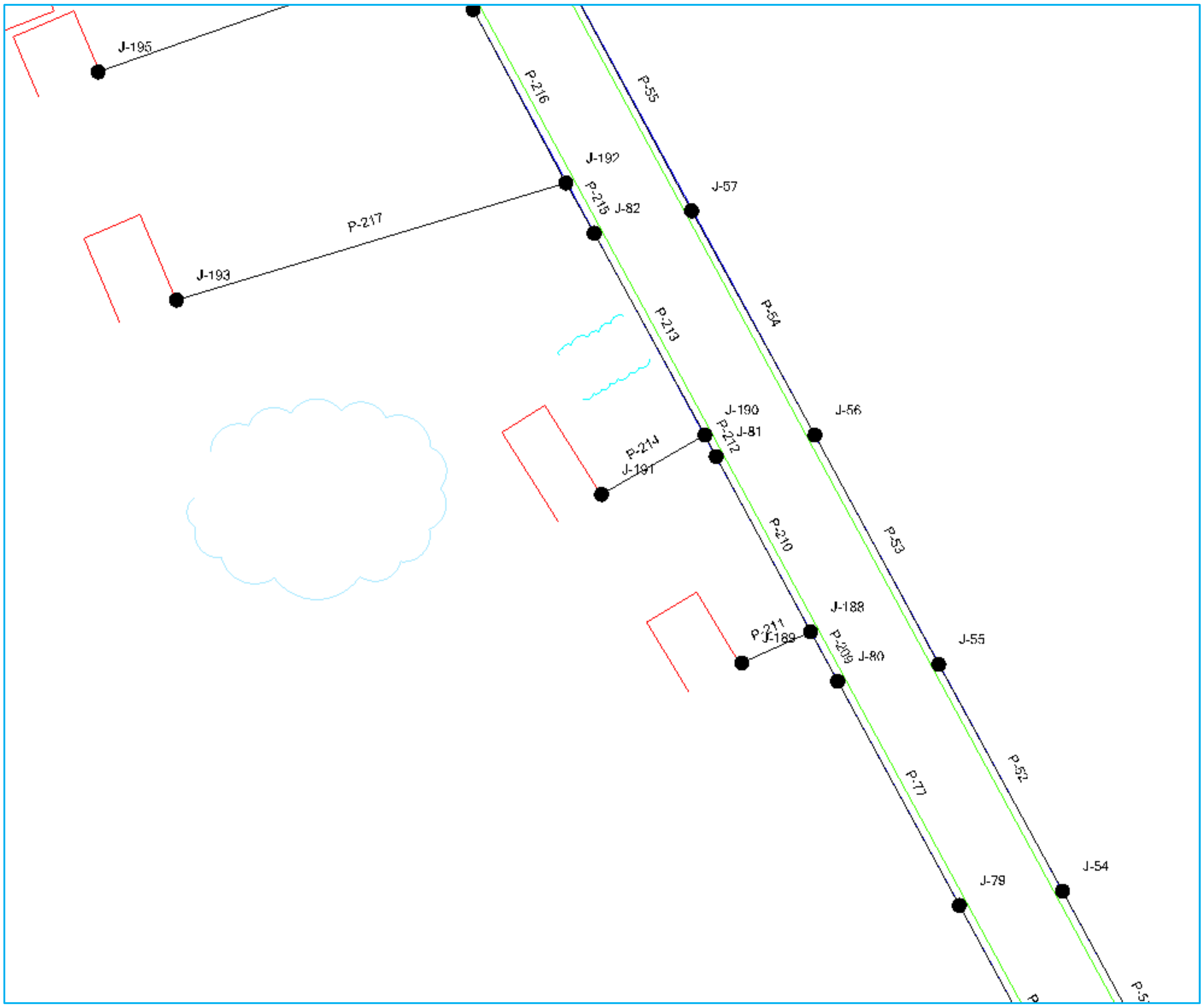


Figure 10: Piping Distribution System Layout (Using WaterCAD V8i)

Figure 9 begins the enlarged versions of the piping distribution system. This first drawing correlates to the top of Figure 8, and moves down the length of the community in sections.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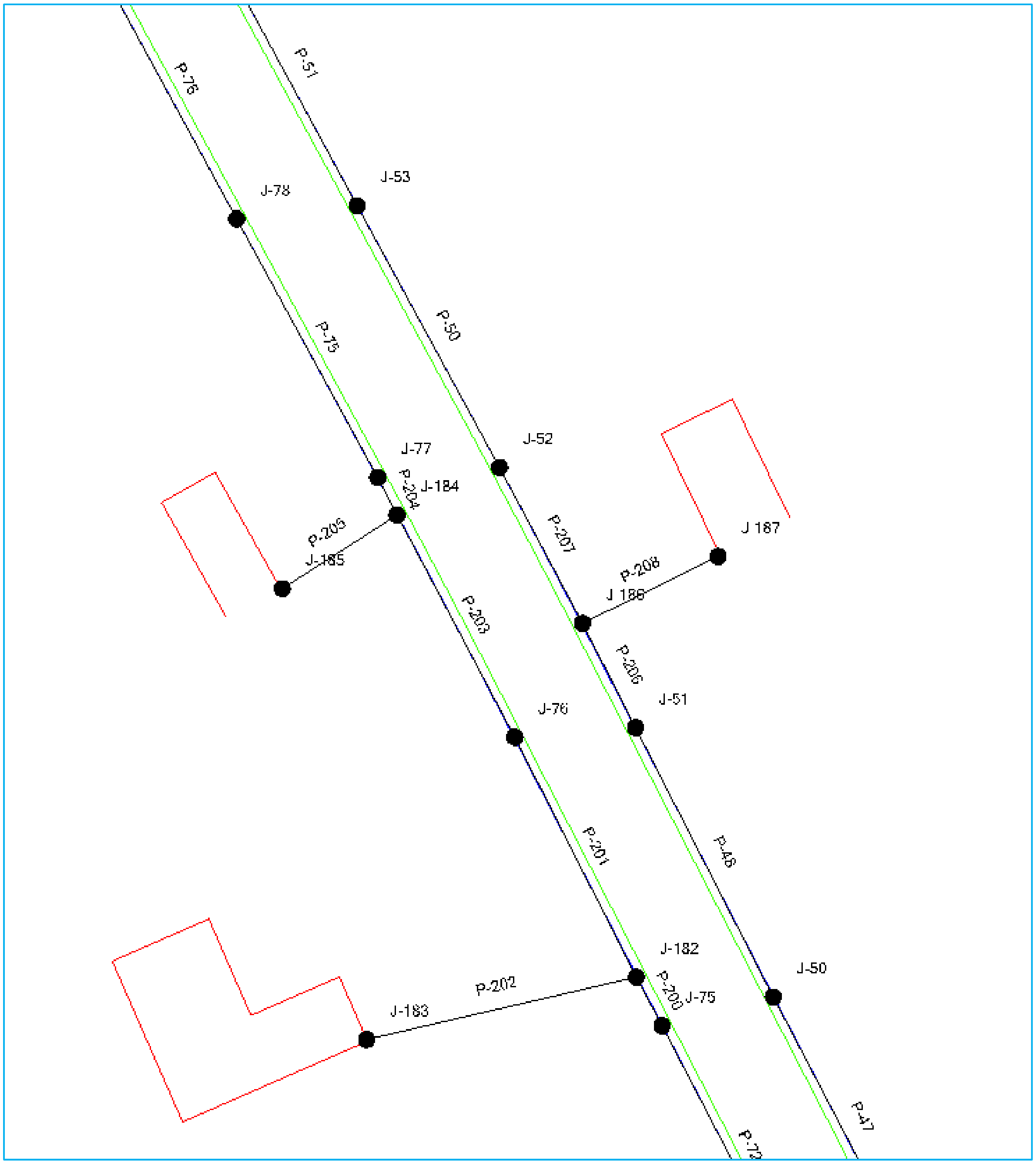
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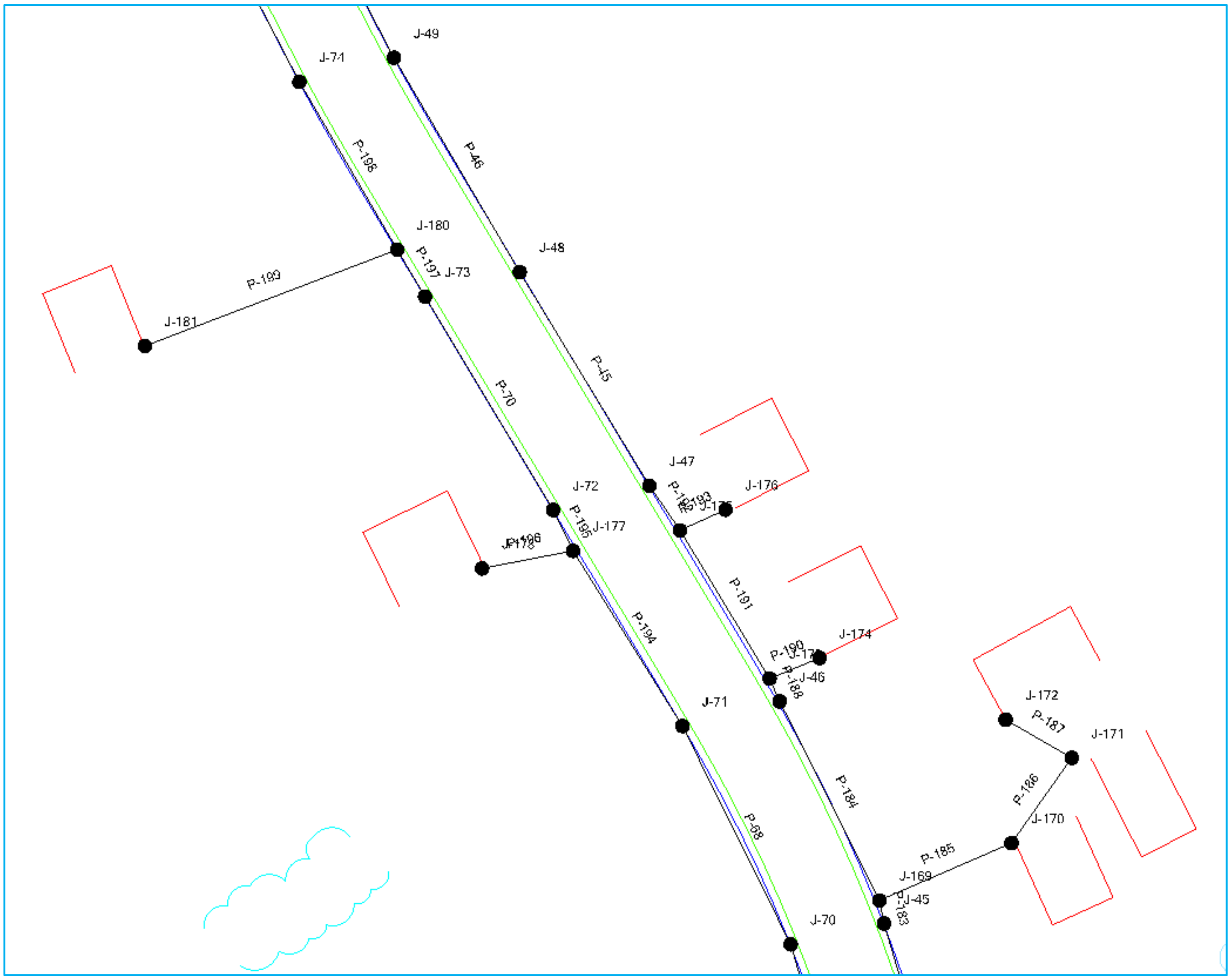
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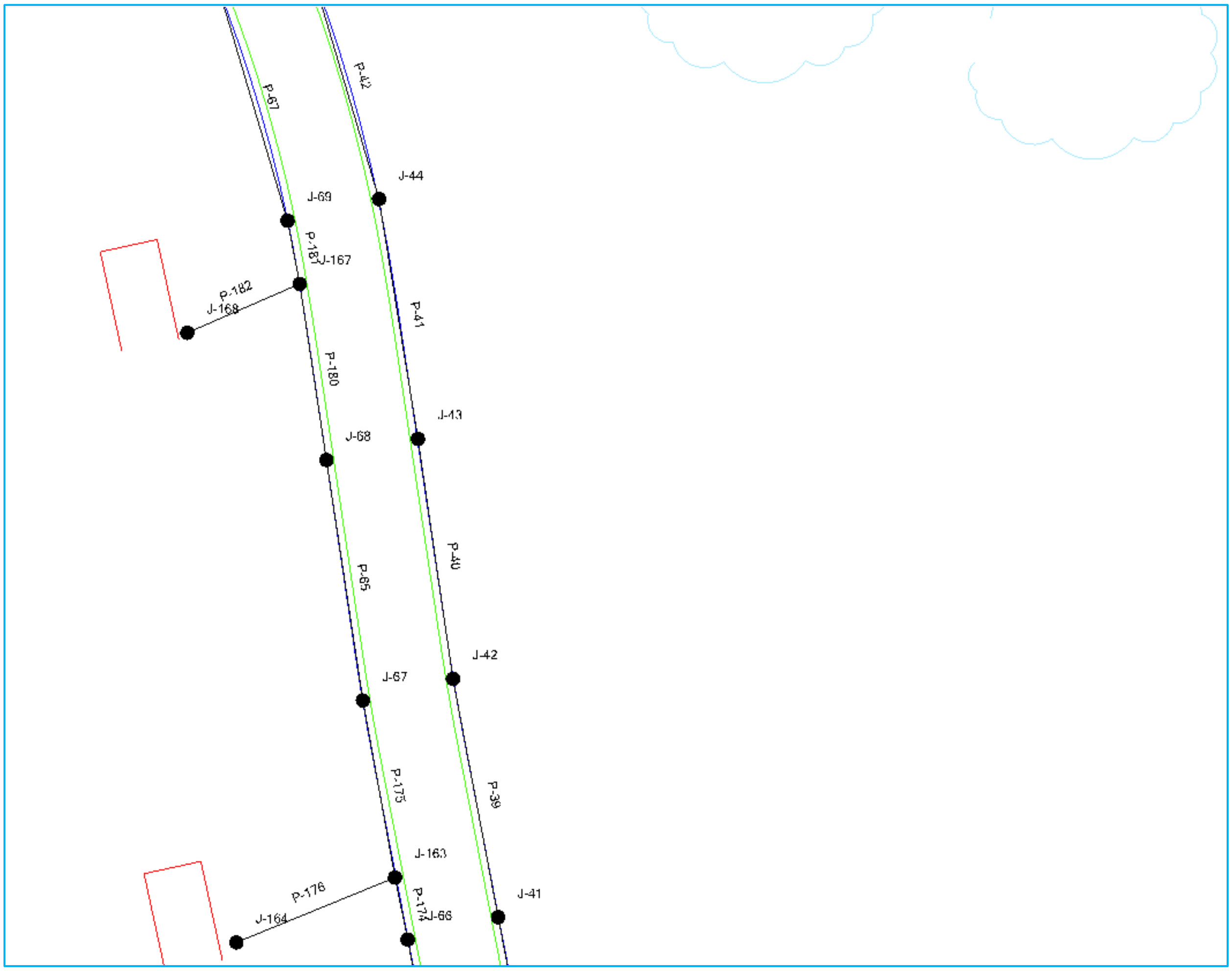
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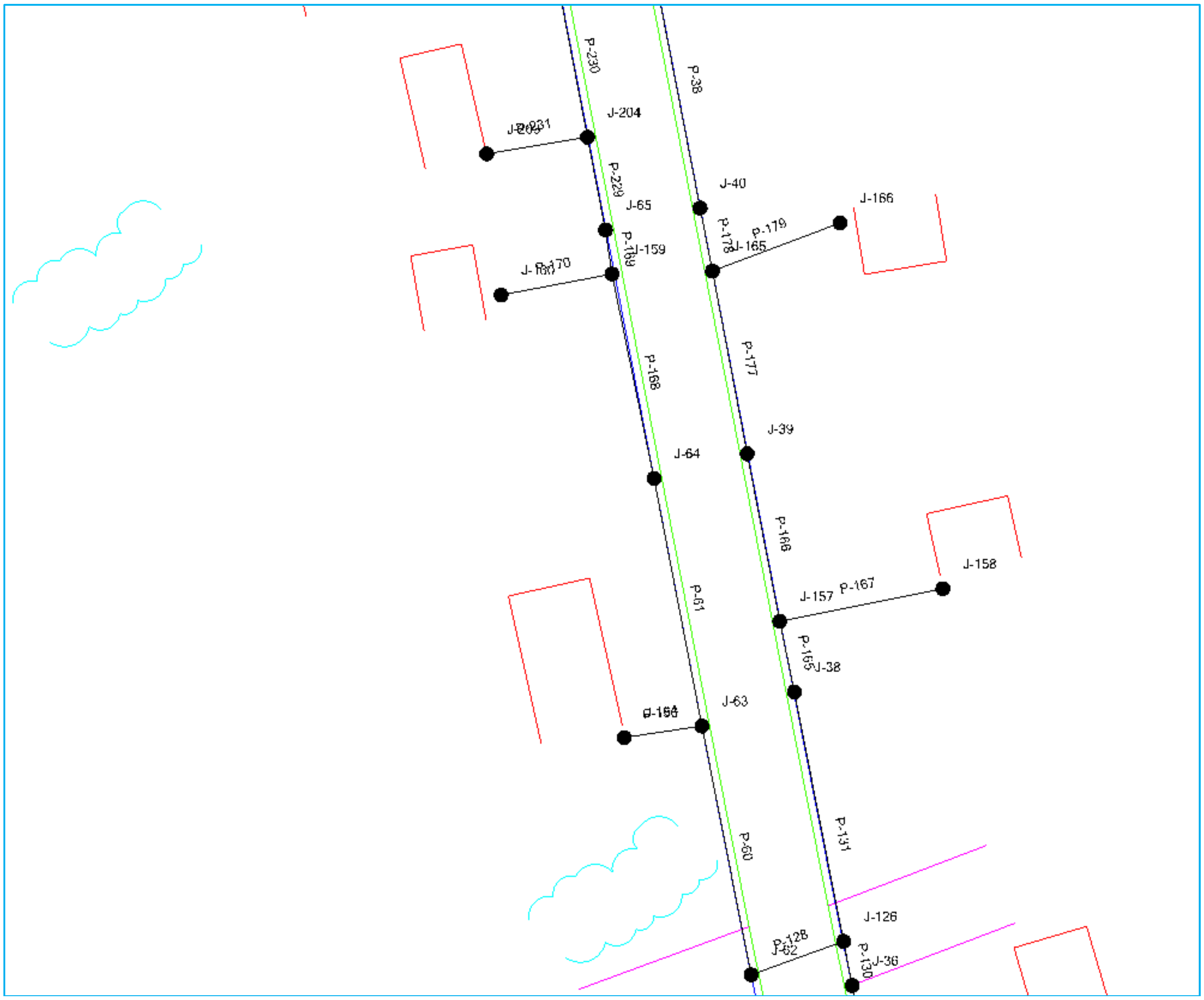
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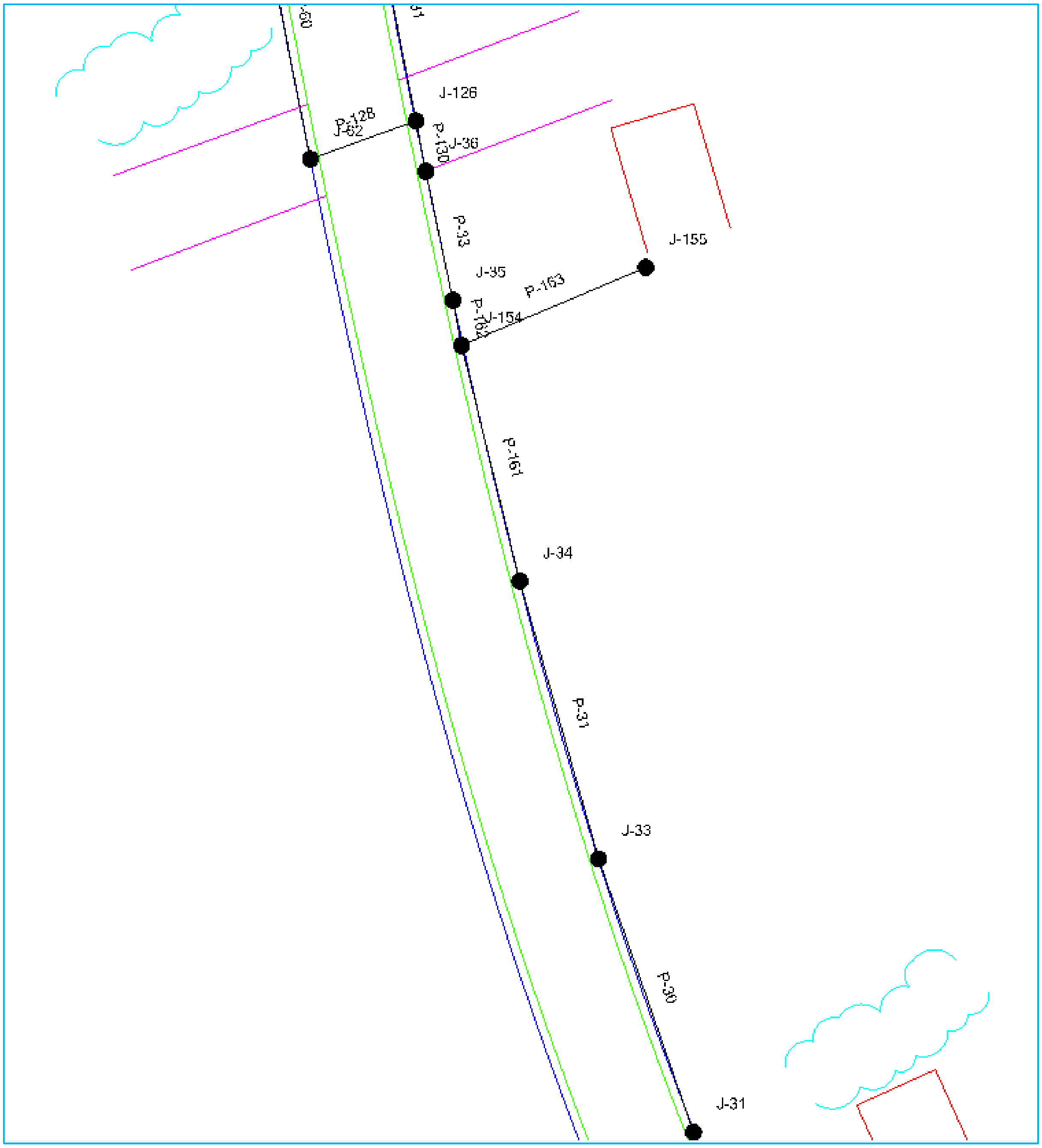
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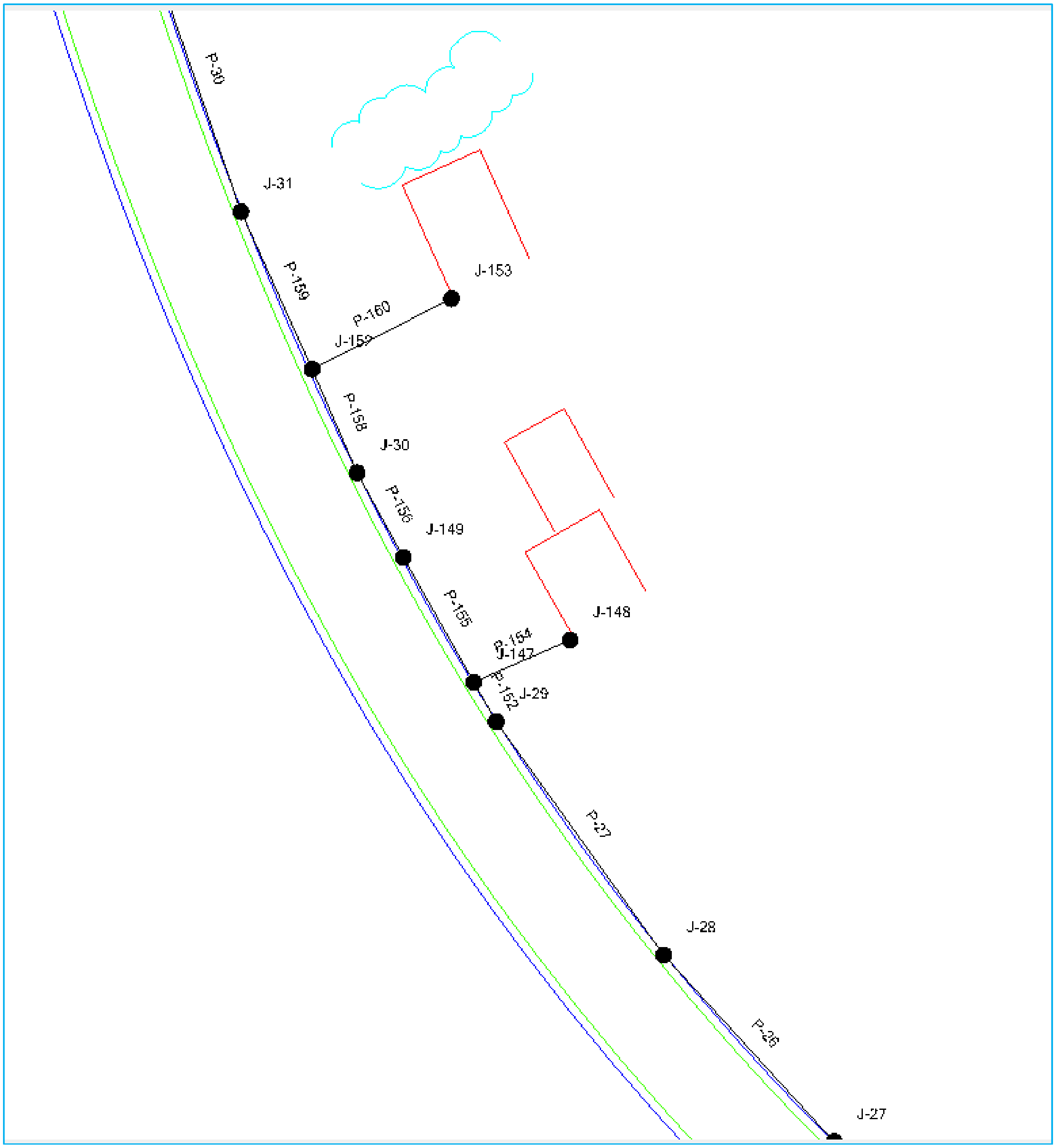
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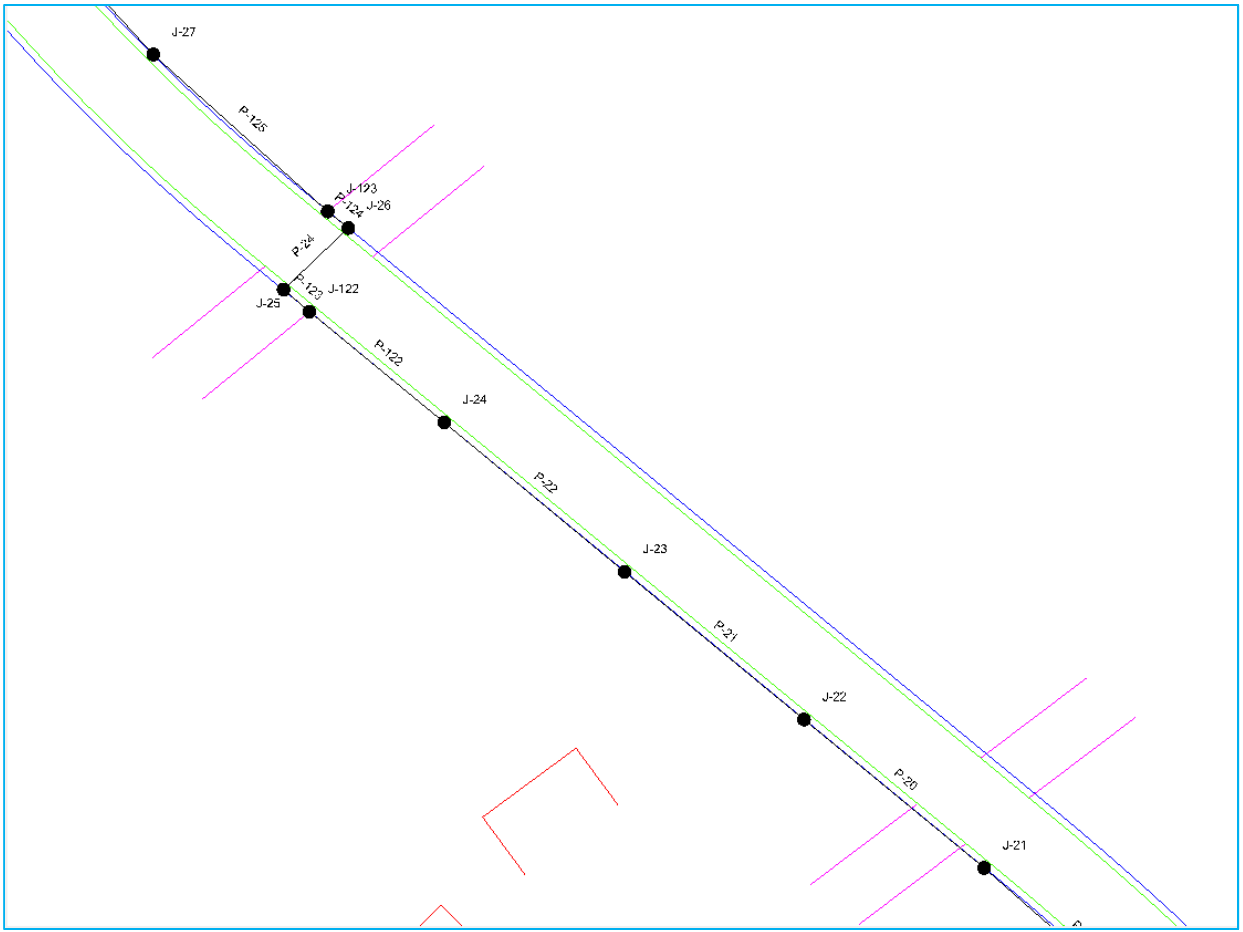
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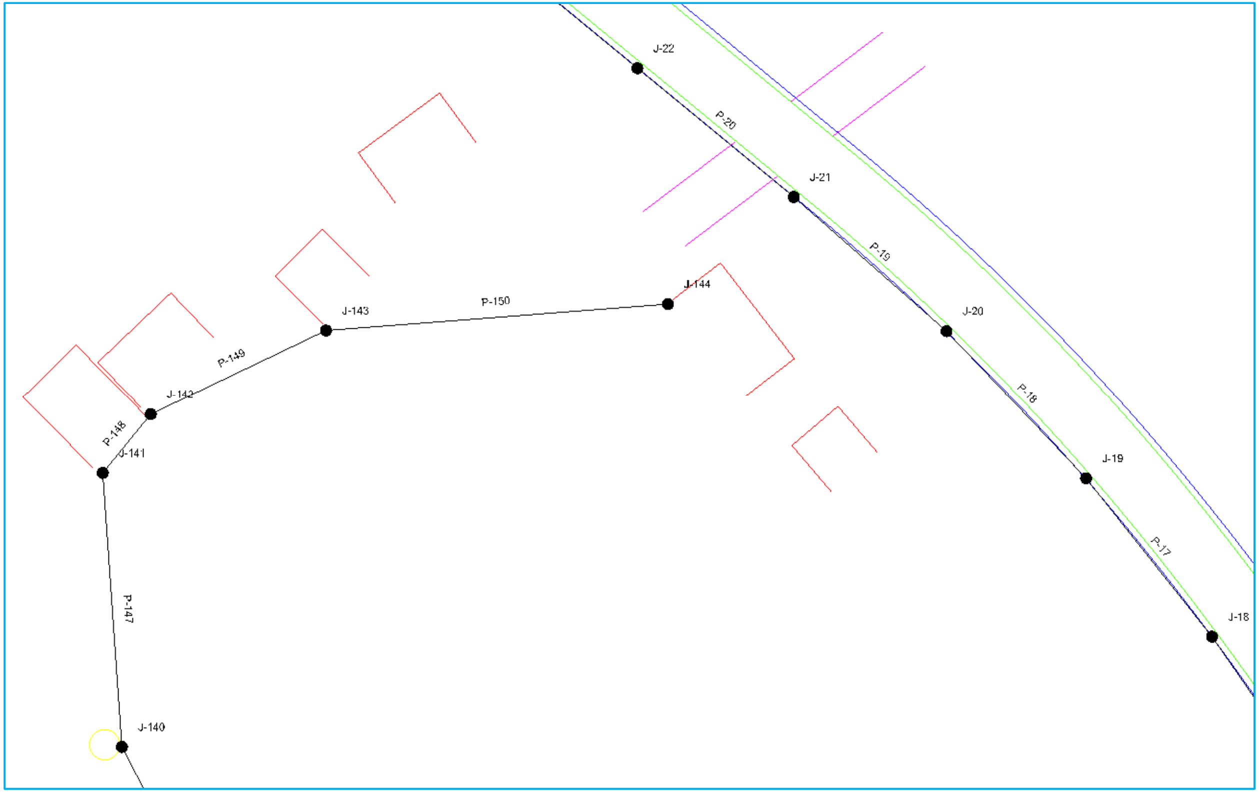
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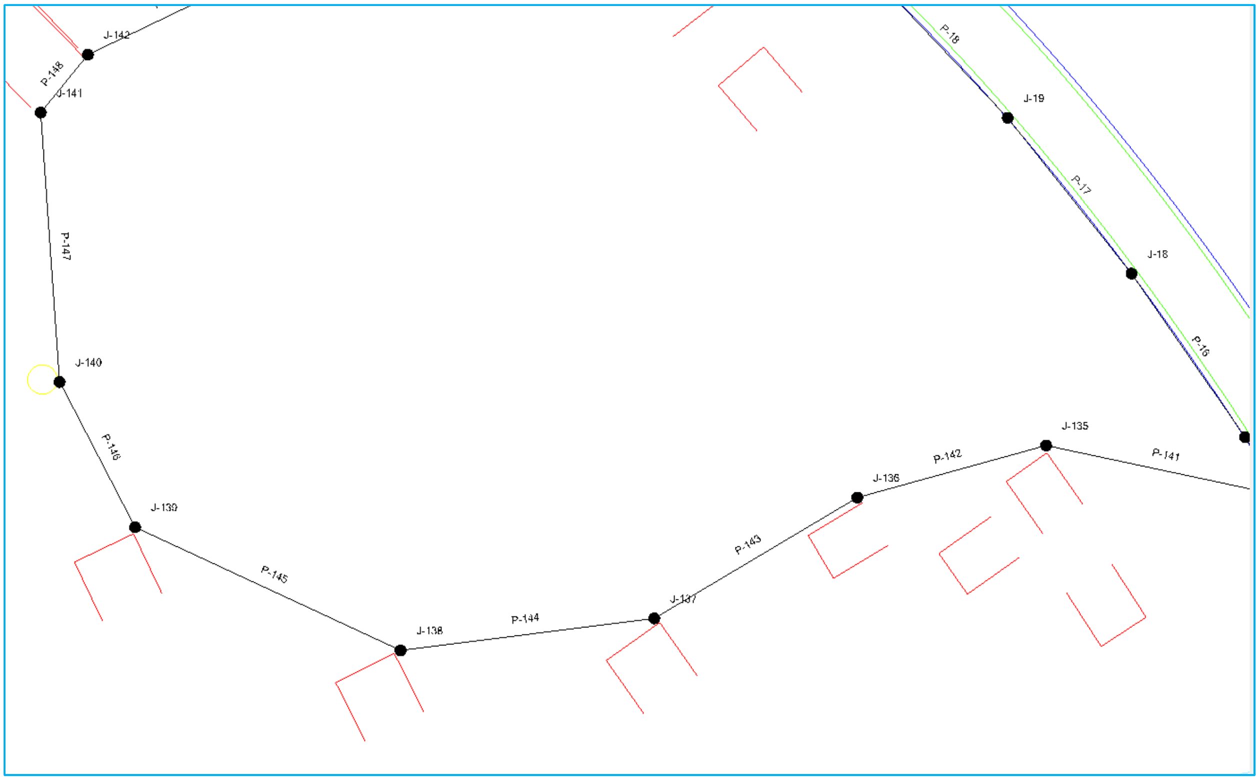
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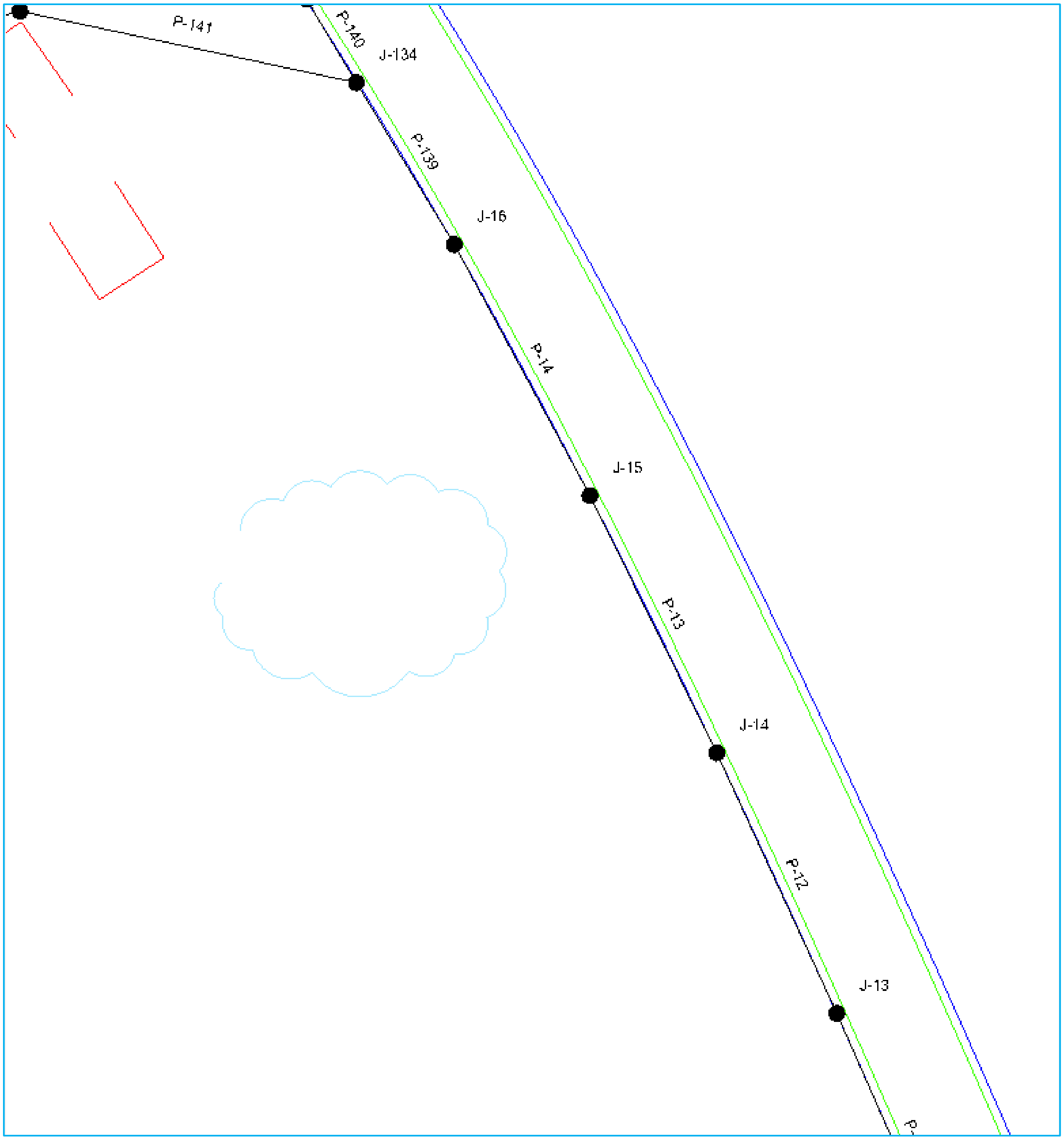
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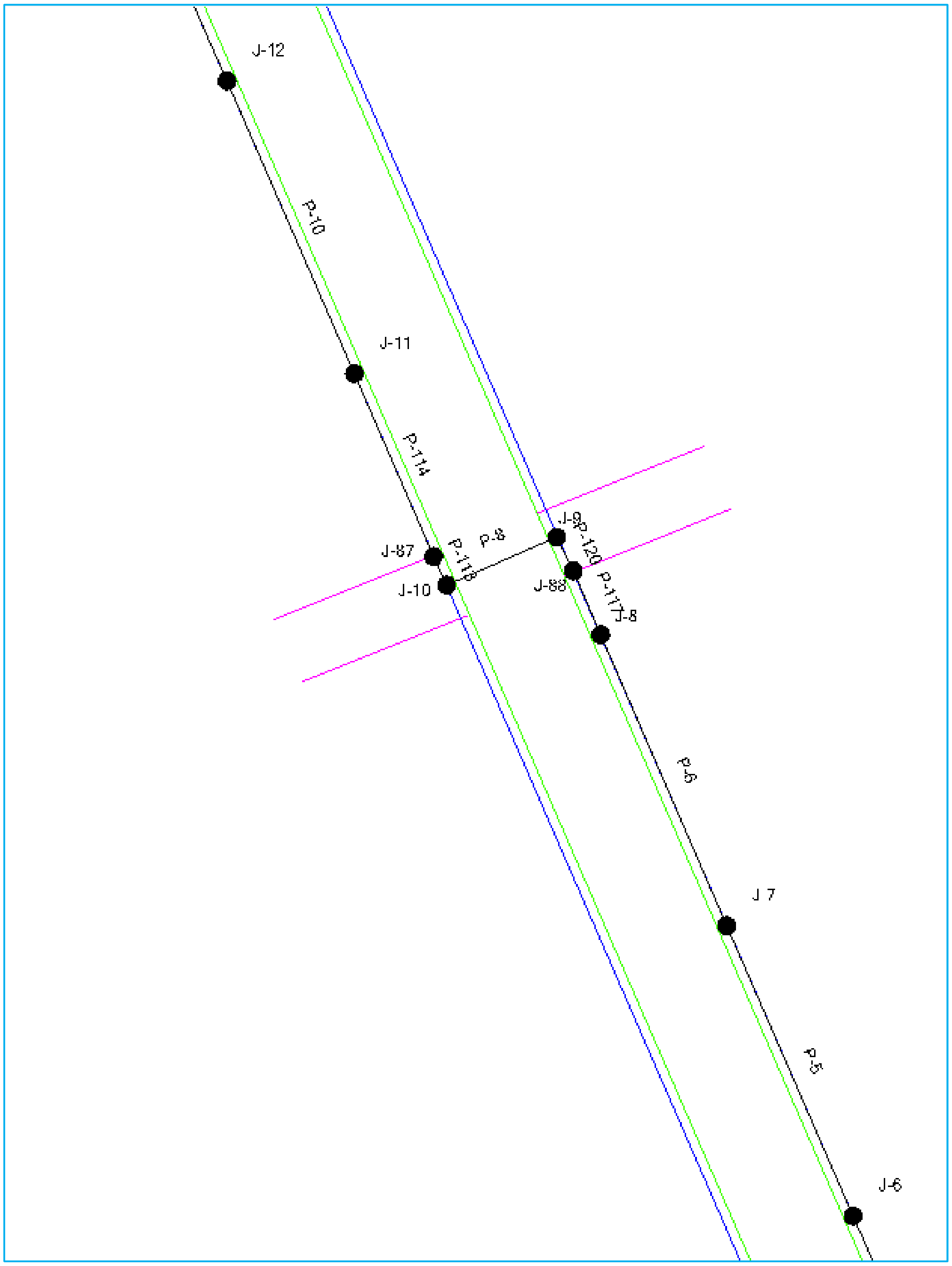
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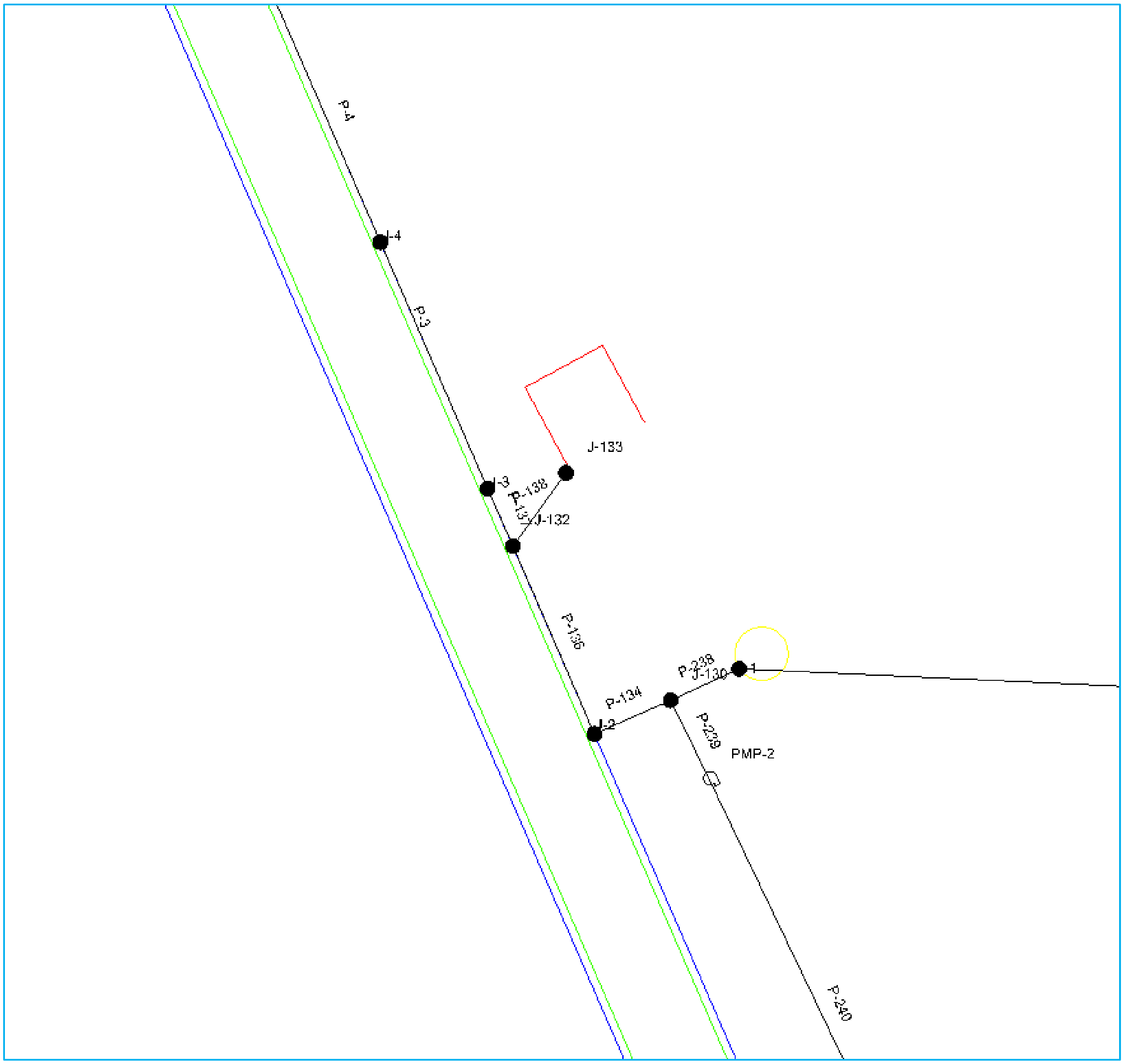
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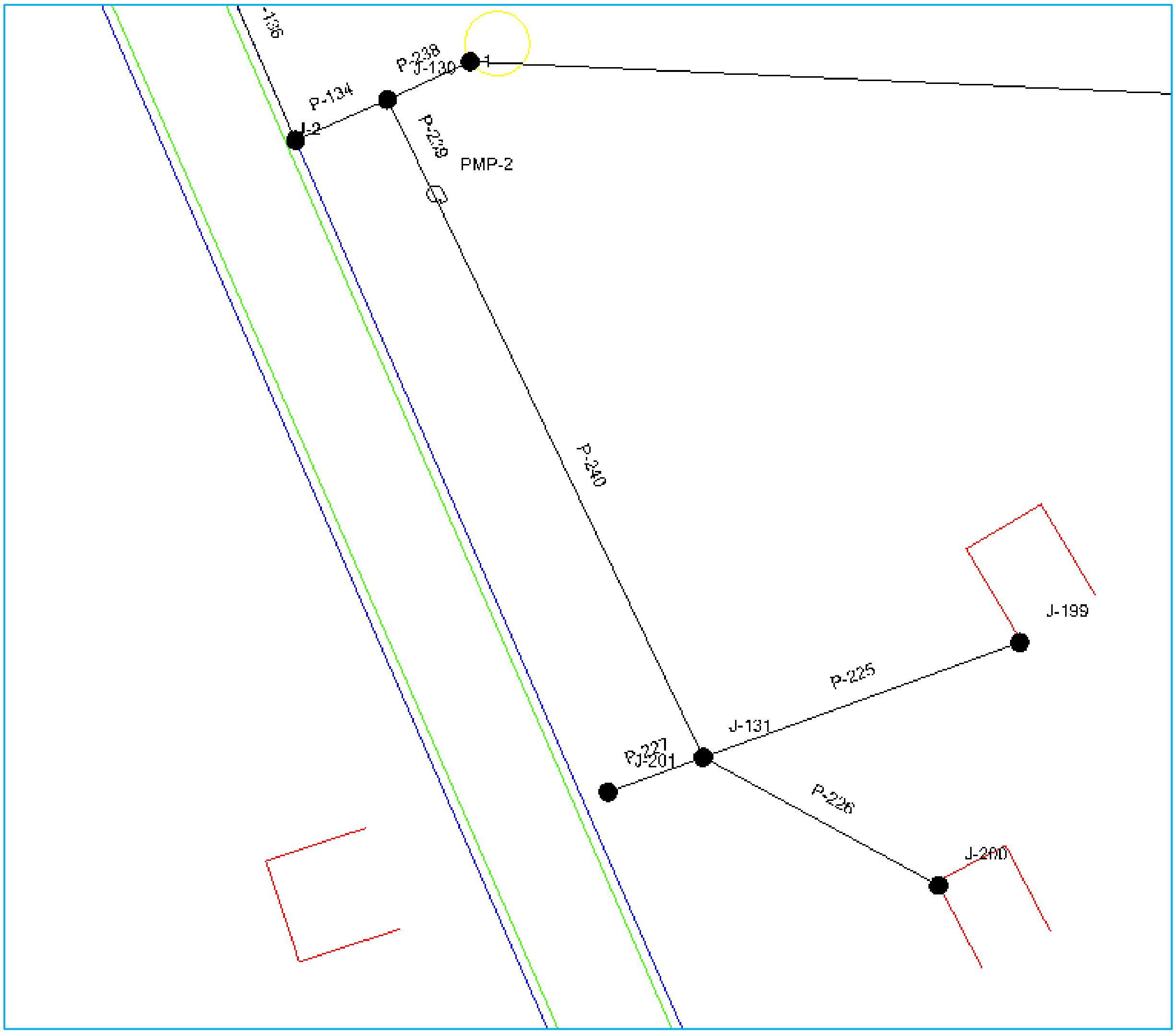
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J-201
P-226
J-200

Appendix E

Cost Estimate of Piping Distribution System

Table 4: Piping Distribution Cost Estimate

Updated Cost Estimate for Yuu, Ecuador Piping Project				
Material	Quantity	Unit Price ($)	Unit	Cost of Materials
2'' Pipe (in ft)	13,679	0.53	ft	7,250.00
Pipe Connections	1,368	2.00	item	2,736.00
Tees	50	0.85	item	43.00
Overhead (20%)	-	-	-	2,000.00
Pump 1	1	9,000.00	item	9,000.00
Pump 2	1	4,000.00	item	4,000.00
		Total		25,029.00

Appendix F

Raw Precipitation Data

Table 5: Raw Precipitation Data – Puyo 2011 (N.O.A.A. website)

Precipitation Data 2011 (Puyo)																							
January		Febuary		March		April		May		June		July		August		September		October		November		December	
Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)	Day	Prcp. (in)
5	0.02	4	0.02	10	0.47	4	0.02	5	0.04	4	0.08	4	0.67	4	0.35	12	0.04	4	2.44	8	0.71	6	0.2
6	0.16	5	1.06	11	0.12	6	1.18	6	0.08	5	0.03	5	0.55	5	1.1	13	0.35	5	0	10	1.61	7	0.51
7	1.57	7	0.08	12	0.08	7	0.16	7	0.94	6	0.43	6	0.91	6	0.08	14	0	6	0.16	11	0.2	8	0.01
8	0.39	8	0.94	13	0.35	8	1.18	8	0.16	7	0.08	7	0.31	7	0	17	0.08	7	0.02	12	0.39	9	0
9	1.3	9	0.39	15	0.24	9	0.94	9	0.08	9	0.08	8	0.63	9	0.2	18	0.16	8	0.59	13	0.43	10	0.43
10	0.87	11	0.31	16	3.35	10	1.38	10	0.03	11	0.83	9	0.28	10	0.12	19	0.28	9	1.1	14	0.63	12	0
11	0.16	12	0.43	17	0.59	11	0	11	0.01	12	0.24	10	0.79	11	0.08	20	0.35	11	0.43	16	0.12	13	0.12
12	0.08	13	0.03	18	0.51	13	0.28	12	0.2	13	0.02	11	0.35	18	0.01	21	0.2	12	0.08	17	0.12	14	0.43
13	0.79	14	1.69	19	0.31	14	0.71	14	0.35	14	0.16	12	0.04	19	0	23	0.24	14	0.02	19	0.83	15	0.28
14	0.16	15	0.51	20	0.51	15	1.89	15	0.35	16	0.59	13	1.34	20	0	24	0.31	15	0.24	21	0.02	18	2.32
16	0.04	16	0.28	21	1.18	16	0.12	16	0.24	17	0.08	14	0.02	21	0.16	25	1.14	16	1.14	22	1.46	19	0.35
17	0.16	18	0.01	22	0.47	17	0.71	17	0.63	18	0.39	15	0.12	22	1.93	26	1.3	17	1.73	23	0.79	20	1.69
18	0.28	19	0.28	23	0.55	17	0.71	18	2.95	19	1.26	16	0.08	23	0.04	27	0.43	20	0.47	24	3.58	21	0.47
21	3.58	21	5.31	24	0.01	18	1.26	20	0.08	21	0	17	0.35			29	0.43	21	0	27	2.13		
28	0.39	22	0.98	26	1.93	19	0.35	21	1.61	22	0.28	18	0.35			30	0	22	0.2	28	0.04		
29	2.48	23	0.67	27	0.04	20	0.28	23	0.24	24	0.39	19	0.35					23	0.63	29	0.16		
30	0.08	24	0.08	29	0.71	22	0.2	24	0.47	25	0.08	20	0.24					24	0.04	30	0.28		
31	0.02	25	1.06	30	0.08	23	0.16	25	0.08	26	0.39	22	2.28					25	0.94				
		26	0.28	31	0.79	24	0.02	26	0.31	27	0.12	23	0.28					26	1.81				
		27	1.18			25	0.87	27	0.31	29	0.12	24	0.71					27	0.08				
		28	0.55			26	0.12	28	0.71	30	0.12	25	0.43					28	1.61				
						27	1.57	29	0.51			27	0.2					30	0.04				
						28	0.2	30	0.16			28	0.08					31	0.12				
						29	0.98	31	0.2			29	0.04										
						30	0.12					31	1.1										

Appendix G

Adjusted Precipitation Data

Table 6: Adjusted Precipitation Data - Puyo 2011

Precipitation Data (Puyo - 2011)

	Day	Prcp. (in)		Day	Prcp. (in)		Day	Prcp. (in)		Day	Prcp. (in)		Day	Prcp. (in)		Day	Prcp. (in)
January	5	0.02	Febuary	1	0	March	1	0	April	1	0	May	1	0	June	1	0
	6	0.16		2	0		2	0		2	0		2	0		2	0
	7	1.57		3	0		3	0		3	0		3	0		3	0
	8	0.39		4	0.02		4	0		4	0.02		4	0		4	0.08
	9	1.3		5	1.06		5	0		5	0		5	0.04		5	0.03
	10	0.87		6	0		6	0		6	1.18		6	0.08		6	0.43
	11	0.16		7	0.08		7	0		7	0.16		7	0.94		7	0.08
	12	0.08		8	0.94		8	0		8	1.18		8	0.16		8	0
	13	0.79		9	0.39		9	0		9	0.94		9	0.08		9	0.08
	14	0.16		10	0		10	0.47		10	1.38		10	0.03		10	0
	15	0		11	0.31		11	0.12		11	0		11	0.01		11	0.83
	16	0.04		12	0.43		12	0.08		12	0		12	0.2		12	0.24
	17	0.16		13	0.03		13	0.35		13	0.28		13	0		13	0.02
	18	0.28		14	1.69		14	0		14	0.71		14	0.35		14	0.16
	19	0		15	0.51		15	0.24		15	1.89		15	0.35		15	0
	20	0		16	0.28		16	3.35		16	0.12		16	0.24		16	0.59
	21	3.58		17	0		17	0.59		17	0.71		17	0.63		17	0.08
	22	0		18	0.01		18	0.51		18	1.26		18	2.95		18	0.39
	23	0		19	0.28		19	0.31		19	0.35		19	0		19	1.26
	24	0		20	0		20	0.51		20	0.28		20	0.08		20	0
	25	0		21	5.31		21	1.18		21	0		21	1.61		21	0
	26	0		22	0.98		22	0.47		22	0.2		22	0		22	0.28
	27	0		23	0.67		23	0.55		23	0.16		23	0.24		23	0
	28	0.39		24	0.08		24	0.01		24	0.02		24	0.47		24	0.39
	29	2.48		25	1.06		25	0		25	0.87		25	0.08		25	0.08
	30	0.08		26	0.28		26	1.93		26	0.12		26	0.31		26	0.39
	31	0.02		27	1.18		27	0.04		27	1.57		27	0.31		27	0.12
				28	0.55		28	0		28	0.2		28	0.71		28	0
							29	0.71		29	0.98		29	0.51		29	0.12
							30	0.08		30	0.12		30	0.16		30	0.12
							31	0.79					31	0.2			

July	1	0	August	1	0	September	1	0	October	1	0	November	1	0	December	1	0
	2	0		2	0		2	0		2	0		2	0		2	0
	3	0		3	0		3	0		3	0		3	0		3	0
	4	0.67		4	0.35		4	0		4	2.44		4	0		4	0
	5	0.55		5	1.1		5	0		5	0		5	0		5	0
	6	0.91		6	0.08		6	0		6	0.16		6	0		6	0.2
	7	0.31		7	0		7	0		7	0.02		7	0		7	0.51
	8	0.63		8	0		8	0		8	0.59		8	0.71		8	0.01
	9	0.28		9	0.2		9	0		9	1.1		9	0		9	0
	10	0.79		10	0.12		10	0		10	0		10	1.61		10	0.43
	11	0.35		11	0.08		11	0		11	0.43		11	0.2		11	0
	12	0.04		12	0		12	0.04		12	0.08		12	0.39		12	0
	13	1.34		13	0		13	0.35		13	0		13	0.43		13	0.12
	14	0.02		14	0		14	0		14	0.02		14	0.63		14	0.43
	15	0.12		15	0		15	0		15	0.24		15	0		15	0.28
	16	0.08		16	0		16	0		16	1.14		16	0.12		16	0
	17	0.35		17	0		17	0.08		17	1.73		17	0.12		17	0
	18	0.35		18	0.01		18	0.16		18	0		18	0		18	2.32
	19	0.35		19	0		19	0.28		19	0		19	0.83		19	0.35
	20	0.24		20	0		20	0.35		20	0.47		20	0		20	1.69
	21	0		21	0.16		21	0.2		21	0		21	0.02		21	0.47
	22	2.28		22	1.93		22	0		22	0.2		22	1.46		22	0
	23	0.28		23	0.04		23	0.24		23	0.63		23	0.79		23	0
	24	0.71		24	0		24	0.31		24	0.04		24	3.58		24	0
	25	0.43		25	0		25	1.14		25	0.94		25	0		25	0
	26	0		26	0		26	1.3		26	1.81		26	0		26	0
	27	0.2		27	0		27	0.43		27	0.08		27	2.13		27	0
	28	0.08		28	0		28	0		28	1.61		28	0.04		28	0
	29	0.04		29	0		29	0.43		29	0		29	0.16		29	0
	30	0		30	0		30	0		30	0.04		30	0.28		30	0
	31	1.1		31	0					31	0.12					31	0

Note: Highlighted days there was no precipitation data collected, therefore it is assumed to be zero

Appendix H

Sample Calculation for Potential Rainwater Collection

Table 7: Potential Rainwater Collection Calculations

L10 Calculation							
Month	Day	Collection (L)	Consumption (L)	Net	Potn. Storage (L)	Actl. Storage (L)	Liters/person
January (2011)	1	0.00	750	-750.00	0.00	0.00	0.00
	2	0.00	750	-750.00	0.00	0.00	0.00
	3	0.00	750	-750.00	0.00	0.00	0.00
	4	0.00	750	-750.00	0.00	0.00	0.00
	5	52.33	750	-697.67	0.00	0.00	3.49
	6	418.64	750	-331.36	0.00	0.00	27.91
	7	4107.87	750	3357.87	3357.87	2500.00	50.00
	8	1020.43	750	270.43	3628.29	2500.00	50.00
	9	3401.42	750	2651.42	6279.71	2500.00	50.00
	10	2276.33	750	1526.33	7806.05	2500.00	50.00
	11	418.64	750	-331.36	7474.68	2168.64	50.00
	12	209.32	750	-540.68	6934.00	1627.95	50.00
	13	2067.02	750	1317.02	8251.02	2500.00	50.00
	14	418.64	750	-331.36	7919.66	2168.64	50.00
	15	0.00	750	-750.00	7169.66	1418.64	50.00
	16	104.66	750	-645.34	6524.31	773.30	50.00
	17	418.64	750	-331.36	6192.95	441.93	50.00
	18	732.61	750	-17.39	6175.56	424.55	50.00
	19	0.00	750	-750.00	5425.56	0.00	28.30
	20	0.00	750	-750.00	4675.56	0.00	0.00
	21	9366.99	750	8616.99	13292.55	2500.00	50.00
	22	0.00	750	-750.00	12542.55	1750.00	50.00
	23	0.00	750	-750.00	11792.55	1000.00	50.00
	24	0.00	750	-750.00	11042.55	250.00	50.00
	25	0.00	750	-750.00	10292.55	0.00	16.67
	26	0.00	750	-750.00	9542.55	0.00	0.00
	27	0.00	750	-750.00	8792.55	0.00	0.00
	28	1020.43	750	270.43	9062.98	270.43	50.00
	29	6488.86	750	5738.86	14801.84	2500.00	50.00
	30	209.32	750	-540.68	14261.16	1959.32	50.00
	31	52.33	750	-697.67	13563.49	1261.65	50.00
Febuary	1	0.00	750	-750.00	12813.49	511.65	50.00
	2	0.00	750	-750.00	12063.49	0.00	34.11
	3	0.00	750	-750.00	11313.49	0.00	0.00
	4	52.33	750	-697.67	10615.82	0.00	3.49
	5	2773.47	750	2023.47	12639.28	2023.47	50.00
	6	0.00	750	-750.00	11889.28	1273.47	50.00
	7	209.32	750	-540.68	11348.60	732.78	50.00
	8	2459.49	750	1709.49	13058.09	2442.27	50.00
	9	1020.43	750	270.43	13328.51	2500.00	50.00
	10	0.00	750	-750.00	12578.51	1750.00	50.00
	11	811.11	750	61.11	12639.62	1811.11	50.00

	12	1125.08	750	375.08	13014.71	2186.19	50.00
	13	78.49	750	-671.51	12343.20	1514.69	50.00
	14	4421.85	750	3671.85	16015.05	2500.00	50.00
	15	1334.40	750	584.40	16599.45	2500.00	50.00
	16	732.61	750	-17.39	16582.06	2482.61	50.00
	17	0.00	750	-750.00	15832.06	1732.61	50.00
	18	26.16	750	-723.84	15108.23	1008.78	50.00
	19	732.61	750	-17.39	15090.84	991.39	50.00
	20	0.00	750	-750.00	14340.84	241.39	50.00
	21	13893.49	750	13143.49	27484.33	2500.00	50.00
	22	2564.15	750	1814.15	29298.48	2500.00	50.00
	23	1753.04	750	1003.04	30301.52	2500.00	50.00
	24	209.32	750	-540.68	29760.84	1959.32	50.00
	25	2773.47	750	2023.47	31784.30	2500.00	50.00
	26	732.61	750	-17.39	31766.91	2482.61	50.00
	27	3087.44	750	2337.44	34104.36	2500.00	50.00
	28	1439.06	750	689.06	34793.42	2500.00	50.00
March	1	0.00	750	-750.00	34043.42	1750.00	50.00
	2	0.00	750	-750.00	33293.42	1000.00	50.00
	3	0.00	750	-750.00	32543.42	250.00	50.00
	4	0.00	750	-750.00	31793.42	0.00	16.67
	5	0.00	750	-750.00	31043.42	0.00	0.00
	6	0.00	750	-750.00	30293.42	0.00	0.00
	7	0.00	750	-750.00	29543.42	0.00	0.00
	8	0.00	750	-750.00	28793.42	0.00	0.00
	9	0.00	750	-750.00	28043.42	0.00	0.00
	10	1229.74	750	479.74	28523.16	479.74	50.00
	11	313.98	750	-436.02	28087.14	43.72	50.00
	12	209.32	750	-540.68	27546.46	0.00	16.87
	13	915.77	750	165.77	27712.23	165.77	50.00
	14	0.00	750	-750.00	26962.23	0.00	11.05
	15	627.95	750	-122.05	26840.18	0.00	41.86
	16	8765.20	750	8015.20	34855.38	2500.00	50.00
	17	1543.72	750	793.72	35649.10	2500.00	50.00
	18	1334.40	750	584.40	36233.50	2500.00	50.00
	19	811.11	750	61.11	36294.61	2500.00	50.00
	20	1334.40	750	584.40	36879.01	2500.00	50.00
	21	3087.44	750	2337.44	39216.45	2500.00	50.00
	22	1229.74	750	479.74	39696.20	2500.00	50.00
	23	1439.06	750	689.06	40385.26	2500.00	50.00
	24	26.16	750	-723.84	39661.42	1776.16	50.00
	25	0.00	750	-750.00	38911.42	1026.16	50.00
	26	5049.80	750	4299.80	43211.22	2500.00	50.00
	27	104.66	750	-645.34	42565.88	1854.66	50.00
	28	0.00	750	-750.00	41815.88	1104.66	50.00

	29	1857.70	750	1107.70	42923.58	2212.36	50.00
	30	209.32	750	-540.68	42382.90	1671.68	50.00
	31	2067.02	750	1317.02	43699.92	2500.00	50.00
April	1	0.00	750	-750.00	42949.92	1750.00	50.00
	2	0.00	750	-750.00	42199.92	1000.00	50.00
	3	0.00	750	-750.00	41449.92	250.00	50.00
	4	52.33	750	-697.67	40752.25	0.00	20.16
	5	0.00	750	-750.00	40002.25	0.00	0.00
	6	3087.44	750	2337.44	42339.69	2337.44	50.00
	7	418.64	750	-331.36	42008.33	2006.08	50.00
	8	3087.44	750	2337.44	44345.77	2500.00	50.00
	9	2459.49	750	1709.49	46055.26	2500.00	50.00
	10	3610.74	750	2860.74	48915.99	2500.00	50.00
	11	0.00	750	-750.00	48165.99	1750.00	50.00
	12	0.00	750	-750.00	47415.99	1000.00	50.00
	13	732.61	750	-17.39	47398.61	982.61	50.00
	14	1857.70	750	1107.70	48506.31	2090.31	50.00
	15	4945.14	750	4195.14	52701.45	2500.00	50.00
	16	313.98	750	-436.02	52265.42	2063.98	50.00
	17	1857.70	750	1107.70	53373.12	2500.00	50.00
	18	3296.76	750	2546.76	55919.88	2500.00	50.00
	19	915.77	750	165.77	56085.65	2500.00	50.00
	20	732.61	750	-17.39	56068.26	2482.61	50.00
	21	0.00	750	-750.00	55318.26	1732.61	50.00
	22	523.30	750	-226.70	55091.56	1505.91	50.00
	23	418.64	750	-331.36	54760.19	1174.55	50.00
	24	52.33	750	-697.67	54062.52	476.87	50.00
	25	2276.33	750	1526.33	55588.86	2003.21	50.00
	26	313.98	750	-436.02	55152.84	1567.19	50.00
	27	4107.87	750	3357.87	58510.70	2500.00	50.00
	28	523.30	750	-226.70	58284.00	2273.30	50.00
	29	2564.15	750	1814.15	60098.15	2500.00	50.00
	30	313.98	750	-436.02	59662.12	2063.98	50.00
May	1	0.00	750	-750.00	58912.12	1313.98	50.00
	2	0.00	750	-750.00	58162.12	563.98	50.00
	3	0.00	750	-750.00	57412.12	0.00	37.60
	4	0.00	750	-750.00	56662.12	0.00	0.00
	5	104.66	750	-645.34	56016.78	0.00	6.98
	6	209.32	750	-540.68	55476.10	0.00	13.95
	7	2459.49	750	1709.49	57185.59	1709.49	50.00
	8	418.64	750	-331.36	56854.22	1378.12	50.00
	9	209.32	750	-540.68	56313.54	837.44	50.00
	10	78.49	750	-671.51	55642.04	165.94	50.00
	11	26.16	750	-723.84	54918.20	0.00	12.81
	12	523.30	750	-226.70	54691.50	0.00	34.89

	13	0.00	750	-750.00	53941.50	0.00	0.00
	14	915.77	750	165.77	54107.26	165.77	50.00
	15	915.77	750	165.77	54273.03	331.53	50.00
	16	627.95	750	-122.05	54150.99	209.49	50.00
	17	1648.38	750	898.38	55049.37	1107.87	50.00
	18	7718.61	750	6968.61	62017.97	2500.00	50.00
	19	0.00	750	-750.00	61267.97	1750.00	50.00
	20	209.32	750	-540.68	60727.29	1209.32	50.00
	21	4212.53	750	3462.53	64189.82	2500.00	50.00
	22	0.00	750	-750.00	63439.82	1750.00	50.00
	23	627.95	750	-122.05	63317.77	1627.95	50.00
	24	1229.74	750	479.74	63797.52	2107.70	50.00
	25	209.32	750	-540.68	63256.83	1567.02	50.00
	26	811.11	750	61.11	63317.94	1628.12	50.00
	27	811.11	750	61.11	63379.05	1689.23	50.00
	28	1857.70	750	1107.70	64486.75	2500.00	50.00
	29	1334.40	750	584.40	65071.15	2500.00	50.00
	30	418.64	750	-331.36	64739.79	2168.64	50.00
	31	523.30	750	-226.70	64513.08	1941.93	50.00
June	1	0.00	750	-750.00	63763.08	1191.93	50.00
	2	0.00	750	-750.00	63013.08	441.93	50.00
	3	0.00	750	-750.00	62263.08	0.00	29.46
	4	209.32	750	-540.68	61722.40	0.00	13.95
	5	78.49	750	-671.51	61050.89	0.00	5.23
	6	1125.08	750	375.08	61425.98	375.08	50.00
	7	209.32	750	-540.68	60885.30	0.00	38.96
	8	0.00	750	-750.00	60135.30	0.00	0.00
	9	209.32	750	-540.68	59594.62	0.00	13.95
	10	0.00	750	-750.00	58844.62	0.00	0.00
	11	2171.68	750	1421.68	60266.29	1421.68	50.00
	12	627.95	750	-122.05	60144.25	1299.63	50.00
	13	52.33	750	-697.67	59446.58	601.96	50.00
	14	418.64	750	-331.36	59115.21	270.60	50.00
	15	0.00	750	-750.00	58365.21	0.00	18.04
	16	1543.72	750	793.72	59158.93	793.72	50.00
	17	209.32	750	-540.68	58618.25	253.04	50.00
	18	1020.43	750	270.43	58888.68	523.47	50.00
	19	3296.76	750	2546.76	61435.44	2500.00	50.00
	20	0.00	750	-750.00	60685.44	1750.00	50.00
	21	0.00	750	-750.00	59935.44	1000.00	50.00
	22	732.61	750	-17.39	59918.05	982.61	50.00
	23	0.00	750	-750.00	59168.05	232.61	50.00
	24	1020.43	750	270.43	59438.48	503.04	50.00
	25	209.32	750	-540.68	58897.79	0.00	47.49
	26	1020.43	750	270.43	59168.22	270.43	50.00

	27	313.98	750	-436.02	58732.20	0.00	38.96
	28	0.00	750	-750.00	57982.20	0.00	0.00
	29	313.98	750	-436.02	57546.18	0.00	20.93
	30	313.98	750	-436.02	57110.15	0.00	20.93
July	1	0.00	750	-750.00	56360.15	0.00	0.00
	2	0.00	750	-750.00	55610.15	0.00	0.00
	3	0.00	750	-750.00	54860.15	0.00	0.00
	4	1753.04	750	1003.04	55863.19	1003.04	50.00
	5	1439.06	750	689.06	56552.25	1692.10	50.00
	6	2380.99	750	1630.99	58183.25	2500.00	50.00
	7	811.11	750	61.11	58244.36	2500.00	50.00
	8	1648.38	750	898.38	59142.74	2500.00	50.00
	9	732.61	750	-17.39	59125.35	2482.61	50.00
	10	2067.02	750	1317.02	60442.37	2500.00	50.00
	11	915.77	750	165.77	60608.13	2500.00	50.00
	12	104.66	750	-645.34	59962.79	1854.66	50.00
	13	3506.08	750	2756.08	62718.87	2500.00	50.00
	14	52.33	750	-697.67	62021.20	1802.33	50.00
	15	313.98	750	-436.02	61585.18	1366.31	50.00
	16	209.32	750	-540.68	61044.49	825.62	50.00
	17	915.77	750	165.77	61210.26	991.39	50.00
	18	915.77	750	165.77	61376.03	1157.16	50.00
	19	915.77	750	165.77	61541.80	1322.93	50.00
	20	627.95	750	-122.05	61419.75	1200.88	50.00
	21	0.00	750	-750.00	60669.75	450.88	50.00
	22	5965.57	750	5215.57	65885.32	2500.00	50.00
	23	732.61	750	-17.39	65867.93	2482.61	50.00
	24	1857.70	750	1107.70	66975.63	2500.00	50.00
	25	1125.08	750	375.08	67350.71	2500.00	50.00
	26	0.00	750	-750.00	66600.71	1750.00	50.00
	27	523.30	750	-226.70	66374.01	1523.30	50.00
	28	209.32	750	-540.68	65833.33	982.61	50.00
	29	104.66	750	-645.34	65187.99	337.27	50.00
	30	0.00	750	-750.00	64437.99	0.00	22.48
	31	2878.12	750	2128.12	66566.11	2128.12	50.00
August	1	0.00	750	-750.00	65816.11	1378.12	50.00
	2	0.00	750	-750.00	65066.11	628.12	50.00
	3	0.00	750	-750.00	64316.11	0.00	41.87
	4	915.77	750	165.77	64481.88	165.77	50.00
	5	2878.12	750	2128.12	66610.00	2293.89	50.00
	6	209.32	750	-540.68	66069.32	1753.21	50.00
	7	0.00	750	-750.00	65319.32	1003.21	50.00
	8	0.00	750	-750.00	64569.32	253.21	50.00
	9	523.30	750	-226.70	64342.61	26.50	50.00
	10	313.98	750	-436.02	63906.59	0.00	22.70

	11	209.32	750	-540.68	63365.91	0.00	13.95
	12	0.00	750	-750.00	62615.91	0.00	0.00
	13	0.00	750	-750.00	61865.91	0.00	0.00
	14	0.00	750	-750.00	61115.91	0.00	0.00
	15	0.00	750	-750.00	60365.91	0.00	0.00
	16	0.00	750	-750.00	59615.91	0.00	0.00
	17	0.00	750	-750.00	58865.91	0.00	0.00
	18	26.16	750	-723.84	58142.07	0.00	1.74
	19	0.00	750	-750.00	57392.07	0.00	0.00
	20	0.00	750	-750.00	56642.07	0.00	0.00
	21	418.64	750	-331.36	56310.71	0.00	27.91
	22	5049.80	750	4299.80	60610.51	2500.00	50.00
	23	104.66	750	-645.34	59965.17	1854.66	50.00
	24	0.00	750	-750.00	59215.17	1104.66	50.00
	25	0.00	750	-750.00	58465.17	354.66	50.00
	26	0.00	750	-750.00	57715.17	0.00	23.64
	27	0.00	750	-750.00	56965.17	0.00	0.00
	28	0.00	750	-750.00	56215.17	0.00	0.00
	29	0.00	750	-750.00	55465.17	0.00	0.00
	30	0.00	750	-750.00	54715.17	0.00	0.00
	31	0.00	750	-750.00	53965.17	0.00	0.00
September	1	0.00	750	-750.00	53215.17	0.00	0.00
	2	0.00	750	-750.00	52465.17	0.00	0.00
	3	0.00	750	-750.00	51715.17	0.00	0.00
	4	0.00	750	-750.00	50965.17	0.00	0.00
	5	0.00	750	-750.00	50215.17	0.00	0.00
	6	0.00	750	-750.00	49465.17	0.00	0.00
	7	0.00	750	-750.00	48715.17	0.00	0.00
	8	0.00	750	-750.00	47965.17	0.00	0.00
	9	0.00	750	-750.00	47215.17	0.00	0.00
	10	0.00	750	-750.00	46465.17	0.00	0.00
	11	0.00	750	-750.00	45715.17	0.00	0.00
	12	104.66	750	-645.34	45069.83	0.00	6.98
	13	915.77	750	165.77	45235.60	165.77	50.00
	14	0.00	750	-750.00	44485.60	0.00	11.05
	15	0.00	750	-750.00	43735.60	0.00	0.00
	16	0.00	750	-750.00	42985.60	0.00	0.00
	17	209.32	750	-540.68	42444.91	0.00	13.95
	18	418.64	750	-331.36	42113.55	0.00	27.91
	19	732.61	750	-17.39	42096.16	0.00	48.84
	20	915.77	750	165.77	42261.93	165.77	50.00
	21	523.30	750	-226.70	42035.23	0.00	45.94
	22	0.00	750	-750.00	41285.23	0.00	0.00
	23	627.95	750	-122.05	41163.18	0.00	41.86
	24	811.11	750	61.11	41224.29	61.11	50.00

	25	2982.78	750	2232.78	43457.07	2293.89	50.00
	26	3401.42	750	2651.42	46108.49	2500.00	50.00
	27	1125.08	750	375.08	46483.58	2500.00	50.00
	28	0.00	750	-750.00	45733.58	1750.00	50.00
	29	1125.08	750	375.08	46108.66	2125.08	50.00
	30	0.00	750	-750.00	45358.66	1375.08	50.00
October	1	0.00	750	-750.00	44608.66	625.08	50.00
	2	0.00	750	-750.00	43858.66	0.00	41.67
	3	0.00	750	-750.00	43108.66	0.00	0.00
	4	6384.20	750	5634.20	48742.86	2500.00	50.00
	5	0.00	750	-750.00	47992.86	1750.00	50.00
	6	418.64	750	-331.36	47661.50	1418.64	50.00
	7	52.33	750	-697.67	46963.83	720.97	50.00
	8	1543.72	750	793.72	47757.55	1514.69	50.00
	9	2878.12	750	2128.12	49885.68	2500.00	50.00
	10	0.00	750	-750.00	49135.68	1750.00	50.00
	11	1125.08	750	375.08	49510.76	2125.08	50.00
	12	209.32	750	-540.68	48970.08	1584.40	50.00
	13	0.00	750	-750.00	48220.08	834.40	50.00
	14	52.33	750	-697.67	47522.41	136.73	50.00
	15	627.95	750	-122.05	47400.36	14.69	50.00
	16	2982.78	750	2232.78	49633.15	2247.47	50.00
	17	4526.50	750	3776.50	53409.65	2500.00	50.00
	18	0.00	750	-750.00	52659.65	1750.00	50.00
	19	0.00	750	-750.00	51909.65	1000.00	50.00
	20	1229.74	750	479.74	52389.39	1479.74	50.00
	21	0.00	750	-750.00	51639.39	729.74	50.00
	22	523.30	750	-226.70	51412.69	503.04	50.00
	23	1648.38	750	898.38	52311.07	1401.42	50.00
	24	104.66	750	-645.34	51665.73	756.08	50.00
	25	2459.49	750	1709.49	53375.22	2465.57	50.00
	26	4735.82	750	3985.82	57361.04	2500.00	50.00
	27	209.32	750	-540.68	56820.36	1959.32	50.00
	28	4212.53	750	3462.53	60282.88	2500.00	50.00
	29	0.00	750	-750.00	59532.88	1750.00	50.00
	30	104.66	750	-645.34	58887.54	1104.66	50.00
	31	313.98	750	-436.02	58451.52	668.64	50.00
November	1	0.00	750	-750.00	57701.52	0.00	44.58
	2	0.00	750	-750.00	56951.52	0.00	0.00
	3	0.00	750	-750.00	56201.52	0.00	0.00
	4	0.00	750	-750.00	55451.52	0.00	0.00
	5	0.00	750	-750.00	54701.52	0.00	0.00
	6	0.00	750	-750.00	53951.52	0.00	0.00
	7	0.00	750	-750.00	53201.52	0.00	0.00
	8	1857.70	750	1107.70	54309.22	1107.70	50.00

	9	0.00	750	-750.00	53559.22	357.70	50.00
	10	4212.53	750	3462.53	57021.75	2500.00	50.00
	11	523.30	750	-226.70	56795.04	2273.30	50.00
	12	1020.43	750	270.43	57065.47	2500.00	50.00
	13	1125.08	750	375.08	57440.55	2500.00	50.00
	14	1648.38	750	898.38	58338.93	2500.00	50.00
	15	0.00	750	-750.00	57588.93	1750.00	50.00
	16	313.98	750	-436.02	57152.91	1313.98	50.00
	17	313.98	750	-436.02	56716.89	877.95	50.00
	18	0.00	750	-750.00	55966.89	127.95	50.00
	19	2171.68	750	1421.68	57388.56	1549.63	50.00
	20	0.00	750	-750.00	56638.56	799.63	50.00
	21	52.33	750	-697.67	55940.89	101.96	50.00
	22	3820.06	750	3070.06	59010.95	2500.00	50.00
	23	2067.02	750	1317.02	60327.97	2500.00	50.00
	24	9366.99	750	8616.99	68944.95	2500.00	50.00
	25	0.00	750	-750.00	68194.95	1750.00	50.00
	26	0.00	750	-750.00	67444.95	1000.00	50.00
	27	5573.10	750	4823.10	72268.05	2500.00	50.00
	28	104.66	750	-645.34	71622.71	1854.66	50.00
	29	418.64	750	-331.36	71291.34	1523.30	50.00
	30	732.61	750	-17.39	71273.96	1505.91	50.00
December	1	0.00	750	-750.00	70523.96	755.91	50.00
	2	0.00	750	-750.00	69773.96	5.91	50.00
	3	0.00	750	-750.00	69023.96	0.00	0.39
	4	0.00	750	-750.00	68273.96	0.00	0.00
	5	0.00	750	-750.00	67523.96	0.00	0.00
	6	523.30	750	-226.70	67297.25	0.00	34.89
	7	1334.40	750	584.40	67881.65	584.40	50.00
	8	26.16	750	-723.84	67157.82	0.00	40.70
	9	0.00	750	-750.00	66407.82	0.00	0.00
	10	1125.08	750	375.08	66782.90	375.08	50.00
	11	0.00	750	-750.00	66032.90	0.00	25.01
	12	0.00	750	-750.00	65282.90	0.00	0.00
	13	313.98	750	-436.02	64846.88	0.00	20.93
	14	1125.08	750	375.08	65221.97	375.08	50.00
	15	732.61	750	-17.39	65204.58	357.70	50.00
	16	0.00	750	-750.00	64454.58	0.00	23.85
	17	0.00	750	-750.00	63704.58	0.00	0.00
	18	6070.23	750	5320.23	69024.81	2500.00	50.00
	19	915.77	750	165.77	69190.57	2500.00	50.00
	20	4421.85	750	3671.85	72862.42	2500.00	50.00
	21	1229.74	750	479.74	73342.16	2500.00	50.00
	22	0.00	750	-750.00	72592.16	1750.00	50.00
	23	0.00	750	-750.00	71842.16	1000.00	50.00
	24	0.00	750	-750.00	71092.16	250.00	50.00
	25	0.00	750	-750.00	70342.16	0.00	16.67
	26	0.00	750	-750.00	69592.16	0.00	0.00
	27	0.00	750	-750.00	68842.16	0.00	0.00
	28	0.00	750	-750.00	68092.16	0.00	0.00
	29	0.00	750	-750.00	67342.16	0.00	0.00
	30	0.00	750	-750.00	66592.16	0.00	0.00
	31	0.00	750	-750.00	65842.16	0.00	0.00

****Note: Calculations were done on house L10 with a household size of 15, consumption of 50 L per day per person, and a tank size of 2500 L*

Appendix I

Tank Size Determination Calculations

Table X: Example Calculations from Table X that correspond to the following equations

L10 Calculation					
Collection (L)	Consumption (L)	Net	Potn. Storage (L)	Actl. Storage (L)	Liters/person
4107.87	1500	2607.87	2607.87	2500.00	100.00
1020.43	1500	-479.57	2128.29	2020.43	100.00
3401.42	1500	1901.42	4029.71	2500.00	100.00
2276.33	1500	776.33	4806.05	2500.00	100.00
418.64	1500	-1081.36	3724.68	1418.64	100.00
209.32	1500	-1290.68	2434.00	127.95	100.00
2067.02	1500	567.02	3001.02	694.97	100.00
418.64	1500	-1081.36	1919.66	0.00	74.24
0.00	1500	-1500.00	419.66	0.00	0.00

- <u>Collection Equation:</u>

$$\boldsymbol{Collection = Roof\ area\ (ft^2) * Daily\ Preciptation\ (ft) * \frac{28.317\ (L)}{1\ (ft^3)} * 0.7}$$

Collection = Liters

Roof Area = Data gathered from previous analysis

Daily Precipitation = Data gathered from previous precipitation analysis

28.317 = Conversion factor from cubic feet to liters

0.7 = Factor of safety, assuming only 70% of rain is collected and stored

- <u>Consumption Equation:</u>

$$\boldsymbol{Consumption = 100\ (L) * \#\ of\ Family\ Members}$$

100 = Desired amount of daily water per family member

# of Family Members = Data gathered from previous population analysis

- <u>Net Equation:</u>

$$\boldsymbol{Net = Collection - Consumption}$$

The purpose of this equation is to subtract the daily consumption directly from the water collected. If there is not enough water collected then the net is displayed as a negative number and is subtracted from the tank volume in a future equation, depending on if there is a sufficient amount of water in the tank.

****Note: The data in this column is only used in further calculation and does not have any valuable significant by itself.*

- Potential Storage Equation:

$$\boldsymbol{Potential\ Storage_t} = \boldsymbol{If}(\ \boldsymbol{Net_t} + \ \boldsymbol{Potential\ Storage_{t-1}} > \ 0, then{:}\ \boldsymbol{Net_t} + \ \boldsymbol{Potential\ Storage_{t-1}}, \boldsymbol{else}{:}\ \boldsymbol{0})$$

The purpose of this equation is to display the potential amount of water that could be collected and stored if the tank size was not a limiting factor. The use of the If Statement to show that if there was not enough rainwater collected along with water in the tank to supply the daily need of the family, there would be no water left at the end of the day.

*******Note: This data is based on the assumption that the tank size would not be a limiting factor.***

- Actual Storage Equation:

$$\begin{aligned}\boldsymbol{Actual\ Storage_t} = \boldsymbol{If}(\ &\boldsymbol{Collection_t}\\ &> 0, then{:}\ If\big(\ \boldsymbol{Actual\ Storage_{t-1}} + \boldsymbol{Net_t}\\ &> 2500, then{:}\ 2500, else{:}\ If(\ \boldsymbol{Actual\ Storage_{t-1}} + \boldsymbol{Net_t}\\ &< 0, then{:}\ 0, else{:}\ \boldsymbol{Actual\ Storage_{t-1}} + \boldsymbol{Net_t})\big), \boldsymbol{else}{:}\ \boldsymbol{If}(\ \boldsymbol{Actual\ Storage_{t-1}} - \boldsymbol{Consumption_t}\\ &< 0, then{:}\ 0, else{:}\ \boldsymbol{Actual\ Storage_{t-1}} - \boldsymbol{Consumption_t}))\end{aligned}$$

This equation sets a limit of the tank size of 2500 L and does not allow any more water to be stored. The equation still takes into account that the daily consumption of water for the household will be taking from the rainwater collection first and then any extra water needed is taking then subtracted from the tank storage volume. If no rainwater is collected then the entire daily consumption is subtracted from the tank storage volume until the tank is empty.

****Note: This data is based on the assumption that the tank size would be limited to a size of 2500 Liters.*

- <u>Liters/Person Equation:</u>

$$\begin{aligned}
&\left(\frac{\boldsymbol{Liters}}{\boldsymbol{Person}}\right)_{\boldsymbol{t}} \\
&= \boldsymbol{If}\left(\ \boldsymbol{Collection}_{\boldsymbol{t}}\right. \\
&= \mathbf{0}, \boldsymbol{then}: \boldsymbol{If}\left(\ \boldsymbol{Actual\ Storage}_{\boldsymbol{t-1}}\right. \\
&> \boldsymbol{Consumption}_{\boldsymbol{t}}, \boldsymbol{then}: \frac{\boldsymbol{Consumption}_{\boldsymbol{t}}}{\#\ \boldsymbol{of\ Family\ Members}}, \boldsymbol{else}: \left.\frac{\boldsymbol{Actual\ Storage}_{\boldsymbol{t-1}}}{\#\ \boldsymbol{of\ Family\ Members}}\right), \boldsymbol{else}: \boldsymbol{If}\left(\ \boldsymbol{Collection}_{\boldsymbol{t}}\right. \\
&+\ \boldsymbol{Actual\ Storage}_{\boldsymbol{t-1}} \\
&>\ \boldsymbol{Consumption}_{\boldsymbol{t}}, \boldsymbol{then}: \frac{\boldsymbol{Consumption}_{\boldsymbol{t}}}{\#\ \boldsymbol{of\ Family\ Members}}, \boldsymbol{else}: \left.\left.\frac{(\boldsymbol{Collection}_{\boldsymbol{t}} +\ \boldsymbol{Actual\ Storage}_{\boldsymbol{t-1}})}{\#\ \boldsymbol{of\ Family\ Members}}\right)\right)
\end{aligned}$$

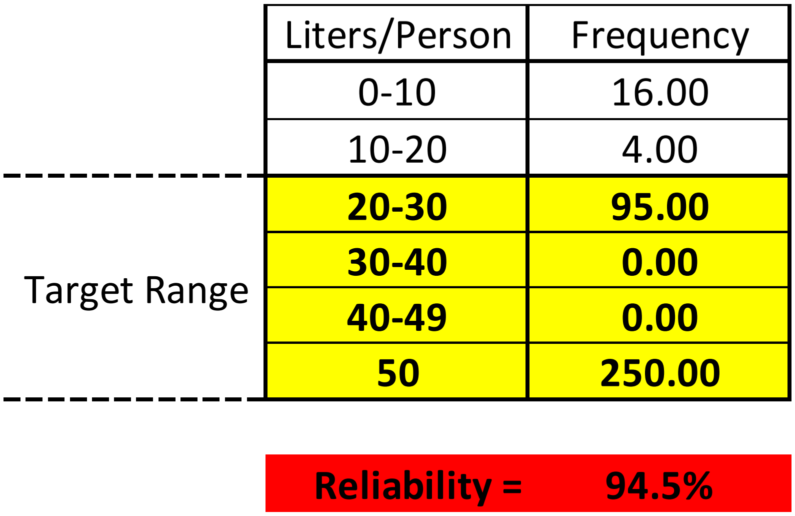
This equation takes into account the daily collection amount of rainwater and also the amount of water available in the tank storage volume. After taking in account the water available to the family through both options, this equation sums the total amount of water and then divides the amount by the number of family members in the household to give a total of amount of liters/person for the household that day.

****Note: This data provides a daily of amount liters/person for every member of the household.*

Appendix J

Tank Size Determination Calculations

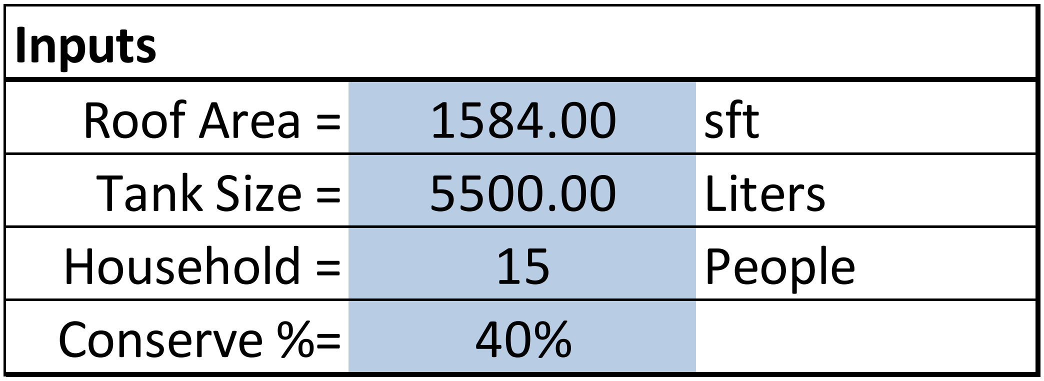
Table 8: Reliability of Tank Size



	Liters/Person	Frequency
	0-10	16.00
	10-20	4.00
Target Range	**20-30**	**95.00**
	30-40	**0.00**
	40-49	**0.00**
	50	**250.00**

Reliability = 94.5%

Table 9: Inputs for Tank Size Reliability



Inputs		
Roof Area =	1584.00	sft
Tank Size =	5500.00	Liters
Household =	15	People
Conserve %=	40%	

Table 10: Required Tank Sizes for 100% Reliability

100% Reliability

House	# of people	Roof Area	Tank Size (L)	
R0	1	1116.00	650.00	
R1	1	728.00	650.00	
R2	5	1320.00	3300.00	
R3	8	1170.00	5500.00	
R4	3	1102.00	2000.00	
R5	4	1296.00	2500.00	
R7	4	1476.00	2500.00	
R8	3	1760.00	1900.00	
R9	7	1440.00	4500.00	
R11	7	1530.00	4700.00	
R12	2	924.00	1300.00	
R13	8	2457.00	5000.00	
R14	4	1116.00	2500.00	
R15	5	1440.00	3300.00	
L0	1	1584.00	650.00	
L1	6	1521.00	3800.00	
L2	5	1521.00	3300.00	
L3	8	1581.00	5400.00	
L4	3	1581.00	2000.00	
L5	4	1386.00	2500.00	
L6	3	1287.00	2000.00	
L7	1	1209.00	650.00	
L9	15	1584.00	5500.00	94.5%
L10	5	1404.00	3300.00	
L11	8	1170.00	5500.00	
L12a/b	6	1287.00	4000.00	
		Max Volume =	5500.00	L

Height of Tank	1.5	meters
Radius of Tank =	1.1	meters
	3.5	ft

Height of Tank =	1.5	meters
Length of Sides =	1.9	meters
	6.3	ft

* Use Max Volume for necessary volume

* Excludes L9

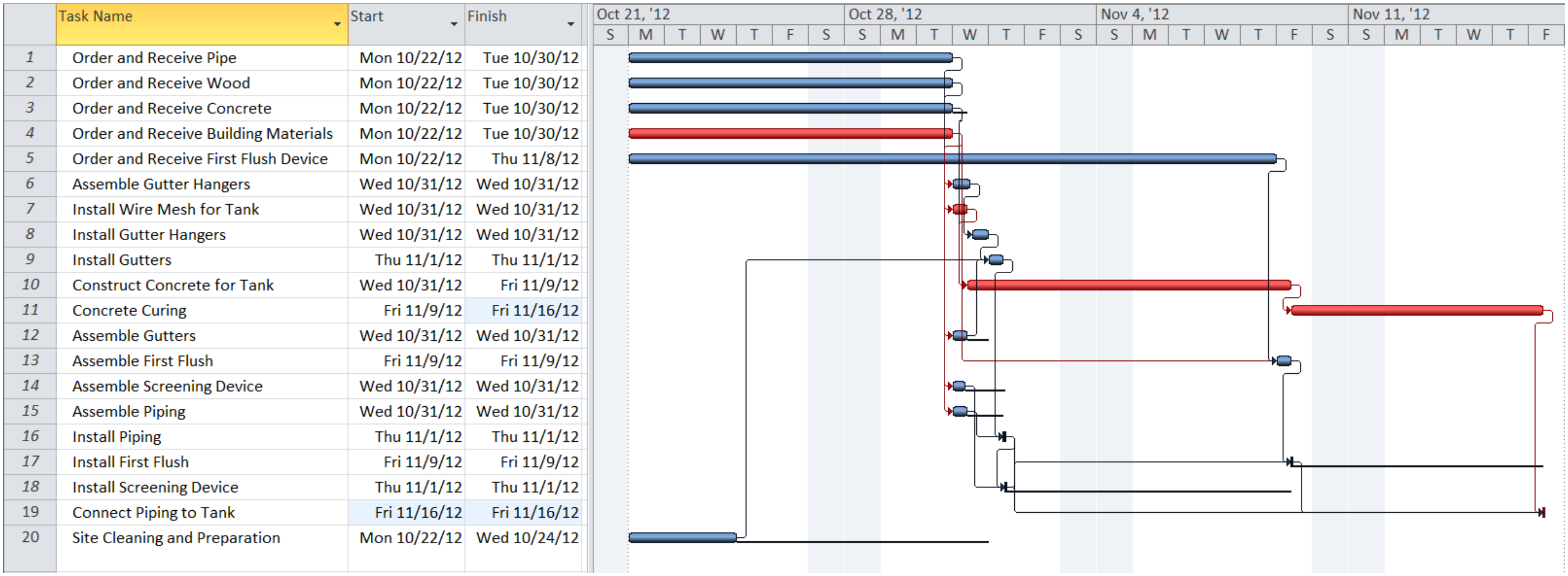
Assumptions:

* 70% of rainwater is harvested

* Conserve % is when the household will begin to move to 20 liters per day instead of 50

Appendix K

Construction Schedule



	Task Name	Start	Finish
1	Order and Receive Pipe	Mon 10/22/12	Tue 10/30/12
2	Order and Receive Wood	Mon 10/22/12	Tue 10/30/12
3	Order and Receive Concrete	Mon 10/22/12	Tue 10/30/12
4	Order and Receive Building Materials	Mon 10/22/12	Tue 10/30/12
5	Order and Receive First Flush Device	Mon 10/22/12	Thu 11/8/12
6	Assemble Gutter Hangers	Wed 10/31/12	Wed 10/31/12
7	Install Wire Mesh for Tank	Wed 10/31/12	Wed 10/31/12
8	Install Gutter Hangers	Wed 10/31/12	Wed 10/31/12
9	Install Gutters	Thu 11/1/12	Thu 11/1/12
10	Construct Concrete for Tank	Wed 10/31/12	Fri 11/9/12
11	Concrete Curing	Fri 11/9/12	Fri 11/16/12
12	Assemble Gutters	Wed 10/31/12	Wed 10/31/12
13	Assemble First Flush	Fri 11/9/12	Fri 11/9/12
14	Assemble Screening Device	Wed 10/31/12	Wed 10/31/12
15	Assemble Piping	Wed 10/31/12	Wed 10/31/12
16	Install Piping	Thu 11/1/12	Thu 11/1/12
17	Install First Flush	Fri 11/9/12	Fri 11/9/12
18	Install Screening Device	Thu 11/1/12	Thu 11/1/12
19	Connect Piping to Tank	Fri 11/16/12	Fri 11/16/12
20	Site Cleaning and Preparation	Mon 10/22/12	Wed 10/24/12

Figure 11: Construction Schedule

Table 11: Detailed Construction Outline

Activity	Activity Number	Activity Duration (Days - 8 hours)	Predecessors	Successors	Early Start (Day)	Late Start (Day)	Free Slack	Total Slack
Site Cleaning and Preparation	1	3	-	10	1	22	5	15.75
Order and Receive Pipe	2	7	-	13, 16	1	16	0	11.5
Order and Receive Wood	3	7	-	7	1	12	0	10.75
Order and Receive Concrete	4	7	-	11	1	1	0.25	0.25
Order and Receive Building Materials	5	7	-	7, 8, 14, 15, 16	1	1	0	0
Order and Receive First Flush Device	6	14	-	9, 14	1	5	0	4.94
Assemble Gutter Hangers	7	0.5	3, 5	9	10	24	0	10.75
Install Wire Mesh for Tank	8	0.25	5	11	10	10	0	0
Install Gutter Hangers	9	0.5	7	10	10	25	0	10.75
Install Gutters	10	0.25	1, 13, 9	12, 17	11	25	0	10.75
Pour Concrete for Tank	11	1	4, 8	12	10	10	0	0
Concrete Curing	12	7	11	20	19	19	0	0
Assemble Gutters	13	0.25	2	10	10	25	0.75	11.5
Assemble First Flush	14	0.25	6, 5	18	19	25	0	4.94
Assemble Screening Device	15	0.125	5	19	10	26	1.25	12
Assemble Piping	16	0.25	2, 5	17	10	25	1	11.75
Install Piping	17	0.125	16, 10	19, 20	11	26	0	10.75
Install First Flush	18	0.0625	14, 19	20	19	26	4.94	4.94
Install Screening Device	19	0.0625	17, 15	18, 20	11	26	5.81	10.75
Connect Piping to Tank	20	0.0625	12, 17, 18, 19	-	26	26	0	0

🟥 = Critical Path

Appendix L

House Data

Table 12: House Data

House	L (ft)	w (ft)	A (ft^2)	Population
R0	31	36	1116.00	1
R1	26	28	728.00	1
R2	30	44	1320.00	5
R3	26	45	1170.00	8
R4	29	38	1102.00	3
R5	27	48	1296.00	4
R6	USED AVERAGE		1400.00	5
R7	36	41	1476.00	4
R8	44	40	1760.00	3
R9	30	48	1440.00	7
R10	USED AVERAGE		1400.00	4
R11	30	51	1530.00	7
R12	28	33	924.00	2
R13	39	63	2457.00	8
R14	31	36	1116.00	4
L0	45	32	1440.00	1
L1	48	33	1584.00	6
L2	39	39	1521.00	5
L3	39	39	1521.00	8
L4	31	51	1581.00	3
L5	31	51	1581.00	4
L6	33	42	1386.00	3
L7	39	33	1287.00	1
L8	39	31	1209.00	4
L9	USED AVERAGE		1400.00	15
L10	33	48	1584.00	5
L11	36	39	1404.00	8
L12a	33	39	1287.00	6

Appendix M

Water Consumption

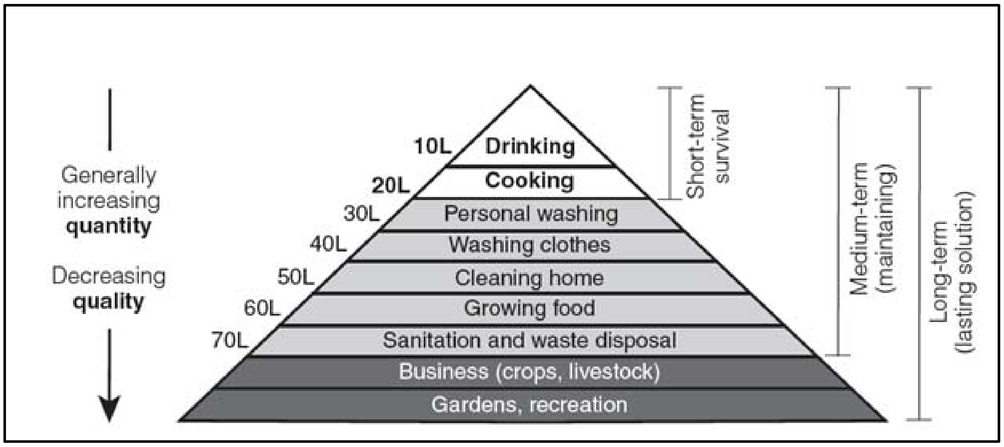


Figure 12: Hierarchy of water requirements (after Maslow's hierarchy of needs)[3]

One of the major design criteria for a water system is how much water should each member of the community be expected to consume on a daily basis. After extensive research, data was found that recommended 20 to 70 liters of water daily for a person in a developing country[3]. Correspondence with Dr. David Watkins (Michigan Technological University) and with Dr. Remigio Gallaraga (Escuela Politecnica Nacional), a value of 50 liters of water daily per person was chosen. In times of water scarcity, it was assumed that members of the community would only rely on 20 liters of water per day, which be adequate to fulfill drinking and cooking requirements. Throughout the design process the main focus was to supply the each household with 50 liters of water per day per person, and ensure minimal days where only 20 liters was available.

Appendix N

Construction Manual (English)

Rainfall Harvesting System Installation

Note: Preparation and installation of the gutter hangers may vary depending on material availability, house dimensions, and roof design. Therefore the following instructions can be altered to fit the needs of each unique house.

Prepare gutter hanger supports

1) Cut six pieces of 2’x2’ wood

-(3) 6 inch pieces
-(1) 1 ft piece
-(1) 1.25 ft piece
-(1) 1.5 ft piece

2) Assemble (1) 6 inch piece and the 1 ft piece into a V shape, and nail the two pieces together with two nails

3) Repeat for the other 6 inch piece and 1.25 ft piece.

4) Repeat for the other 6 inch piece and 1.5 ft piece.

Attach gutter supports to house rafters

1) Attach the longest gutter support to the rafter closest to the front of the house. Make sure the 1 ft section is straight out in relation to the house.
    a. Nail the gutter support to the rafter of the house with three nails.
2) Attach the next gutter support to the middle rafter. Make sure the 1.25 ft section is straight out in relation to the house.
    a. Nail the gutter support to the rafter of the house with three nails.
3) Attach the next gutter support to the last rafter closest to the back of the house. Make sure the 1.5 ft section is straight out in relation to the house.
    a. Nail the gutter support to the rafter of the house with three nails.

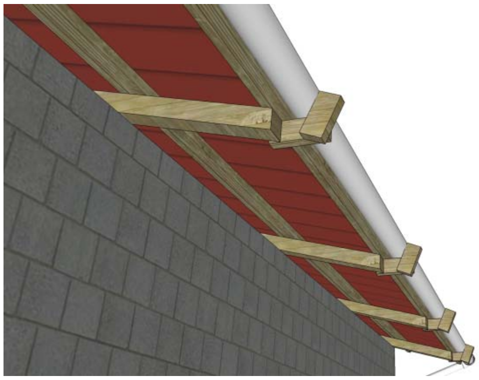


Figure 13: Gutter hanger orientation

Install Gutter

1) Cut to length of the house 6” PVC pipe and use 6” connectors to connect the pipes together
2) Place PVC gutter on top of gutter hanger supports
3) Ensure that the roof overhangs the gutter slightly, to reduce wasted water
4) Ensure gutter will not slip off the gutter hangers
5) Ensure downward slope towards back of house

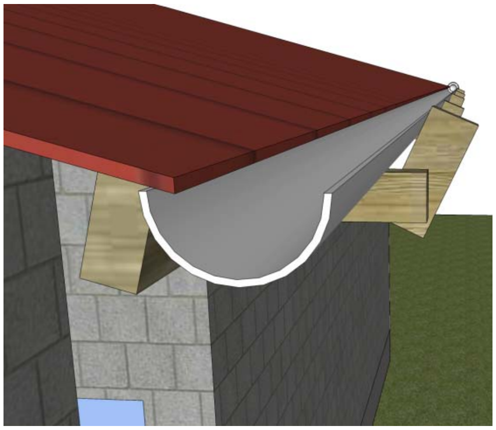


Figure 14: Gutter orientation

Repeat steps 1 and 2 for the other side of the house

Downpipe Assembly

1) Attach 4” end of 90° reducer elbow to 4” PVC pipe
2) Attach 6” end of 90° reducer elbow to end of gutter
3) Pivot the downpipe so that it points down towards the middle of the house
4) Place the downpipe so that it fits snugly into the filtration cone
5) Repeat for other side of house

Figure 15: Downpipe orientation

First Flush Device

1) Attach first flush device to filter cone
2) Secure filter cone into wooden fork support secured in the ground by concrete
3) Attach other side of first flush device to the inflow pipe of storage tank

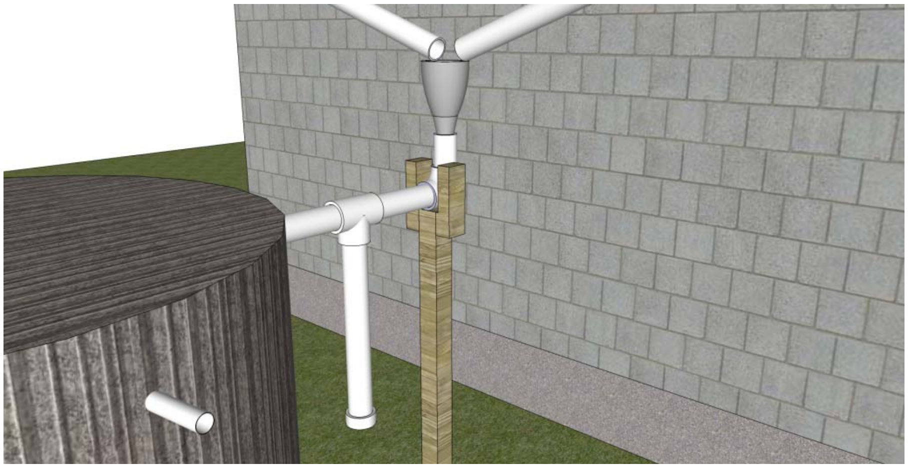


Figure 16: First flush orientation

Construction of water jar or jumbo jar built of Ferro cement (3000 – 6500 liters/3 m^3)

Worm, Janette, and Tim Hattum. "Rainwater Harvesting for Domestic Use." *Journeytoforever*. Http://journeytoforever.org/farm_library/AD43.pdf, n.d. Web. 30 Nov. 2012.

Foundation

1) Draw the contour of a circular foundation with a radius of 75 cm by using a string of 75 cm and a peg in the center of the jar.

2) Dig out the soil within the circle until firm soil is reached, or the height to the eaves of the roof is 220 cm.

3) Level the excavation and fill it with 10 cm of concrete, using a mix of 1:3:4 (sand: cement: water). Reinforce the concrete with two layers of chicken wire. Allow 300 mm of chicken wire to stick out all around the edge of the base. This will be connected to the wall mesh later.

4) Lay 10 anchor bolts for the legs in the base while casting (the diameter will depend on the diameter of the holes in the legs).

5) Make it level and compact it well. Let the base set for 7 days, wetting it each day.

Framework

6) Prepare skeleton / framework legs from five long pieces of chicken wire (or bamboo). Cut 5 lengths of 7 m-long 3 mm galvanized wire. Bend the wire-ends to avoid injuries. Mark the middle of each wire using pliers. Tie the 5 wires together at the marks like spokes in a wheel. Make a ring of 3 mm wire, 116 cm in diameter, and place upon spokes and tie together.

7) The draw-off pipe is made of a piece of 18 mm GI pipe that is 90 cm long. An elbow and a nipple are screwed onto the inner end, and a socket and a tap to the outer end. Place the pipe upon the foundation.

8) Place the wires and mesh on the foundation and stuff it with light, dry material, e.g. sawdust, hay or dung. Sand may be used if buckets can handle the weight.

9) Secure the 10 skeleton legs using the bolts and the crown ring. Take a 6 mm steel rod and wrap it around the outside of the legs, starting at the bottom and working up.

10) Fix 2 layers of chicken mesh over the outside of the skeleton. The filter tower can be added at this point if a filter is to be fitted.

11) Secure 4” inflow pipe to top of wire mesh.

Wall and Top Construction

12) Plaster the outside of the mesh. Mortar (1:3) is smeared onto the mold in a thin layer. After a couple of hours more mortar is plastered on to the mold until the mortar is 2 cm thick.

13) While the plaster sets for 3 days, build the tap station.

14) Remove the skeleton from the inside of the tank. The jar is cleaned before mortar 1:3 is plastered onto the inside in 2 layers, each layer being 1 cm thick. Water proofing can be added to the mortar. This can be a special additive or liquid dishwashing soap.

15) Cure the tank for 7-10 days.

16) Place 2 concentric rings of plain sheet metal that 10 cm high and 60 cm in diameter on top of the jar. Fill the space between the two sheets with mortar (1:3) to form a manhole and a lip.

17) Place a pipe for an overflow through the lip.

18) Cover the manhole with mesh to prevent insects and debris from entering the jar.

19) After 7 days fill the tank gradually (first flush!) at a rate of approximately 300 mm per day by controlling the inflow into the tank in case the rainfall is very intensive during the first rainfall season.

Figure 17: Ferrocement Tank Design

Appendix O

Rain Water Harvesting Cost Estimate

Table 13: Rainfall Harvesting Unit per House Cost

Rainfall Harvesting Unit per House Cost

Engineering Estimate

10/22/2012

Item	Quantity	Unit	Unit Price	Amount	Subtotal
FERROCEMENT TANK					
Type I Portland Cement (94lb Bag)	11	Bag	$9.27	$101.97	
Galvanized 100' 6" x 6" Concrete Reinforcement Mesh	0.16	Roll	$70.00	$11.05	
3' x 150' Chicken wire 1" Mesh	0.08	Roll	$43.00	$3.39	
Copper Binding Wire 16-Gauge	1	Spool	$9.20	$9.20	
Clean Concrete Sand	0.705	Ton	$5.00	$3.53	
Water	107	L	$0.00	$0.00	
Water Tap Unit	1	each	$5.79	$5.79	
Elbow	2	each	$1.00	$2.00	
Plug	1	each	$1.00	$1.00	
10' 2" PVC Schedule 40 Pipe	4	each	$3.00	$12.00	
FERROCEMENT TANK SUBTOTAL					$149.93
WATER FILTRATION UNITS					
First Flush Device	1	each	$15.00	$15.00	
Generic Bleach	1	gal	$1.00	$1.00	
5' x 2' Coarse Screen	1	each	$12.44	$12.44	
36" x 25' Aluminum Fine Screen	1	each	$25.00	$25.00	
WATER FILTRATION UNITS SUBTOTAL					$53.44
GUTTER SYSTEM					
10' 6" PVC Pipe	6	each	$10.05	$60.30	
6" to 4" Reducer	2	each	$1.35	$2.70	
4" 90° Elbow	2	each	$1.00	$2.00	
3" 90° Elbow	1	each	$1.10	$1.10	
2" x 4" x 20' Lumber	1	each	$5.25	$5.25	
10' 4" PVC Pipe	4	each	$5.05	$20.20	
3.5" Nails	1	box	$14.77	$14.77	
1.5" Nails	1	box	$14.28	$14.28	
GUTTER SYSTEM SUBTOTAL					$120.60

BASE CONSTRUCTION COST ESTIMATE	$323.97

Table 14: Rainfall Harvesting Units Overall Cost

Rainfall Harvesting Units Overall Cost

Engineering Estimate

10/22/2012

Item	Quantity	Unit	Unit Price	Amount	Subtotal
FERROCEMENT TANK					
Type I Portland Cement (94lb Bag)	418	Bag	$9.27	$3,874.86	
Galvanized 100' 6" x 6" Concrete Reinforcement Mesh	6	Roll	$70.00	$420.00	
3' x 150' Chicken wire 1" Mesh	3	Roll	$43.00	$129.00	
Copper Binding Wire 16-Gauge	38	Spool	$9.20	$349.60	
Clean Concrete Sand	27	Ton	$5.00	$133.95	
Water	4059	L	$0.00	$0.00	
Water Tap Unit	38	each	$5.79	$220.02	
Elbow	76	each	$1.00	$76.00	
Plug	38	each	$1.00	$38.00	
10' 2" PVC Schedule 40 Pipe	152	each	$3.00	$456.00	
FERROCEMENT TANK SUBTOTAL					$5,697.43
WATER FILTRATION UNITS					
First Flush Device	38	each	$15.00	$570.00	
Generic Bleach	38	gal	$1.00	$38.00	
5' x 2' Coarse Screen	38	each	$12.44	$472.72	
36" x 25' Aluminum Fine Screen	38	each	$25.00	$950.00	
WATER FILTRATION UNITS SUBTOTAL					$2,030.72
GUTTER SYSTEM					
10' 6" PVC Pipe	228	each	$10.05	$2,291.40	
6" to 4" Reducer	76	each	$1.35	$102.60	
4" 90° Elbow	76	each	$1.00	$76.00	
3" 90° Elbow	38	each	$1.10	$41.80	
2" x 4" x 20' Lumber	38	each	$5.25	$199.50	
10' 4" PVC Pipe	152	each	$5.05	$767.60	
3.5" Nails	38	box	$14.77	$561.26	
1.5" Nails	38	box	$14.28	$542.64	
GUTTER SYSTEM SUBTOTAL					$4,582.80
OVERHEAD(20%)					$2,462.19
BASE CONSTRUCTION COST ESTIMATE					$14,773.14

Table 15: Simplified Rainwater Harvesting Cost Estimate

Cost Estimate of Rain Water Collection System	
FERROCEMENT TANK	$ 150
WATER FILTRATION UNITS	$ 53
GUTTER SYSTEM	$ 121
OVERHEAD (20%)	$ 57
TOTAL COST PER HOUSE	**$ 324**
TOTAL COST FOR COMMUNITY	**$ 14,774**

***Note: 38 Houses in the community*