Water Distribution System for the Village Punta Sirain, Panama

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Submitted to:

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CE4916 - International Senior Design

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Disclaimer

The following represents the efforts of undergraduate students completing the idesign capstone design program through the Civil and Environmental Engineering Department of Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report should not be considered professional engineering.

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1.0 Executive Summary

Bä Noire Designs has designed a water distribution system that will provide the 250-resident community of Punta Sirain, Panama with drinking water. The team spent one week in the community in August 2009 obtaining assessment data and interviewing the residents.

The current water supply system is insufficient in that it provides water directly to only ten of about forty households. Spring water is collected in the *toma*—a 6,000 gallon (22,700 L), uncovered, water catchment and storage tank—and then gravity fed to the community. Since the *toma* is uncovered, the stored water is contaminated by debris and algae. Consequently, many of the children suffer from water borne illnesses.

The new design proposes that the *toma* be modified into a smaller three-chamber, covered springbox. This will help protect the spring water from contamination. The water will be pumped using solar power to a storage tank located on a hill fifty feet higher in elevation than the *toma*. The distribution system will gravity feed water from the storage tank to each of the forty homes in the community. The estimated cost to implement the recommended design is $15,300, and construction should take approximately 43 work days to complete. These estimates plan for the use of as much local materials and donated local labor as possible.

The recommended water distribution system design should reduce the risk of contamination between the spring source and human consumption, resulting in the improved health of the residents of Punta Sirain.

2.0 Introduction

Bä Noire Designs is one of four student design groups that participated in the idesign capstone design program through Michigan Technological University's Department of Civil and Environmental Engineering during the summer and fall of 2009. The team is comprised of the project manager, Ashley Maes, and project members Ashley Thode, Dan Smith, Kevin Bierlein and Kristian Bartell. All participants of idesign traveled to Panama for two weeks in August of 2009. Each team partnered with a Peace Corps Volunteer (PCV) working in a rural community to assess the community needs and select an appropriate engineering design project to help meet these needs. The fall 2009 semester was used to develop design recommendations.

Ease of access to potable water for both drinking and cooking is a major contributor to improved health. Unfortunately, much of the world lacks the infrastructure to meet this basic need. Punta Sirain is a remote indigenous community of approximately 250 people located on Peninsula Valiente in the Comarca Ngobe-Buglé Reserve and is a prime example of this issue. The community has an abundance of water, from both groundwater and rainwater sources. However, due to an outdated and primitive water distribution system, unnecessary contamination is being introduced to the drinking water, and only a small portion of households have access to the system in their household.

Members of Bä Noire Designs lived with this community for seven days in August 2009 to collect the necessary technical and social information to develop a recommendation for an improved water distribution system design. Kaitlin Green, the PCV in Punta Sirain, informed the team that a pumped delivery system had been requested by the community. The most viable alternative, rainwater collection systems at the household level, is being analyzed in a separate study by the PCV.

This report describes Bä Noire Designs' recommendations for improvement of the community water distribution system in Punta Sirain. Included are design documents, cost estimates, construction details and construction schedules for a recommended design. Design documents and cost estimates are also included for two alternative designs, along with methods and results from the site assessment completed in August 2009.

3.0 Background

The Republic of Panama is located in Central America, between Costa Rica and Columbia. Its capital is Panama City, which is located on the Pacific Ocean. Panama was originally a part of Columbia, but in 1903 Panama seceded with the aid of the United States, seeking to construct a canal linking the Atlantic and Pacific oceans.

Today, the Panama Canal and tourism provide the nation with its major sources of revenue. These sources have helped to reduce Panama's national poverty level; however, in Latin America the nation also ranks the second worst in terms of distribution of income (CIA Factbook). This disparity between incomes is easily identified while travelling through the country. Panama City is crowded with high rise buildings, but most of the rural indigenous population lives in remote areas with limited infrastructure (World Travel Guide).

The unequal distribution of wealth can also be identified by analyzing the differences in health between the rural and industrialized regions. The infant mortality rate is 20% greater in rural regions than in urban areas (Meditz & DHanratty, 1987). It is likely that some of these health issues are directly linked to contaminated drinking water. Due to lack of funding and difficulty in transportation of materials, Punta Sirain is an example of a community that lacks an adequate potable water system.

Located at the remote tip of Peninsula Valiente in the Bocas del Toro region of northwest Panama, as shown in Figure 1, Punta Sirain is an indigenous community of roughly 250 individuals. The village subsists mainly on fishing and seasonal construction work on Isla Colon and Bocas del Toro, as well as regular welfare checks provided by the Panamanian government, which amount to roughly $4 per day per family. The residents of Punta Sirain are of the Ngobe tribe, who are prevalent in northwest Panama. The village itself is situated on rolling green hills overlooking the Caribbean Sea, and is reachable only by boat. The three main hills in the community each house a different family group. Younger Ngobe often remain in the community and build or buy their own home near their parents.

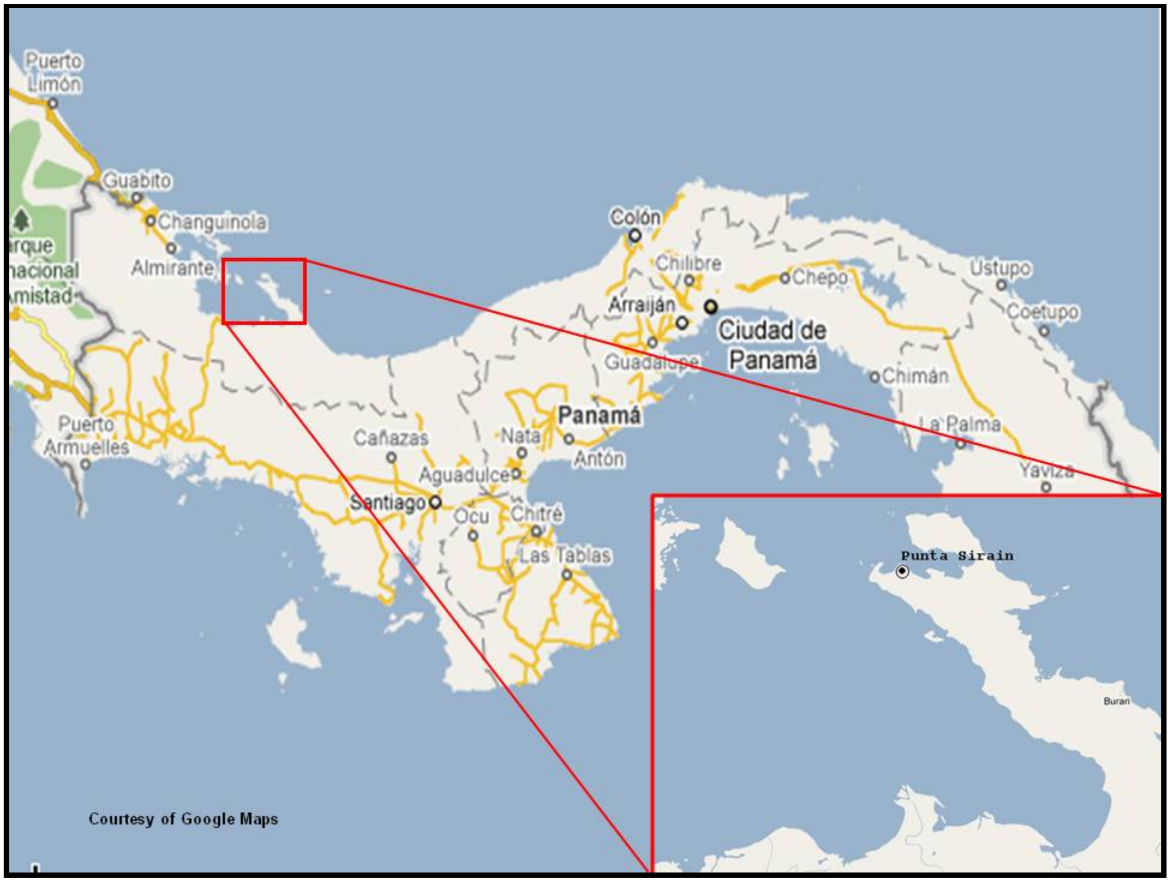

Figure 1: Location of Punta Sirain, Panama

Through an interview with the local doctor, the team learned that children six years old and younger often suffer such ailments as diarrhoea, vomiting and stomach aches. He suspects these illnesses come as a result of drinking contaminated water. The doctor also commented that the adults have fewer health problems.

4.0 Site Assessment

Certain technical data is mandatory for the design of a community water distribution system. In order to complete feasibility calculations for system improvements, Bä Noire Designs collected spring flow rates and completed a topographical survey of the area. Since the community demonstrated strong interest in adding a motorized pump to the system, an analysis of the existing electrical system was also conducted.

4.1 Existing Water System

Currently, Punta Sirain has water supplied primarily from a contaminated water distribution system that only directly serves a quarter of the community households. It is composed of a large holding tank (the *toma*), a PVC piped system, and a series of spigots, as shown in Figure 2. The houses in the community are distributed on three hills, and the current system carries water to only two of the three hills and only 10 of 40 households. Consequently, many of the families on the third hill elect to collect water from a stream that passes through the village. Although bathing, defecating, and clothes washing takes place downstream, the stream water is likely contaminated from surface runoff (farm animals graze freely in the community), and thus there is strong reason to believe the use of this water negatively impacts the health of the residents.

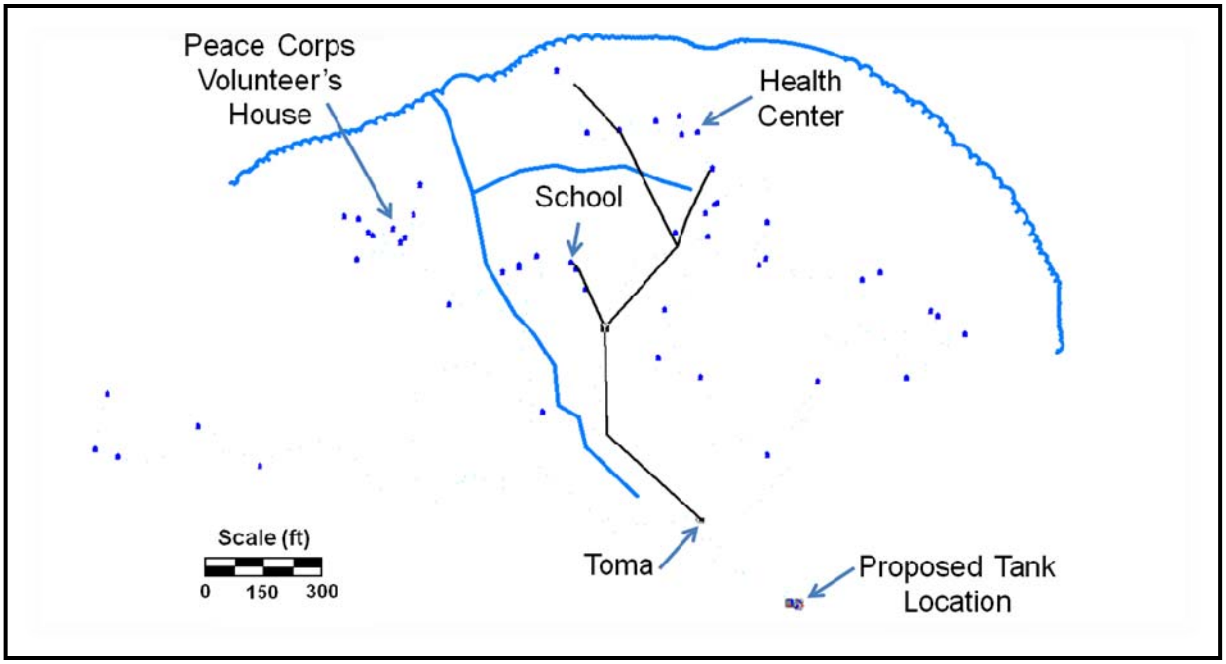

Figure 2: EPANET model of existing water distribution system (1 ft = 0.3048 meters)

4.1.1 Toma

The *toma,* shown in Image 1, serves as the spring water catchment and storage tank. The water in the *toma* is of poor quality due to lack of proper treatment and protection from contamination. Since the *toma* is uncovered, debris is able to fall into the tank, and aquatic plants and animals grow in the tank.

Image 1: Existing *toma* with a volume of 6,000 gallons (23,000 liters). Photo by Kristian Bartell.

Spring water feeds into the *toma* along one wall at a rate of approximately ten gallons per minute (38 liters per minute). This provides sufficient flow of water to meet the daily needs of the homes, school and churches in the community; however, many people do not have convenient access at or near their home, which may limit the amount of water they use for basic needs such as hygiene and food washing. The *toma* stores approximately 6,000 gallons (23,000 liters) of water, and the water level remains fairly constant throughout the rainy and dry seasons, as observed by community members and the PCV living in Punta Sirain. However, due to the excessive size of the *toma* (200 ft^2 by 5 ft deep), it is difficult to protect and treat the water before it is distributed to the community.

4.1.2 Pipe System

The spring water that is stored in the *toma* is discharged through a two-inch PVC main line directed to the school. The pipeline then splits off and supplies water to two of the three clusters of houses. There are 14 taps in the system--10 feed directly to houses and four are public access taps. The spigots frequently break and are not maintained. The school provides one example of this. During the site assessment, the spigot was broken, leaving the pipe to rest in the soil. When children want to drink water they place the dirty pipe in their mouths, suck on the pipe, and then throw it back in the dirt. The spigot at the school is shown in Image 2. Additionally, in the current system much of the pipe is exposed, thus increasing weathering of the PVC.

In summary, the current pipe system needs improvements since it is easily weathered, difficult to maintain, limits water access, and forces the users to resort to unsanitary drinking methods.

Image 2: Spigot at school. Photo by Elizabeth Quinley.

4.1.3 Water Committee

The drinking water system has been in place for approximately 20 years and was constructed by a government funded program. For the past ten years a water committee has managed the weekly chlorine treatment of the water and the monthly cleaning of the *toma*. Additionally, the water committee is responsible for collecting a $1/month fee paid by the ten families with a tap directly in their home. The fee is used to maintain the *toma*, while the Panamanian Health Ministry (Ministeria de Salud, or MINSA) provides the community with chlorine tablets. Once a week, a committee representative places one half of a 10-cm diameter tablet in the distribution pipe and the other half in the *toma*. Each month, all water is bailed out and the *toma* is scrubbed free of algae in an attempt to improve water quality, as shown in Image 3.

This cleaning and treatment routine demonstrates a functioning water committee, as well as the community's dedication to improving their circumstances. However, it is evident that these efforts are not enough to provide adequate water treatment. Without clean water delivered in-house, there are still many opportunities for contamination. With contaminated water, it is likely that substantial health impacts will continue.

Image 3: Emptying and cleaning of existing *toma*. Photo by Ashley Thode.

4.2 Survey Methods

Topographical data along the current and proposed water supply pipelines are necessary to assess the current system and design an improved system. The equipment used to collect these data included a water level, shown in Image 4, a handheld GPS device and a 100-foot tape measure. A water level is a low technology device that can be used to determine relative elevations for a series of points. It is composed of a storage reservoir made of two- and four-inch PVC pipe, a thin hose made of translucent material, a wooden board to which a tape measure is attached, and a valve, as shown in Figure 3.

First, the water level is zeroed by placing the bottom of the instrument on level ground and opening the valve to allow water to flow between the storage reservoir and the hose until it has reached equilibrium at the same height. Then relative elevations can be determined by reading the tape measure to determine the level of water in the hose and subtracting the zeroed value from the measurement. For each data point, a relative elevation was measured using the water level, and latitude and longitude coordinates were recorded using the GPS. Maps were drawn to relate each point to house locations and major landmarks. All data was recorded and can be found in Appendix A.

Image 4: Surveying using a water level. Photo by Ashley Thode.

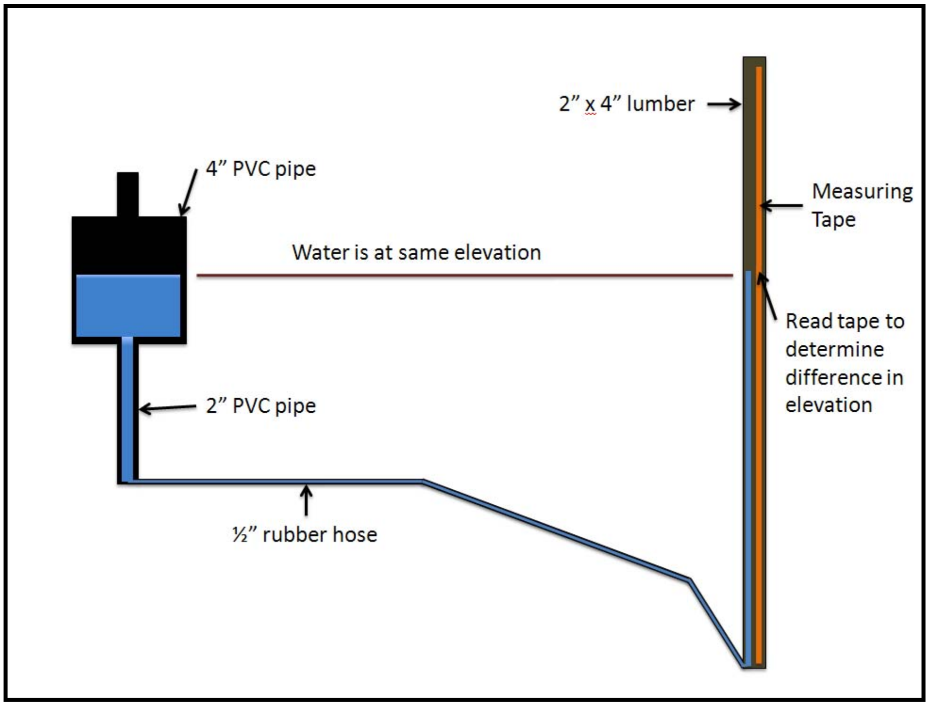

Figure 3: Components of a water level

4.3 Measuring Spring Water Flow Rate into the Existing *Toma*

The flow rate of spring water into the *toma* was measured to determine the capacity and flow of water available to the community using the existing spring source.

Initially, the water level of the *toma* exceeded the level of the capped overflow pipe (see Image 5). A trench was dug to allow the water to drain from the overflow pipe into the swamp north of the drain pipe. Once the trench was completed, the cap was removed and water exited the *toma* through the overflow pipe. The pipe supplying water to the community was then capped to limit the system flow such that water entering from the spring was continuously exiting through the overflow pipe.

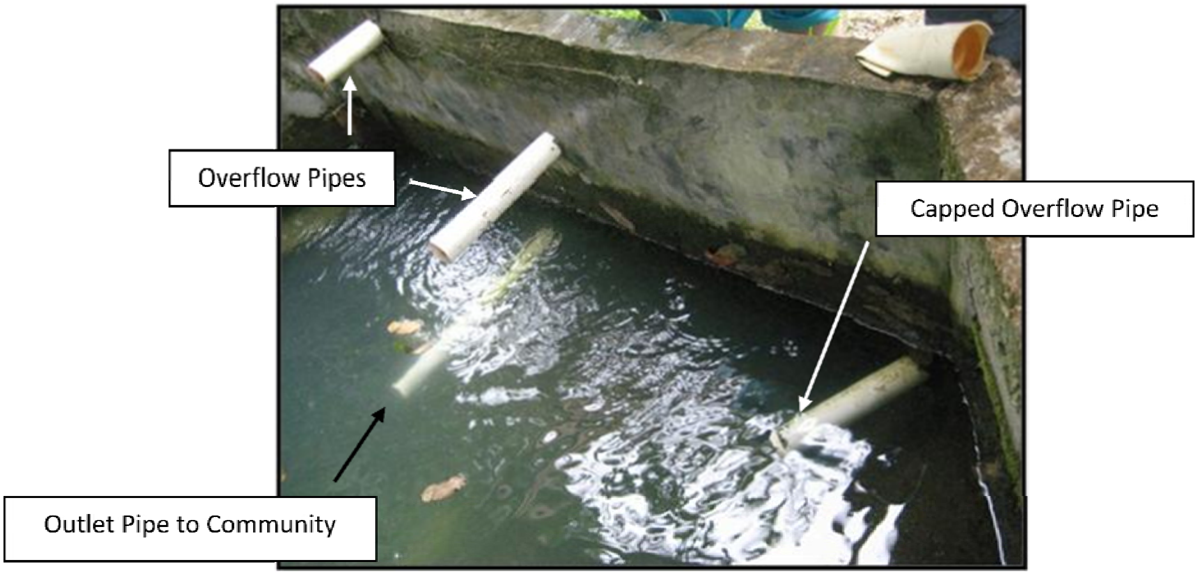

Image 5: Pipes exiting the *toma*. Photo by Elizabeth Quinley.

After the *toma* drained for a few minutes, equilibrium was reached. This was determined when the level in the tank remained approximately ¼" above the top of the overflow pipe for five minutes without any variation. A five gallon bucket was then used to catch the water flowing from the overflow pipe, and filling was timed (see Image 6). Six measurements were made to determine the average flow rate. This process was completed on two separate occasions: following a storm and after a two-day dry spell. Results are shown in Table 1, and all data is included in Appendix A. Community members commented that the level of water remains nearly constant during all seasons and that they had never witnessed the *toma* run dry. Based on these observation and our limited measurements, a reliable spring discharge of 9 gpm (35 liters per minute) may be expected.

Image 6: Measuring flow rate. Photo by Elizabeth Quinley.

Table 1: *Toma* flow rate results (1 GPM = 3.8 liters per minute)

Date	8/14/2009	8/16/2009
Trial Number	After Rain Storm (GPM)	After Dry Period (GPM)
1	10.71	9.38
2	9.45	9.52
3	9.52	9.23
4	9.45	9.23
5	9.38	9.09

4.4 Analysis of Current Photovoltaic System

Using a pumped-storage delivery system requires a source of electricity to power the pump. Since the school and doctor's office have existing photovoltaic (PV) systems, it was necessary to conduct a feasibility study to determine if the systems could handle the load requirements of a solar water pump. However, since the exact specifications of the pump could not be determined during the assessment trip, most of the in-country work involving the PV systems was to obtain information on how the system is currently set up and to estimate existing load demands on the system (see Image 7).

Image 7: Doctor's office PV system 1. Photo by Kristian Bartell.

The community doctor granted access to the system at his office, which allowed the team to see how the control panel for the system is configured, shown in Image 8. Information and photographs were also collected from the junction boxes mounted on the panel brackets, allowing the team to determine the physical wiring configuration of the system. The same procedure was repeated at the school the following day to compare the two system configurations.

Image 8: Photovoltaic control panel 1. Photo by Kristian Bartell.

The doctor's office has two separate PV systems installed. The larger of the two systems has a peak power output capability of 600 Watts. This system is used to power four fluorescent light bulbs and a television. Without knowing exact wattages of the lights, a safe estimate of the total maximum load between the lights and the television would be less than 300 Watts. The second system at the doctor's office has a peak power output of 450 Watts and was designed to be used strictly in powering the refrigerator. This system should not be considered for inclusion in the solar pump project.

An identical PV system is installed at the school and has a peak power output of 800 Watts. The total load on the system was unable to be identified because the school was locked. However, it is known that the system is used to light at least three classrooms (approximately 12 lights) and power a television. Additional solar panels will be needed due to the location of the existing PV systems and the variability of the existing load on them.

5.0 Design Options and Analysis

The gravity-fed water distribution system designed for Punta Sirain consists of four major design components: a spring box, a solar-powered pump system, a storage tank, and the distribution system (pipe network). The current *toma* structure will be modified to consist of two spring boxes and a pumping chamber. The spring water that flows into the spring boxes will overflow into the pumping chamber. From there, water will be pumped to a storage tank on a nearby hill. The water will then be gravity-fed from this storage tank to the entire community. Refer to Figure 4 for a representation of the interactions between system components. All construction drawings are included in Appendix D.

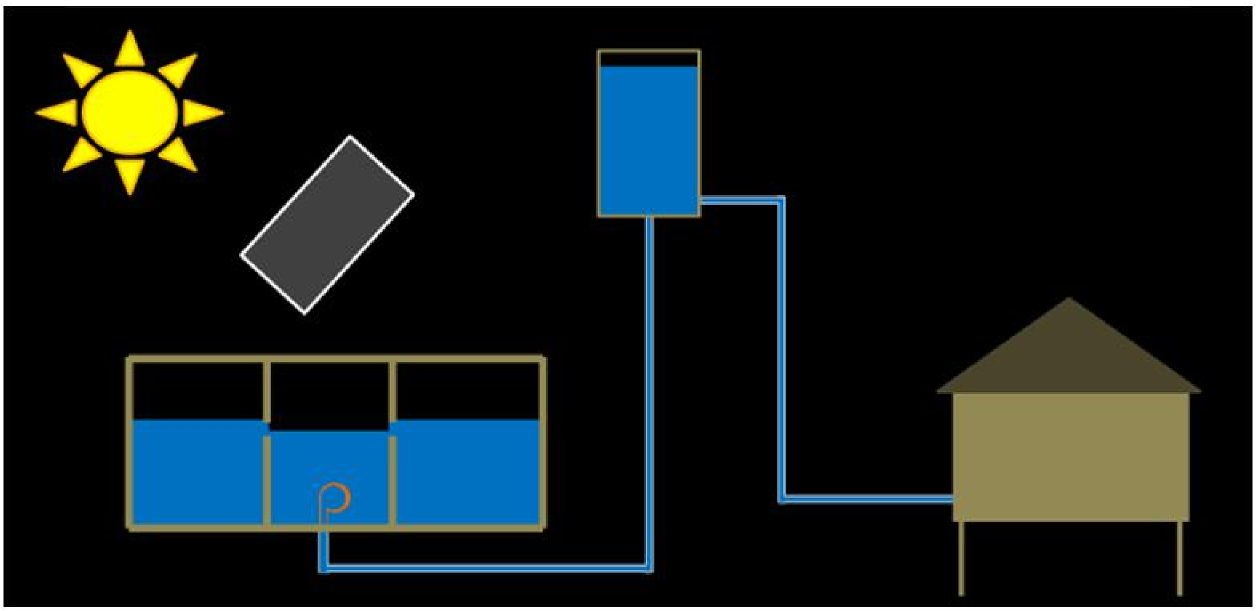

Figure 4. Graphic representation of distribution system components.

5.1 Spring Box Design

Bä Noire Designs recommends using an improved version of the existing *toma* as the point of collection for the water distribution system. The *toma* would be divided roughly in half lengthwise - one half will be split into three chambers and the other half will no longer be used. Please see Figure 5 for a plan view of the improved *toma* layout. Water enters the *toma* in the corners of the right half. All of the new walls will be constructed of steel reinforced concrete block. The covers will be individually cast of reinforced concrete, so as to be easily handled by two to four able-bodied men. It is important that the covers be sealed closed with mortar at all times except during cleaning and maintenance.

The outer two chambers will act as spring boxes (collection areas for spring water), and the center chamber will house the pump. The water will overflow through openings in the concrete blocks into the center chamber. This design allows sediment to settle before entering the pump chamber, preventing premature wear of pump components and buildup of particulate matter in the system. The spring boxes are sized and located to ensure that they will capture the majority of water entering the *toma* based on firsthand observations of the spring flow entrance into the *toma*. The pump house is sized to prevent excessive overflow out of the *toma*.

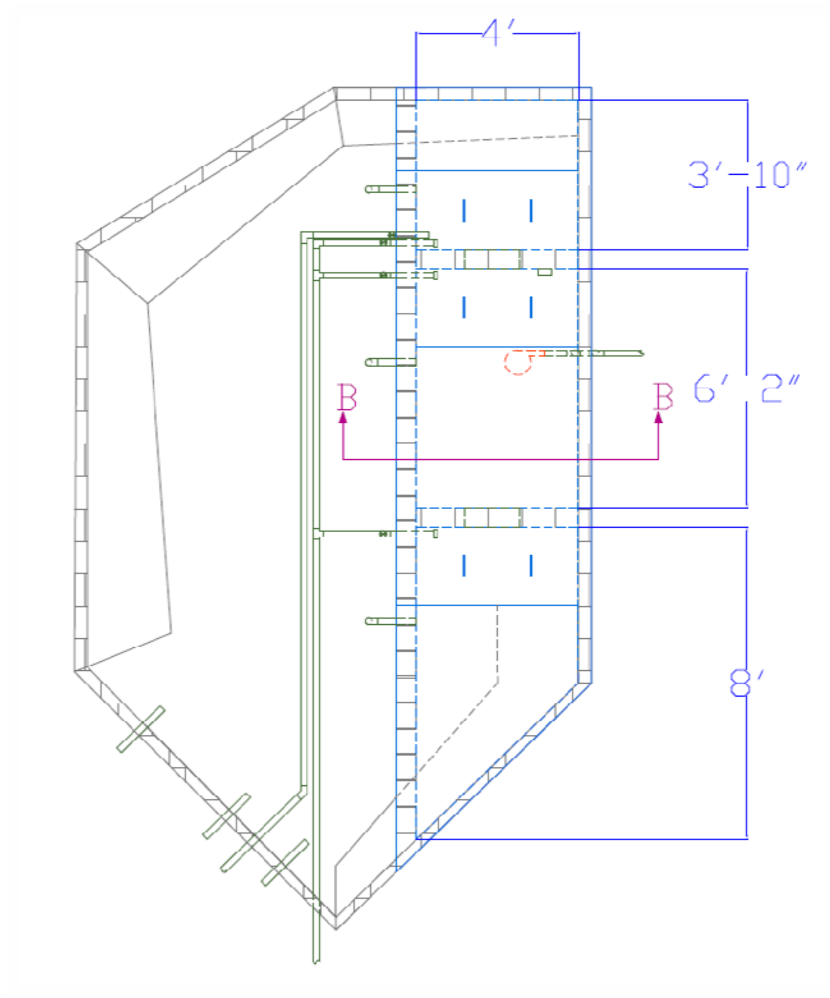

Figure 5: Plan view of recommended *toma* modifications

One important feature of the improved *toma* is that the existing supply line to the school will be connected to an outlet from one of the spring boxes and will remain the primary water source for the school. This gravity fed line will supply water to a centralized location in the case that any part of the pump or solar power system should fail. In addition to this supply line, screen-covered overflow pipes will be added with 90° bends for protection from insects and other hazards. Cleanout pipes with gate valves, built exiting the bottom of each chamber, will drain into an existing pipe in the *toma* floor and then to a nearby marsh. The cleanout pipes and the smaller three-chamber design will reduce the burden of cleaning and maintenance. Appendix G contains a cleaning guide for use in training the community in appropriate cleaning techniques and schedules for the *toma* and storage tank.

5.2 Spring Protection

An important step in spring box design is protecting the source from contamination. Please see Figure 6 for a rough sketch detailing good spring protection. To protect the improved *toma,* Bä Noire Designs recommends erecting a new fence at least nine meters in every direction from the *toma.* A runoff diversion ditch should be dug inside the fence on the uphill side of the *toma* as a means of guarding it against contamination from animal feces and storm runoff. The ditch should be able to catch and divert all runoff directly uphill from the spring source. If possible, this ditch should also be lined with large stones to prevent erosion. These measures should protect the spring boxes from contamination by direct runoff, as well as help prevent contaminants from leaching into the ground water close to the spring.

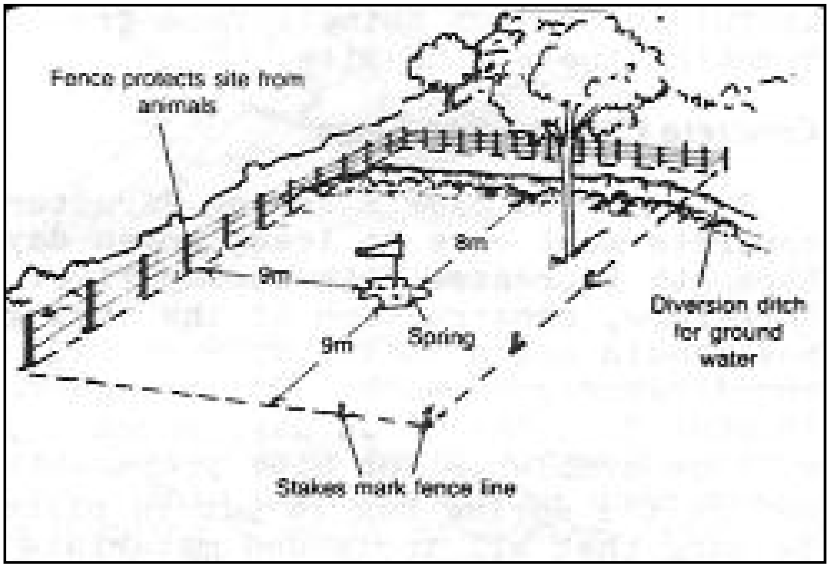

Figure 6: Recommended spring protection measures (Water for the World)

5.3 Solar-powered Pump and Controls

5.3.1 Pump Selection

The pump chosen for the distribution system needs to meet a few important criteria and be cost-effective. First, it needs to be able to move a sufficient amount of water each day to meet the community demand. Second, the pump has to use a relatively small amount of energy to accomplish the design pumping rate. Third, the pump must be durable and able to handle variable input power conditions.

The Grundfos SQ Flex pump, shown in Figure 7, is designed for deep well applications in remote areas and for operation using renewable energy sources. The specific model of pump that will be used is the 11 SQF-2. The pump needs to produce a flow rate of approximately eight gallons per minute (30 liters per minute) to keep up with the community demand, at 100 feet (30 meters) of head to reach the storage tank elevation. The head requirement was calculated by adding the elevation change between the *toma* and proposed storage tank location, the height of the tank and the head loss from pipe. A safety factor of 25% was added. Full calculations are included in Appendix B. Figure 8 shows that the pump will require about 280 watts of power to operate under these conditions. Not only does the pump require a small amount of power to produce required flow rates, it is also able to operate on a wide range of voltages. This is important because it allows freedom in the design of the power supply which will make price optimization easier. The pump requires minimal maintenance and has a 15-year life expectancy making it a durable and reliable choice for the rugged conditions in Punta Sirain (solarwellpumps.com).

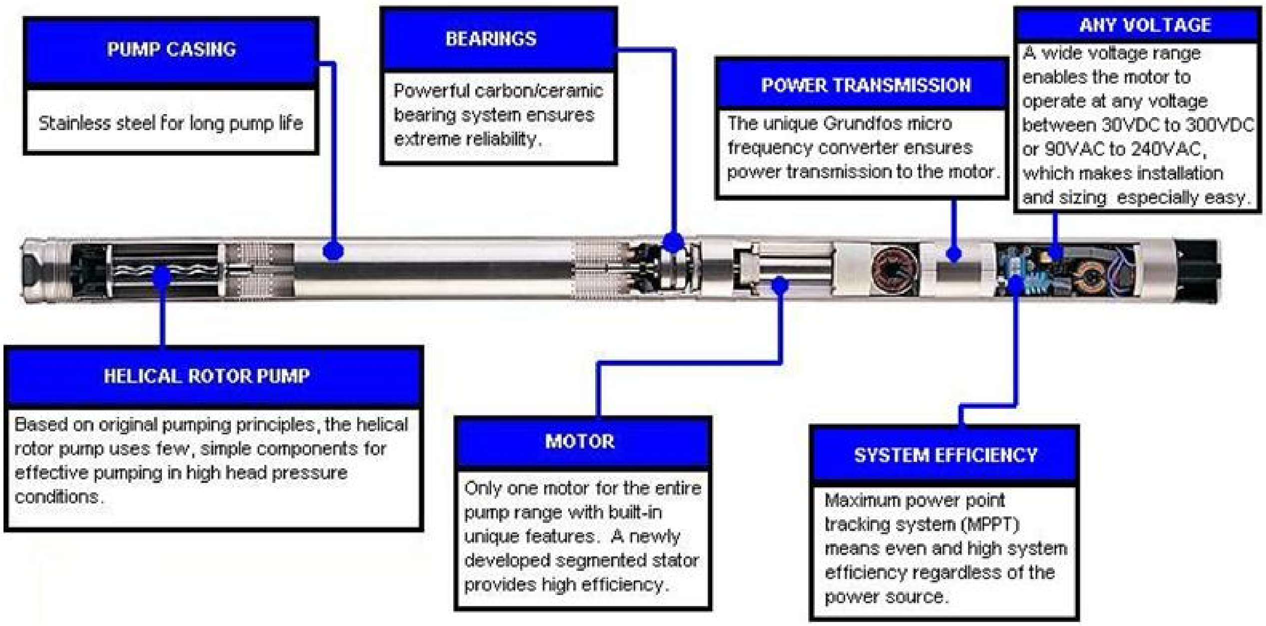

Figure 7: SQFlex Pump (Image from www.solarwellpumps.com)

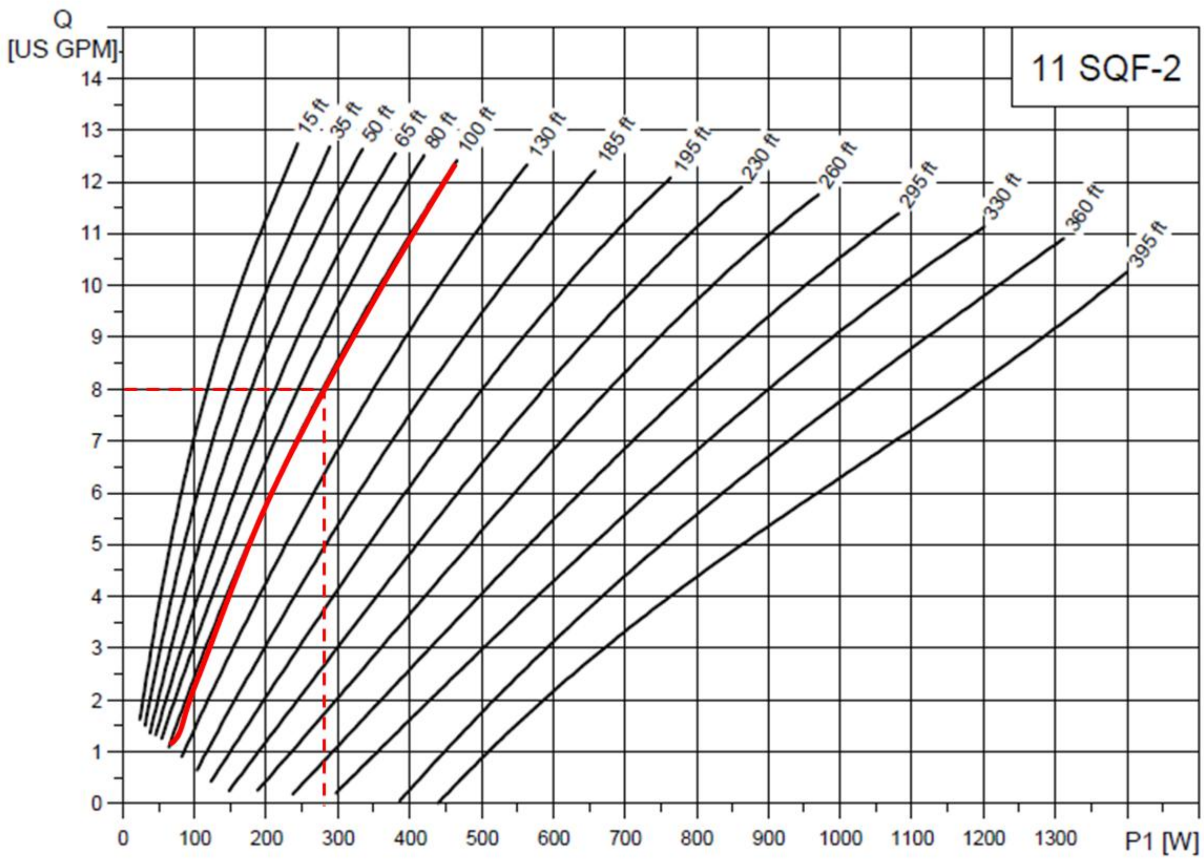

Figure 8: Power requirements of 11 SQF-2 based on pressure and flow rate. At a design discharge of 8 gallons per minute (30 liters per minute) and required head of 100 ft (30 meters), the pump will require 280 Watts of power (Grundfos).

5.3.2 Overall Electrical System Design

A photovoltaic system is required to power the SQ Flex water pump, as there is no electrical grid in Punta Sirain. The school and doctor's office in the community already have photovoltaic arrays for lighting, television, and refrigeration of medical supplies, so the community is familiar with this technology. This particular region of Panama has a very high solar density, as can be seen in Figure 8, and there are about 12 hours of daylight year round since it is near the equator. The familiarity and the geographic location of the community make solar power an excellent choice for powering the SQ Flex pump.

The main components of the system will be photovoltaic panels, a battery bank and the pump. A diagram showing how all of the components in the system will fit together can be seen in Figure 10. The system has been designed to run the pump at eight gallons per minute (30 liters per minute) to optimize the cost and the trade-off between required power and pump flow rate. The system will operate at 48 volts to minimize line losses and increase the pump efficiency. Table 2 shows that operating the pump at 48 volts will result in about a 15% loss in pumping capacity each day, which is negligible compared to the prohibitive costs associated with the additional components required to operate at a higher voltage. The calculated system requirements using different pump rates can be seen in Table 3; these values are used to size the photovoltaic array and the battery bank.

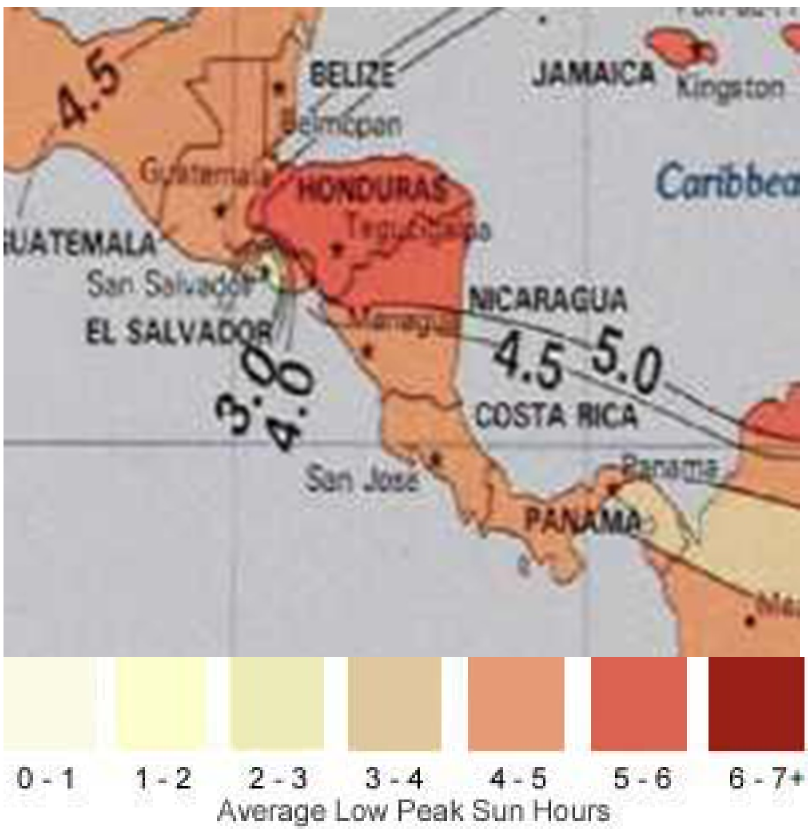

Figure 9: Map of peak sun hours in Central America (Advanced Energy Group)

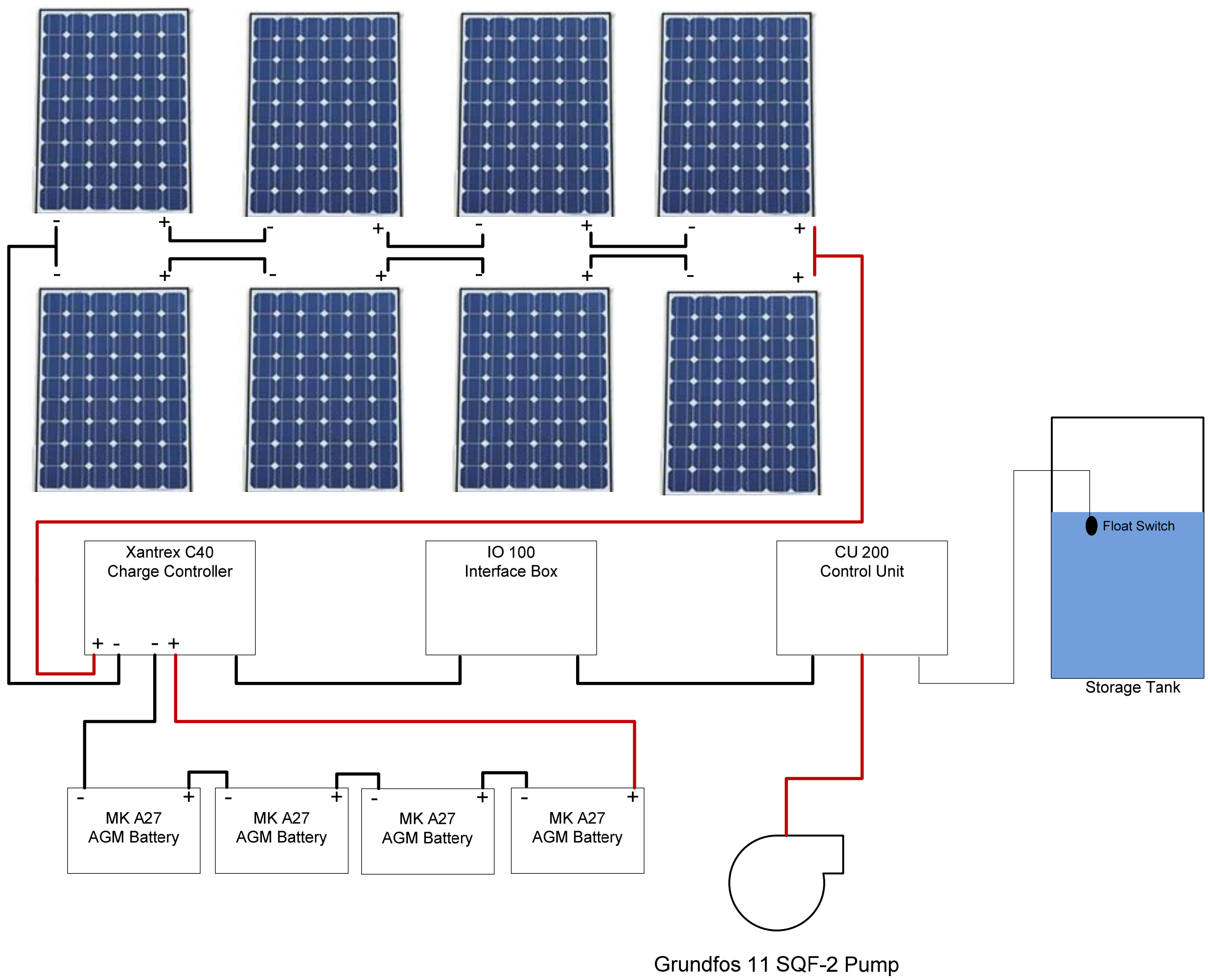

Figure 10: Electrical system layout

Table 2: SQ Flex pump efficiency at different operating voltages (Grundfos)

SQ Flex Optimal Efficiency	
Output Voltage	% Loss in Gallons/Day
120 V - 300 V	0%
90 V	-5%
60 V	-10%
35 V	-20%

Table 3: System requirements at different pumping rates (1 gpm = 3.8 liters/min)

Pumping Rate (gpm)	Power (Watts)	Amps (PV)	Ah (battery)	Pump Time (hrs/day)
9	325	16.4	77.3	9.1
8	280	15.9	66.6	10.2
7	250	16.2	59.5	11.7
Note: Battery Ah is determined based on ability to pump for 6 hours on battery power				

Figure 11 shows the time sequence of volumes of water in the storage tank throughout each day. It also shows when the pump will be running. These profiles are based on the demand schedule described in detail in Section 5.5 and a pumping rate of 8 gallons per minute (30 liters per minute). The pump turn-on point, for refilling the tank, was set at 3,500 gallons. The lowest volume at any time is shown to be about 3,300 gallons (13,200 L). This level should be an acceptable contingency as it would provide 80% of the daily demand should the pump be down for maintenance or cleaning. It is important to note that the demand is based on a 20-year projection of community population. Therefore, the tank volume profile and pump status profile are conservative estimates under current conditions. The MATLAB program code used to produce Figure 11 is in Appendix B.

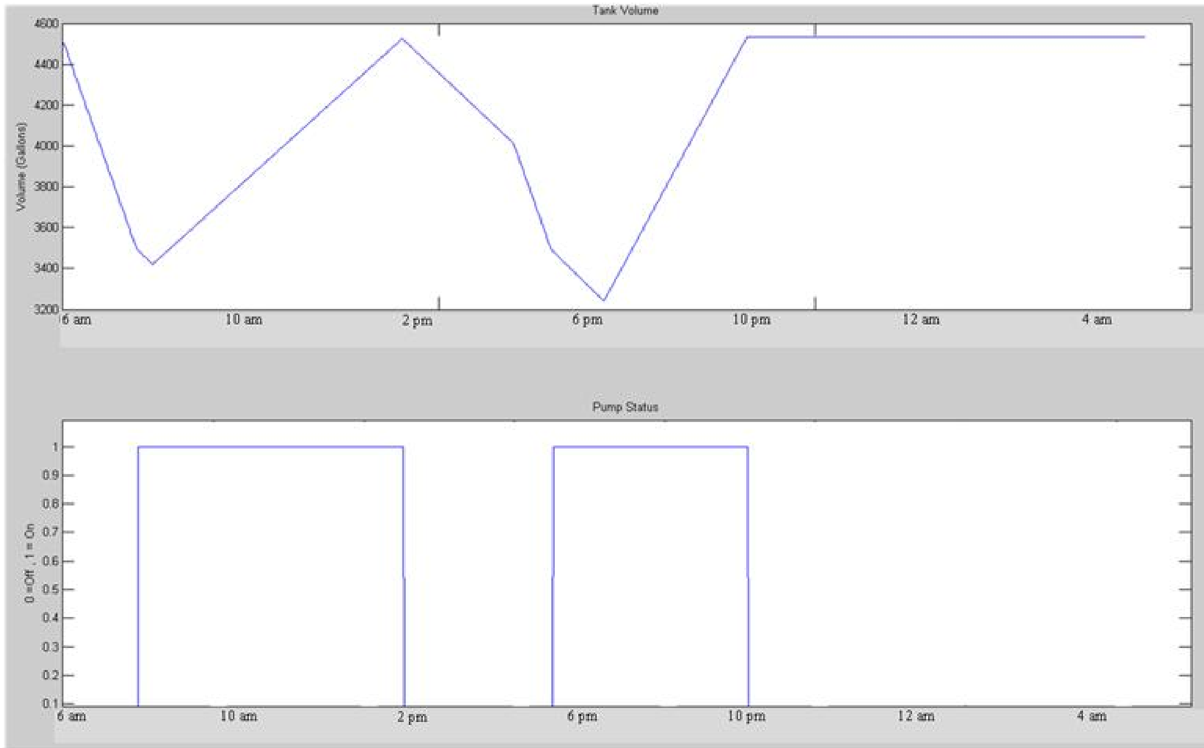

Figure 11: Tank volume profile and pump status profile

5.3.3 Photovoltaic Array

Bä Noire Designs is recommending a photovoltaic (PV) array consisting of eight Evergreen Solar ES-A-200-fa3 solar panels, connected as shown in Figure 9. The current capacity (Amps) of PV arrays adds for panels that are connected in parallel, and the voltage capacity (V) adds for panels connected in series. Table 3 shows that for a pump rate of eight gallons per minute, the photovoltaic needs to supply a peak current of 15.9 amperes. Connecting two of the 11.05 amp panels in parallel will provide 22.1 peak-amps of current, which exceeds the system requirements. Each panel is rated at 12 volts, so four of them will need to be connected in series to achieve the system operating voltage of 48 volts. The recommended PV array design will exceed the demands of the pump during peak conditions, which should allow the system to operate even during non-ideal conditions.

5.3.4 Battery Bank

A 48-volt battery bank will be used to keep a constant pump voltage during variations in weather conditions throughout the day and to allow pumping during periods of insufficient sunlight. Designs for similar systems often include enough battery capacity to meet the needs of the system demand for three days without being recharged. Proper sizing increases the life of the batteries by decreasing the depth of discharge on each battery. The less each battery is drained during each cycle, the more charge cycles a battery can have over its lifetime, as can be seen in Figure 12 for the battery selected for the system.

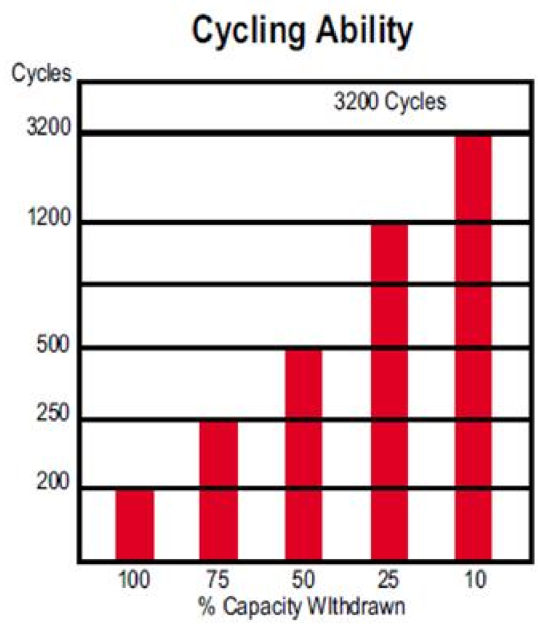

Figure 12: Battery life vs. depth of charge for the MK 8A27 (MK Battery)

Due to budget constraints, it is not feasible to design a system that would include a battery bank with enough capacity to run the pump for a few days without being recharged. The storage tank has been designed to hold a full day's worth of water, which means the batteries only have to have enough capacity to run the pump at the end of the day for a few hours, or during the afternoon periodically if it is cloudy. This storage tank design has allowed the battery bank capacity to be reduced from a U.S. standard of three days to about six hours.

The MK 8A27 battery is rated at 12 volts and has a 92 amp-hour capacity, which is nearly 1.5 times the 66 amp-hours found in Table 3. Choosing a battery that exceeds the requirement will accomplish the task of increasing the battery life by lowering the depth of charge required during each cycle. Following the power requirements calculated for the distribution system, pumping for six hours each day will draw approximately 50% of the battery capacity. Calculations are included in Appendix B. A conservative assumption that the batteries will cycle at this 50% rate each day means that the battery bank would have a lifespan of approximately one and a half years. Buying larger batteries will increase the life span but will also increase the cost of the system. Similar to the PV panels, battery voltages add in series, so a total of four batteries will be needed to produce the 48 volts for the pump.

5.3.5 Controls

The control sequence for the pumping system is very simple and has been reduced to only the essential elements to minimize cost and complexity. The location of the following components can be seen above in Figure 10.

A Xantrex C40 charge controller will be used to regulate input voltage to the batteries from the PV array. The Xantrex C40 is an inexpensive controller that is reliable and has been designed to maximize battery life (Xantrex Technology Inc.).

The pump will be controlled using a combination of the Grundfos CU 200 control unit and the Grundfos level switch. The control unit has been specially designed for the SQ Flex system and allows for system monitoring and integration of pump control using a float switch. The float switch will be installed in the storage tank and will be calibrated to turn the pump on when the water level in the tank has reached 3,500 gallons (13,200 L). The system has been designed in this way to ensure that the pump only needs to cycle on a maximum of three times each day, which will reduce the wear on the motor.

Lastly, the Grundfos IO 100 switch box will be used as a connection box for wiring and as a disconnect switch if maintenance is needed on the system. This component is optional, but is highly recommended because it is inexpensive and increases safety for any one working on the system by allowing them to disconnect the power.

5.4 Storage Tank Design

The water will be pumped from the *toma* to a storage tank and then gravity fed to the community. The storage tank was sized to contain slightly more than one day's worth of water for the village in the case of pump failure. The storage capacity was then compared to a demand curve, which estimated the water usage throughout the day, to ensure that enough water would be in the tank to meet the demand at all times of the day.

The estimated need for the village was calculated as 4,161 gallons per day (16,000 liters/day), based on a 20-year population projection and a daily need of 40 lpcd. Demand calculations can be found in Appendix B. The most appropriate volume was determined to be 4,525 gallons (18,000 liters), which equates to a tank with inner dimensions of 11ft x 11ft by 5ft deep (approximately 3.1 m x 3.1 m by 1.5 m). Similar to the improvements to the *toma*, the tank will be constructed using reinforced concrete block with a concrete cover. This final tank will have a height of 6 ft (1.8 m), to account for overflow, and will be connected to the *toma* with a 2-inch PVC pipe.

5.5 Piping System Design

The pipe network for Punta Sirain's water distribution system (gravity-fed from the storage tank) has been designed to provide water to each house in the community, as well as the school, two churches, and the health center. During the design of the system, EPANET 2.00.12 was used to model the steady-state performance of the distribution system during peak demand conditions (Unites States Environmental Protection Agency). By using EPANET, variables such as pipe size, pipe material, location, length, and elevation could be modeled and changes made as needed to develop a system capable of providing adequate flow and pressure to the taps in the community.

Three distribution network design options were modeled with EPANET. The first model, "Existing Plus," was constructed to represent the existing system with an additional distribution pipe from the *toma* leading to a proposed community tap stand in the cluster of houses near the PCV's house. The second, "Linear Option," was a branched gravity-fed network with transmission lines running from the proposed storage tank to each cluster of houses and branching out from there. The third, "Grid Option," was a modification of the second. Instead of simply branching to each house, the pipes were connected in a grid once the transmission lines reached the clusters of houses. The grid design is meant to equalize water pressures and reduce the likelihood of reduced pressures at a tap due to demand at another tap along the pipeline. All three of the design options utilize the existing gravity fed pipe from the *toma* to the taps at the school. This pipe is utilized in the linear and gridded option to deliver water to the school, but also as a contingency. If a component of the distribution system fails, such as the pump or solar panel, and water is not able to be lifted to the storage tank, water from the *toma* will continue to feed the tap at the school, providing a centralized tap for the community until the system is repaired.

5.5.1 Model Development

Survey point GPS locations collected while onsite in Punta Sirain, Panama were imported into AutoCAD to generate a plan view map of the community. Important landmarks, such as houses, buildings, and rivers were marked. This map was used as a backdrop for the EPANET model, allowing for an aerial view of the distribution pipe layout once the model was constructed.

Nodes were placed at all proposed tap locations, tee locations in pipelines, and at important low points or high points in the pipelines. Nodes were numbered to correspond with the GPS coordinates. Data entered for each node included elevations and demand values.

Pipe sizes, roughness, and lengths were added for the pipes connecting each node. Sizes were varied among locally available sizes (1-inch, 1.5-inch, 2-inch and 4-inch) to find sizes that would result in adequate pressure at each node. Head loss in the distribution system was calculated using the Darcy-Weisbach equation in EPANET. The Darcy-Weisbach equation is shown in equation 1 (Geankoplis, 2003).

$$H_L = f * \frac{L*V^2}{D*2g} \tag{1}$$

Where H_L = headloss (L)

L = pipe length (L)

D = pipe diameter (L)

V = velocity (L/T)

g = gravitational constant (L/T^2)

f = friction factor (from Moody diagram using Reynolds number and relative roughness) (dimensionless)

Reynolds number (dimensionless) is found using equation 2 (Geankoplis, 2003).

$$Re = \frac{VD\rho}{\mu} \tag{2}$$

Where ρ = fluid density (M/L^3)

μ = absolute viscosity (M/LT)

Relative roughness (dimensionless) is defined by equation 3 (Walski, Chase, & Savie, 2001).

$$relative\ roughness = \frac{\varepsilon}{D} \tag{3}$$

Where ε = mean height of pipe roughness (L)

The mean height of pipe roughness (ε) for PVC pipe was assumed to be 0.005 millifeet (0.0015 mm) (Walski, Chase, & Savie, 2001). Pipe lengths were determined using GPS points from onsite surveys and an online calculator (Schneider, 2009) that determined the distance between two GPS points. The calculator uses the vicinity formula for distance between two latitude/longitude points, taking into account the curvature of the earth. For information on the actual formula the calculator uses, visit http://www.movable-type.co.uk/scripts/latlong-vincenty.html (Movable Type Scripts). Minor losses accounting for added turbulence at pipe bends, contractions, valves, etc. were also estimated in early versions of the model to compare the effects of minor losses relative to major losses due to pipe friction. Modeling the system with minor losses resulted in relatively small changes in pressure compared to models neglecting minor losses-less than 0.5 psi at most nodes, small compared to the minimum design pressure of 14.2 psi. Since the effect of minor losses was relatively small, they were disregarded in later versions to keep the model simple.

Table 4. Demand schedules from Jordan(1986).

Demand Schedule 1		Demand Schedule 2	
Time	% of Total Demand	Time	% of Total Demand
6 AM - 8AM	30%	5 AM - 7 AM	10%
8 AM - 4 PM	40%	7 AM - 11 AM	25%
4 PM - 6 PM	30%	11 AM - 1 PM	35%
6 PM - 6 AM	negligible	1 PM - 5 PM	20%
		5 PM - 7 PM	10%
		7 PM - 5 AM	negligible

Two demand curves were entered into EPANET, adapted from demand curves from (Jordan, 2006). Jordan provides two estimates of demand during periods of the day as a percent of the total daily demand, as shown in Table 4. The percentage of daily demand was converted to a demand multiplier and entered in EPANET. (For example, if the demand is 4200 gal/day, then the average demand per hour would be 4200/24 = 175 gal/hr. If 30% of the daily demand (4200 x 0.3 = 1250) is used between 6-8 AM, then the rate is 1250/2 = 625 gal/hr, and the demand multiplier would be 625/175 = 3.6.) Demand curves 1 and 2 as entered into EPANET are given in Figure 13 and Figure 14, respectively.

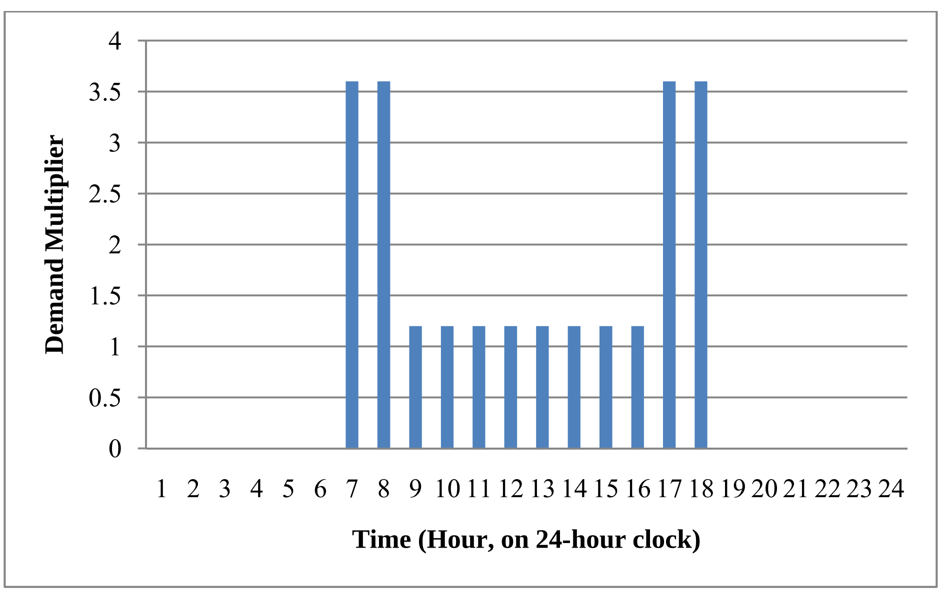

Figure 13: Demand curve 1, as entered into EPANET, adapted from (Jordan, 2006)

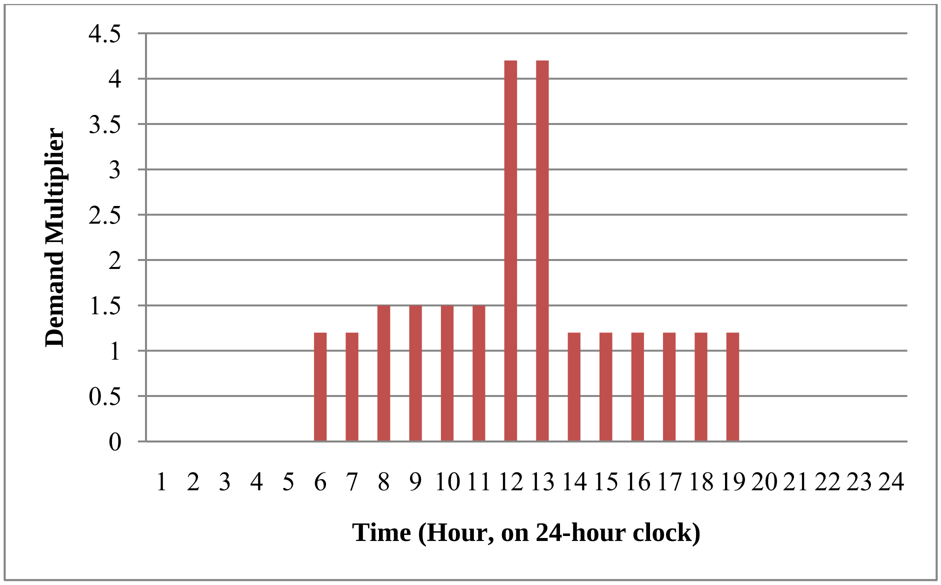

Figure 14: Demand curve 2, as entered into EPANET, adapted from (Jordan, 2006).

An additional multiplier was used to account for variability in instantaneous use rates (i.e., two or more taps opened at the same time). With an additional multiplier of 2 (meaning the actual demand at any given time is two times higher than the demand specified by the demand curve), the system was modeled to determine if all taps would have adequate water pressure, even under relatively high instantaneous water usage rates. A tap was considered to have adequate pressure if it had at least the desired minimum pressure of 14.2 psi. Minimum, ideal, and maximum pressures are given in Table 5 (Jordan, 2006).

Table 5: Minimum, ideal, and maximum pressures at taps, adapted from (Jordan, 2006).

	Meters of water	Feet of water	psi
Absolute Minimum	7	23.0	10.0
Desired Minimum	10	32.8	14.2
Ideal	15	49.2	21.4
Desired Maximum	30	98.4	42.8
Absolute Maximum	56	183.7	79.9

5.5.2 Model Results

Detailed results from the simulations are provided in Appendix C. This appendix includes overview maps of the proposed network layout, overview maps displaying simulated pressures, and tables describing the node and pipe data, including pressure, elevation, pipe length and size.

Results indicate the "Existing Plus" system is unable to deliver water to the proposed and existing taps if peak demands are considered. The node pressures delivered under this scenario are much less than desired. Most of the taps experience negative pressures under peak demand. This means that the taps may not provide water when the system is experiencing peak demands. A summary of node pressures for the "Existing Plus" model is shown in Table 6.

Table 6: Node pressure summary for "Existing Plus" model

	Minimum Pressure	Maximum Pressure	Average Pressure
	(psi)	(psi)	(psi)
Demand Curve 1 (2X)	-67.12	3.48	-33.75
Demand Curve 2 (2X)	-89.59	1.34	-45.75

The same simulations were performed for the "Linear Option" system, resulting in node pressures throughout the system that were more desirable than those from the "Existing Plus" model. Each node in the system maintained adequate pressure, even under peak demand conditions. A summary of the node pressures in this model is given in Table 7.

Table 7. Node pressure summary for "Linear Option" model

	Minimum Pressure	Maximum Pressure	Average Pressure
	(psi)	(psi)	(psi)
Demand Curve 1 (2X)	14.74	42.64	25.56
Demand Curve 2 (2X)	13.61	41.82	24.36

Finally, results from the “Grid Option” model proved to be similar but with slightly higher pressures than those from the “Linear Option” model. This system also had adequate pressure at each node under peak demand conditions. The grid design did help to improve node pressures, since the minimum and maximum pressures were higher than with the “Linear Option. Table 8 shows a summary of the pressures from the “Gridded Option” model.

Table 8. Node pressure summary for "Grid Option" model

	Minimum Pressure	Maximum Pressure	Average Pressure
	(psi)	(psi)	(psi)
Demand Curve 1 (2X)	15.49	43.68	27.55
Demand Curve 2 (2X)	15.14	43.22	27.02

These simulations suggest that both the linear and gridded design options will provide a reliable source of water to the community, even during periods of peak use. The existing system, however, fails to meet demand under peak usage.

Based on these simulations and their associated costs, it is recommended that the linear option be constructed. Use of the existing plus option may result in non-functioning taps during peak water demand times. The grid option does result in higher pressures in the system, but at an increased cost of construction materials and labor. The linear option provides the best balance between construction cost and performance under peak demand conditions.

6.0 Cost Estimate

While in Panama, information was gathered regarding costs of materials for the proposed design. These prices, obtained from several PCVs, were used in the cost estimate. Particularly useful were prices obtained from a PCV in the process of buying local supplies to construct a similar water supply system in his village. Due to lack of information, some items were priced using a variety of suppliers in the United States. These items include the concrete masonry units for the storage tank and *toma* design, the horizontal "ladder" steel reinforcing that is used in the walls, and all solar power system components.

The project estimate is higher than the budgeted value of $10,000 which means materials such as the solar power system would need to be donated. The PCV will assist the community in its search for project funding. Examples of funding sources include Peace Corps grants, local government representatives and Panamanian Health Ministry water grants. The "Existing Plus" alternative design option has been provided as a low cost alternative, with an estimated cost of $2,000. Detailed cost estimates for all major components of the design, and for all alternative designs, are included in Appendix F.

Table 9: Cost estimate summary of recommended design

System	**Cost**
Gravity-fed Distribution System, Linear Option	$ 3,800
Toma and Tank Materials	$ 2,400
Solar Power System	$ 8,600
Shipping from David to Chiriqui Grande	$ 500
Total:	$ 15,300

7.0 Construction Scheduling

Construction schedules in Panama are much different than those in the United States. In Punta Sirain, there is no heavy machinery available, nor are there highly skilled workforces or widely available materials. During the field assessment trip, a basketball court and sidewalk were under construction. A hired Latino workforce was directing work on the project, and their daily progress, as well as work habits and schedule, were observed in order to create a realistic schedule for village conditions. In Panama the work day is far more relaxed than in America, and as a result of the different pace of life it was not possible to use traditional American estimating measures such as *RS Means* to estimate labor and crew sizes.

It is estimated that the construction of the proposed design could be completed in roughly two months. The critical path of construction is laying the pipe work. Almost 9,000 feet (2,700 m) of piping will be necessary to hook up all of the homes in the community, and the work associated with laying the pipe and connecting the homes of the community will be the most time-consuming of all tasks. This task alone is estimated to take approximately 40 days based on a workforce of 7 unskilled volunteer workers and one skilled supervisor. Table 10 shows the schedule for major components of the project. The full construction timeline is included as Appendix E.

Table 10: Durations of key construction tasks and total project.

Task	**Duration**
Tank Construction	35 Days
Toma Improvements	38 Days
Distribution Piping	43 Days
Pump System Installation	33 Days
Miscellaneous	9 Days
Total Duration:	**43 Days**

8.0 Final Recommendation

Based on the data and research described in this report, Bä Noire Designs has recommended a design that meets Punta Sirain's need for a low cost solution to supply each household with clean drinking water. Design objectives that led to this recommendation included ease of construction, low maintenance, minimal cost, cultural acceptance and community ownership.

The recommended design includes improvements to the existing *toma*, construction of a 4,525 gallon (17,100 L) storage tank, installation of a solar-powered pump with associated solar panels and battery bank and expansion of the PVC distribution system with spigots in each house. The *toma* improvements create three chambers within half of the existing structure. Two chambers act as spring boxes and settling tanks, with overflow spilling into the pump house chamber. Covers added over each chamber will protect the spring water from contamination. A submersible centrifugal pump will deliver the water from the *toma* to a storage tank on a nearby hill. The pump will be powered by a photovoltaic system consisting of eight solar panels, four batteries and control electronics. Placing the storage tank at a higher elevation will provide adequate pressure to gravity feed water to all houses in the community.

The recommended design will cost an estimated $15,300 in materials, labor and transportation expenses. Construction is expected to take 43 work days to complete and will be directed by the PCV and three hired skilled workers. The community is expected to contribute volunteer labor throughout the construction process. This design will be passed on to the PCV in Punta Sirain, who will be in charge of discussing the designs with the residents of Punta Sirain, acquiring the funds for the materials and overseeing the construction of the project.

Once the improved water distribution system has been constructed, the existing water committee will once again oversee maintenance and operation of the system. It is recommended that the existing $1/month usage fee be expanded to all households. Although this may not be sufficient for sustainable operation and maintenance, it is the highest reasonable monthly payment for the families in the community. The water committee will be responsible to use these fees for system repairs. The community PCV will assist the committee in developing new maintenance schedules, usage guidelines and community education programs to ensure the success of an expanded system.

All recommendations are intended to improve community health, stimulate community pride and increase knowledge of technology throughout the region.

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10.0 Appendices

10.1 Appendix A: Field data

Survey Data

All data collected using water level and GPS device August 14-19, 2009

GPS Point	Latitude	Longitude	Elevation (ft)	Note
				Elevations based on assigned elevation of 500 ft at top of highest hill (GPS Point 101)
69	9° 8.707	81° 55.437	476	starting point
70	9° 8.717	81° 55.445	476	tie in tree
71	9° 8.711	81° 55.436	473	
72	9° 8.714	81° 55.431	467	
73	9° 8.715	81° 55.427	462	
74	9° 8.716	81° 55.425	456	
75	9° 8.718	81° 55.424	453	
76	9° 8.718	81° 55.420	446	
77	9° 8.717	81° 55.416	441	across swamp
78	9° 8.717	81° 55.407	444	
79	9° 8.713	81° 55.407	450	
80	9° 8.725	81° 55.393	455	
81	9° 8.721	81° 55.390	455	
82	9° 8.713	81° 55.380	454	
83	9° 8.706	81° 55.372	450	
84	9° 8.701	81° 55.366	448	
85	9° 8.702	81° 55.363	447	
86	9° 8.697	81° 55.360	447	
87	9° 8.699	81° 55.350	448	
88	9° 8.699	81° 55.346	446	
89	9° 8.700	81° 55.334	447	
90	9° 8.702	81° 55.328	447	
91	9° 8.700	81° 55.323	444	door to toma
92	9° 8.697	81° 55.326	452	
93	9° 8.693	81° 55.321	456	
94	9° 8.684	81° 55.316	458	
95	9° 8.679	81° 55.306	458	
96	9° 8.678	81° 55.303	465	
97	9° 8.679	81° 55.303	471	
98	9° 8.679	81° 55.302	476	
99	9° 8.670	81° 55.284	482	
100	9° 8.668	81° 55.285	494	
101	9° 8.666	81° 55.283	500	top highest hill
102	9° 8.693	81° 55.317	447	
103	9° 8.697	81° 55.316	458	92 to 103
104	9° 8.704	81° 55.309	459	
105				DELETED POINT
106				DELETED POINT
107				DELETED POINT
108				DELETED POINT
109	9° 8.708	81° 55.299	459	
110	9° 8.710	81° 55.295	460	
111	9° 8.716	81° 55.290	467	
112	9° 8.721	81° 55.286	474	
113	9° 8.724	81° 55.283	478	top ridge, 2nd tallest hill
114	9° 8.690	81° 55.313	447	92 to 114 door to outlet pipe of toma
115	9° 8.690	81° 55.313	447	

Survey Data

GPS Point	Latitude	Longitude	Elevation (ft)	Note
116	9° 8.734	81° 55.357	437	main pipe to town, starting out of swamp
117	9° 8.735	81° 55.365	436	
118	9° 8.738	81° 55.372	435	
119	9° 8.735	81° 55.367	433	
120	9° 8.750	81° 55.369	432	
121	9° 8.756	81° 55.371	432	
122	9° 8.760	81° 55.368	431	
123	9° 8.765	81° 55.369	432	
124	9° 8.771	81° 55.367	435	
125	9° 8.772	81° 55.367	437	fence behind volleyball court
126	9° 8.782	81° 55.368	439	
127	9° 8.791	81° 55.364	440	
128	9° 8.799	81° 55.357	441	
129	9° 8.802	81° 55.355	442	
130	9° 8.809	81° 55.349	438	just across side walk
131	9° 8.813	81° 55.341	434	fence by pink house
132	9° 8.814	81° 55.337		DELETED POINT
133	9° 8.822	81° 55.333	436	Pink House
134	9° 8.829	81° 55.329	439	
135	9° 8.825	81° 55.328	437	faucet next to side walk
136	9° 8.839	81° 55.323	437	
137	9° 8.850	81° 55.318	439	
138	9° 8.854	81° 55.318	441	capped end point - normally no flow
139	9° 8.842	81° 55.314	443	
140	9° 8.858	81° 55.320	444	138 to 140, Salud
141	9° 8.863	81° 55.325	441	
142	9° 8.857	81° 55.327	440	to new house
143	9° 8.865	81° 55.328	440	141-143 doctor's house
144	9° 8.860	81° 55.336	437	141-144
145	9° 8.863	81° 55.338	438	house
146	9° 8.863	81° 55.348	435	144-146
147	9° 8.859	81° 55.354	436	Dionicio's house
148	9° 8.856	81° 55.360	433	
149	9° 8.858	81° 55.368	427	house behind Dionicio's
150	9° 8.863	81° 55.370	426	
151	9° 8.867	81° 55.376	424	
152	9° 8.879	81° 55.382	423	
153	9° 8.885	81° 55.381	423	house on ridge
154	9° 8.880	81° 55.373	421	spigot by house
155	9° 8.774	81° 55.366	439	125-155 starting at fence behind vb court
156	9° 8.789	81° 55.373	441	
157	9° 8.797	81° 55.375	441	
158	9° 8.798	81° 55.377	441	School Faucet
159	9° 8.801	81° 55.379	441	Sinks near cafeteria
160	9° 8.804	81° 55.394	444	Teacher's housing
161	9° 8.797	81° 55.391	443	
162	9° 8.796	81° 55.391	441	stairs over fence
163	9° 8.797	81° 55.409	436	house by stairs
164	9° 8.793	81° 55.406	442	162-164
165	9° 8.799	81° 55.402	442	house
166	9° 8.800	81° 55.402	442	packer house

Survey Data

GPS Point	Latitude	Longitude	Elevation (ft)	Note
167	9° 8.788	81° 55.397	435	162-167
168	9° 8.785	81° 55.398	430	
169	9° 8.780	81° 55.398	425	
170	9° 8.772	81° 55.399	429	
171	9° 8.765	81° 55.400	434	
172	9° 8.756	81° 55.401	437	
173	9° 8.751	81° 55.396	441	
174	9° 8.740	81° 55.395	441	
175	9° 8.736	81° 55.392	443	house with blue side
176	9° 8.733	81° 55.396	440	
177	9° 8.742	81° 55.401	438	
178	9° 8.750	81° 55.408	435	across quebrada upstream
179	9° 8.754	81° 55.415	439	
180	9° 8.758	81° 55.421	444	abandoned house
181	9° 8.757	81° 55.429	448	
182	9° 8.756	81° 55.434	450	
183	9° 8.746	81° 55.447	454	
184	9° 8.745	81° 55.447	459	
185	9° 8.742	81° 55.446	466	
186	9° 8.725	81° 55.448	473	
187	9° 8.718	81° 55.447	476	tie-in tree
188	9° 8.784	81° 55.406	421	169-188 in Quebrada
189	9° 8.781	81° 55.408	426	
190	9° 8.787	81° 55.419	428	
191	9° 8.788	81° 55.418	429	
192	9° 8.791	81° 55.424	431	
193	9° 8.782	81° 55.427	431	
194	9° 8.797	81° 55.442	432	
195	9° 8.799	81° 55.445	428	
196	9° 8.803	81° 55.447	433	
197	9° 8.804	81° 55.452	439	
198	9° 8.809	81° 55.459	440	
199	9° 8.805	81° 55.461	441	197-199 cement post near Kaitlin's
200	9° 8.808	81° 55.454	441	House
201	9° 8.805	81° 55.465	446	199-201
202	9° 8.801	81° 55.473	448	House
203	9° 8.811	81° 55.466	440	199-203
204	9° 8.813	81° 55.460	439	
205	9° 8.814	81° 55.457	438	Kaitlin's
206	9° 8.811	81° 55.455	440	199-206
207	9° 8.810	81° 55.452	441	House
208	9° 8.817	81° 55.448	435	
209	9° 8.820	81° 55.448	431	House
210	9° 8.829	81° 55.446	425	
211	9° 8.834	81° 55.447	428	
212	9° 8.838	81° 55.445	432	House
213	9° 8.812	81° 55.465	440	199-213, Chi-Chi's House
214	9° 8.817	81° 55.465	437	
215	9° 8.819	81° 55.469	433	House
216	9° 8.825	81° 55.473	432	House
217	9° 8.826	81° 55.479	429	House

Survey Data

GPS Point	Latitude	Longitude	Elevation (ft)	Note
218	9° 8.793	81° 55.431	436	192-218
219	9° 8.790	81° 55.433	443	
220	9° 8.787	81° 55.434	448	House
221	9° 8.830	81° 55.318	440	135-222 starting at spigot, House
222	9° 8.829	81° 55.320	438	House
223	9° 8.826	81° 55.322	439	House (Green/Yellow)
224	9° 8.816	81° 55.321	442	House
225	9° 8.810	81° 55.316	450	House
226	9° 8.816	81° 55.324	443	224-226
227	9° 8.800	81° 55.330	442	
228	9° 8.791	81° 55.329	449	
229	9° 8.787	81° 55.337	456	
230	9° 8.784	81° 55.340	456	House
231	9° 8.778	81° 55.337	456	
232	9° 8.769	81° 55.335	452	
233	9° 8.763	81° 55.343	452	House
234	9° 8.759	81° 55.343	450	232-234
235	9° 8.758	81° 55.333	452	
236	9° 8.756	81° 55.324	453	House
237	9° 8.748	81° 55.319	457	
238	9° 8.743	81° 55.313	459	
239	9° 8.728	81° 55.318	460	
240	9° 8.730	81° 55.305	463	
241	9° 8.722	81° 55.295	467	
111			468	241-111 tie-in on medium hill
242	9° 8.735	81° 55.283	476	113-242
243	9° 8.737	81° 55.281	471	
244	9° 8.738	81° 55.279	465	
245	9° 8.738	81° 55.277	459	
246	9° 8.746	81° 55.278	454	
247	9° 8.748	81° 55.275	448	
248	9° 8.752	81° 55.274	442	
249	9° 8.754	81° 55.273	436	Blue House
250	9° 8.774	81° 55.267	439	
251	9° 8.774	81° 55.267	434	
252	9° 8.775	81° 55.268	429	
253	9° 8.773	81° 55.266	423	
254	9° 8.775	81° 55.262	416	
255	9° 8.778	81° 55.257	411	
256	9° 8.785	81° 55.251	410	
257	9° 8.783	81° 55.248	403	walking bridge
258	9° 8.779	81° 55.240	407	
259	9° 8.781	81° 55.231	413	
260	9° 8.770	81° 55.235	421	
261	9° 8.789	81° 55.221	424	white house
262	9° 8.786	81° 55.218	424	260-262
263	9° 8.787	81° 55.218	420	House
264	9° 8.781	81° 55.212	424	262-264
265	9° 8.779	81° 55.206	430	House
266	9° 8.779	81° 55.212	436	
267	9° 8.778	81° 55.212	441	

Survey Data

GPS Point	Latitude	Longitude	Elevation (ft)	Note
268	9° 8.775	81° 55.213	444	site of future house
269	9° 8.776	81° 55.215	446	
270	9° 8.767	81° 55.222	441	
271	9° 8.761	81° 55.229	433	
272	9° 8.760	81° 55.232	429	house
273	9° 8.797	81° 55.249	416	256-273
274	9° 8.803	81° 55.251	408	church gate
275	9° 8.802	81° 55.248	408	
276	9° 8.806	81° 55.243	418	House
277	9° 8.800	81° 55.257	403	274-277
278	9° 8.805	81° 55.264	398	
279	9° 8.805	81° 55.272	394	
280	9° 8.806	81° 55.280	387	
281	9° 8.808	81° 55.281	392	
282	9° 8.810	81° 55.284	398	
283	9° 8.814	81° 55.292	402	House
284	9° 8.811	81° 55.295	408	House
285	9° 8.819	81° 55.296	405	
286	9° 8.822	81° 55.294	399	
287	9° 8.826	81° 55.290	397	
288	9° 8.831	81° 55.290	402	House
289	9° 8.840	81° 55.289	404	
290	9° 8.847	81° 55.289	407	
291	9° 8.851	81° 55.290	414	
292	9° 8.850	81° 55.294	421	
293	9° 8.848	81° 55.300	426	
294	9° 8.844	81° 55.307	432	
295	9° 8.840	81° 55.312	438	
135			437	295-135 tie in to spigot
296	9° 8.716	81° 55.457	472	187-296 starting at tie-in tree
297	9° 8.722	81° 55.463	467	
298	9° 8.727	81° 55.470	460	
299	9° 8.730	81° 55.479	454	
300	9° 8.727	81° 55.487	452	
301	9° 8.726	81° 55.492	456	
302	9° 8.723	81° 55.500	463	
303	9° 8.718	81° 55.506	468	house
304	9° 8.724	81° 55.512	466	
305	9° 8.725	81° 55.521	461	
306	9° 8.733	81° 55.525	454	
307	9° 8.735	81° 55.533	451	house
308	9° 8.728	81° 55.539	454	
309	9° 8.723	81° 55.547	449	
310	9° 8.721	81° 55.554	452	
311	9° 8.722	81° 55.563	455	
312	9° 8.722	81° 55.568	455	eyeball reading
313	9° 8.725	81° 55.578	456	house
314	9° 8.734	81° 55.576	454	
315	9° 8.743	81° 55.574	449	
316	9° 8.748	81° 55.573	447	house

Spring Flow Rate Data

Data from "pail and scale method" / "bucket time method" to calculate spring water flow rate into *toma*

Date:	**8/14/2009**	
Trial Number	**Time**	**Flow Rate**
1	28.0	10.7
2	31.8	9.4
3	31.5	9.5
4	31.8	9.4
5	32.0	9.4

Notes: after rain storm

Date:	**8/16/2009**	
Trial Number	**Time**	**Flow Rate**
1	32.0	9.4
2	31.5	9.5
3	32.5	9.2
4	32.5	9.2
5	33.0	9.1

Notes: after two day dry spell

10.2 Appendix B: Calculations

Head Loss and Pump Head Requirement Calculations

Constants:				
ρ	density	62.2	lb/ft^3	from Geankoplis
μ	kinematic viscosity	0.000578	lb/ft*s	from Geankoplis
v	velocity	5	ft/s	assumption (CE4507)
ε	roughness factor	0.00003937	in	from Wurbs
ε	roughness factor	3.28083E-06	ft	from Wurbs

D (in)	D (ft)	Re	ε/D	f	HL/ft (ft)
0.5	0.042	22,419	7.87E-05	0.025	0.236
1.0	0.083	44,839	3.94E-05	0.021	0.100
1.5	0.125	67,258	2.62E-05	0.020	0.061
2.0	0.167	89,677	1.97E-05	0.018	0.043
2.5	0.208	112,096	1.57E-05	0.018	0.033
3.0	0.250	134,516	1.31E-05	0.017	0.026
3.5	0.292	156,935	1.12E-05	0.016	0.022
4.0	0.333	179,354	9.84E-06	0.016	0.019

friction factors calculated at:
www.lmnoeng.com/moody.htm

Results		
Pump Head Loss 2"(ft)	10.19	
Pump Head Loss 3"(ft)	6.24	
Pump Head Loss 4"(ft)	4.42	
Pump Head Required 2" (ft)	82.19	57 feet of pipe and assuming 15ft high tank
Pump Head Required 3" (ft)	78.24	57 feet of pipe and assuming 15ft high tank
Pump Head Required 4" (ft)	76.42	57 feet of pipe and assuming 15ft high tank

Water Demand Calculations and Schedule

Calculated Total Demand			
Population	350	People	20 year projection
	40	Lpcd	from WHO
	10.6	Gpcd	
School	175	Students	assume 1/2 school aged
	10	Lpcd	(from Jordan, 1984)
	2.64	Gpcd	
Total Demand	15750	Liters/Day	
	4161	Gallons/Day	

Demand Schedule 1 (from Jordan 1984, pg 125)

Time	% of Total Demand	Demand (Gal)	Supply (Gal)	Difference (Gal)
6 AM - 8AM	30%	1248	480	-768
8 AM - 4 PM	40%	1664	1920	256
4 PM - 6 PM	30%	1248	480	-768
6 PM - 6 AM	negligible	0	2880	2880

Demand Schedule 2 (from Jordan 1984, pg 125)

Time	% of Total Demand	Demand (Gal)	Supply (Gal)	Difference (Gal)
5 AM - 7 AM	10%	416	480	64
7 AM - 11 AM	25%	1040	960	-80
11 AM - 1 PM	35%	1456	480	-976
1 PM - 5 PM	20%	832	960	128
5 PM - 7 PM	10%	416	480	64
7 PM - 5 AM	negligible	0	2400	2400

Photovoltaic Calculations

Equations

$$Pump\ Energy/day\ = Pump\ Power\ \times Pump\ Run\ Time/\text{day}$$

$$Pump\ Amp\ Hours/day = \frac{Pump\ Energy/day}{Pump\ Voltage} \times Line\ Loss\ Factor$$

$$Solar\ Array\ Amps = \frac{Pump\ Amp\ Hours}{Average\ Sun\ Hours}$$

$$Battery\ Amp\ Hours = \frac{Pump\ Amp\ Hours/day}{Battery\ Discharge\ \%} \times Temperature\ Effect\ \times Number\ of\ Days\ Storage$$

OR

$$Battery\ Discharge\ \% = \frac{Pump\ Amp\ Hours/day}{Battery\ Amp\ Hours} \times Temperature\ Effect\ \times Number\ of\ Days\ Storage$$

Example

$$Pump\ Energy/day = 280\ watts\ \times 10.2\ hours = 2856\ watt\ hours/day$$

$$Pump\ Amp\ Hours/day = \frac{2856\ watt\ hours/day}{48\ volts} \times 1.2 = 71.4\ Amp\ hours/day$$

$$Solar\ Array\ Amps\ = \frac{71.4\ Amp\ hours/day}{4.5\ sun\ hours/day} = 15.9\ Amps$$

$$Battery\ Discharge\ \% = \frac{71.4\ Amp\ hours/day}{92\ Amp\ hours} \times 1.11\ \times .58\ days = 50\%$$

MATLAB Pump Simulation Program

```matlab
%Author:    Kris Bartell
%Date:      10-22-09
%Team:      BaNoire Designs
%Project:   idesign Water Distribution System in Punta Sirain, Panama

%***************************************************************************
%This program calculates the amount of time that a selected pump will need
%to run based on the demand schedules in Jordan 1984 and pump rate supplied
%by a pump. It also graphs the profile of the volume in the tank over time
%and shows exactly when the pump is on. Lastly, the program will output the
%time that the pump is on in hours and the minumum volume of water in the
%tank over a 24 hour time period.

%NOTE: The time period of the program starts at 6am; this is the
%approximate time that the community wakes up and begins using water.
%We also assume that no water is used between 6pm and 6am, which is fairly
%accurate based on our experiences in the community.
%***************************************************************************


%Tank Calculations
%***************************************************************************
clear all, clc,clf

tank_volume = 4525;         %Volume of storage tank in gallons, 11x11x5 (ft)

ideal_pump_rate = 8         %Pump rate capacity in gallons/min (this is used
                            %to find power used by pump)

pump_rate = ideal_pump_rate*.85;        %pump rate with 15% efficiency loss
                                        %due to 48 volt system
                                        %(this is the rate at which the tank
                                        %will fill)

turn_on = 3500;     %Set the threshold for when pump will turn on; in
                    %Gallons.

demand1 = 10.4;     %Average usage between 6am and 8am (gallons/min). From
                    %demand schedule in Jordan 1984, pg 125

demand2 = 3.47;     %Average usage between 8am and 4pm (gallons/min). From
                    %demand schedule in Jordan 1984, pg 125

demand3 = 10.4;     %Average usage between 4pm and 6pm (gallons/min). From
                    %demand schedule in Jordan 1984, pg 125

demand4 = 0;        %Average usage between 6pm and 6am (gallons/min). From
                    %demand schedule in Jordan 1984, pg 125

pump_time = 0;      %Initialize counter for the time pump must be on
```

MATLAB Pump Simulation Program

```
time = [1:1:1440];
length(time);
for t = 1:length(time)

%*************************************************************************
   %Initialize time and volume variable
    if t == 1
        volume(t) = tank_volume - demand1;
        pump_on(t) = 0;

%*************************************************************************
    %6am-8am
        elseif t <= 120
       if pump_on(t-1) == 0
           if volume(t-1) >= turn_on
               volume(t) = volume(t-1)-demand1;
               pump_on(t) = 0;
           else
               volume(t) = volume(t-1)-(demand1-pump_rate);
               pump_on(t) = 1;
           end
       else
           if volume(t-1) <= tank_volume
               volume(t) = volume(t-1)-(demand1-pump_rate);
               pump_on(t) = 1;
           else
               volume(t) = volume(t-1)-demand1;
               pump_on(t) = 0;
           end
       end

%************************************************************************
    %8am-4pm
    elseif t <= 600
      if pump_on(t-1) == 0
           if volume(t-1) >= turn_on
               volume(t) = volume(t-1)-demand2;
               pump_on(t) = 0;
           else
               volume(t) = volume(t-1)-(demand2-pump_rate);
               pump_on(t) = 1;
           end
       else
           if volume(t-1) <= tank_volume
               volume(t) = volume(t-1)-(demand2-pump_rate);
               pump_on(t) = 1;
           else
               volume(t) = volume(t-1)-demand2;
               pump_on(t) = 0;
           end
       end
%************************************************************************
    %4pm-6pm
    elseif t <= 720
```

MATLAB Pump Simulation Program

```
        if pump_on(t-1) == 0
           if volume(t-1) >= turn_on
               volume(t) = volume(t-1)-demand3;
               pump_on(t) = 0;
           else
               volume(t) = volume(t-1)-(demand3-pump_rate);
               pump_on(t) = 1;
           end
       else
           if volume(t-1) <= tank_volume
               volume(t) = volume(t-1)-(demand3-pump_rate);
               pump_on(t) = 1;
           else
               volume(t) = volume(t-1)-demand3;
               pump_on(t) = 0;
           end
       end
%************************************************************************
    %6pm-6am
    elseif t <= 1440
        if pump_on(t-1) == 0
           if volume(t-1) >= turn_on
               volume(t) = volume(t-1)-demand4;
               pump_on(t) = 0;
           else
               volume(t) = volume(t-1)-(demand4-pump_rate);
               pump_on(t) = 1;
           end
       else
           if volume(t-1) <= tank_volume
               volume(t) = volume(t-1)-(demand4-pump_rate);
               pump_on(t) = 1;
           else
               volume(t) = volume(t-1)-demand4;
               pump_on(t) = 0;
           end
       end
    end
    if pump_on(t) == 1
       pump_time = pump_time + 1;
    end
end

%**************************************************************************
%Plots the tank volume profile and pump status
%**************************************************************************

fprintf('The pump needs to run for %1.1f hours.\n',pump_time/60)
fprintf('The minimum volume of water in the storage tank is %3.1f
gallons.',min(volume))
fprintf('\n')
fprintf('\n')

subplot(2,1,1)
plot(time,volume)
title('Tank Volume')
```

MATLAB Pump Simulation Program

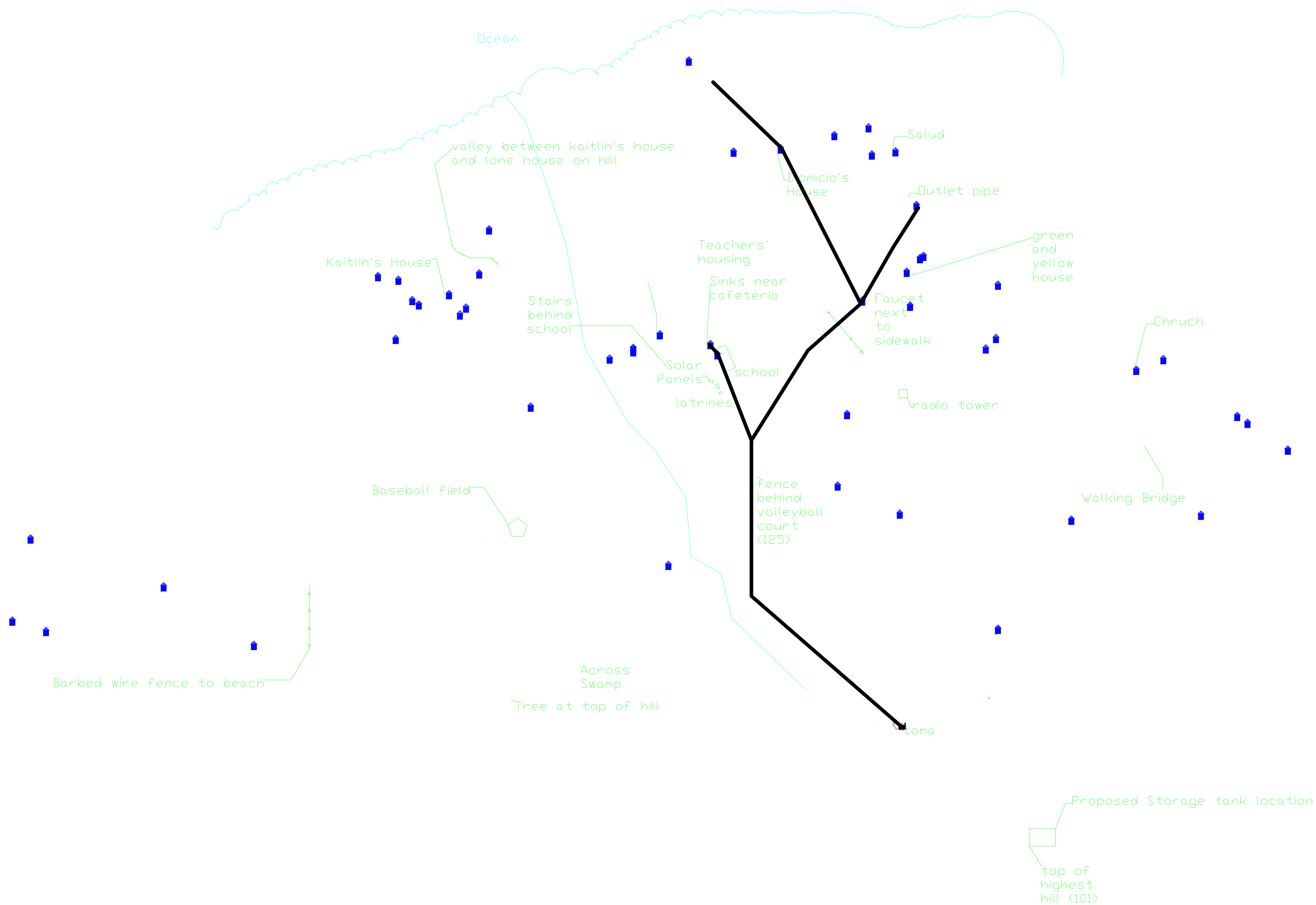
```
xlabel('Time (Minutes Past 6am)')
ylabel('Volume (Gallons)')
subplot(2,1,2)
plot(time,pump_on)
title('Pump Status')
xlabel('Time (Minutes Past 6am)')
ylabel('0 =Off , 1 = On')


%***************************************************************************
%Solar System Calculations
%***************************************************************************
%Most of the follwing calculation methods are outlined on www.solar4power.com

pump_volt = 48;           %system will run the pump at 48 volts

sun_hrs = 4.5;            %(sun~hours)/day in panama from www.solar4power.com

batt_time = 6;         %time pump is required to run off batteries (in hours)

batt_charge_percent= .7;                   %describes what the maximum
                                           %allowed discharge of batteries is
                                           % i.e. .8 = 80% of charge used.

batt_temp_effect = 1.11;    %effect of temperature on battery, depends on
                            %location and average temp.
                            %Source:www.solar4power.com

batt_percent = (batt_time/(pump_time/60));  %number of hours the system
                                            %will run on batteries per day
                                            %as a percentage of the total
                                            %pump time.

%EXAMPLE: If the pump has to run for 8 hours each day and you want it to be
%able to run for 4 hours off the batteries, the batt_percent = 4/8 = .5

if ideal_pump_rate == 9
    power = 325;                     %pump load power in Watts
    energy = power*(pump_time/60);   %(Watt~Hours)/day
    ah = (energy/pump_volt)*1.2;     %system (amp~hours)/day, 1.2 is to
                                     %account for losses

    %solar panel array sizing
    array_amps = ah/sun_hrs;         %current needed from the pv array

    %battery bank sizing
    batt_ah_req = ((ah/batt_charge_percent)*batt_temp_effect)*batt_percent;

end

if ideal_pump_rate == 8
    power = 280;                    %pump load power in Watts
    energy = power*(pump_time/60);  %(Watt~Hours)/day
    ah = (energy/pump_volt)*1.2;    %system (amp~hours)/day, 1.2 is to
```

MATLAB Pump Simulation Program

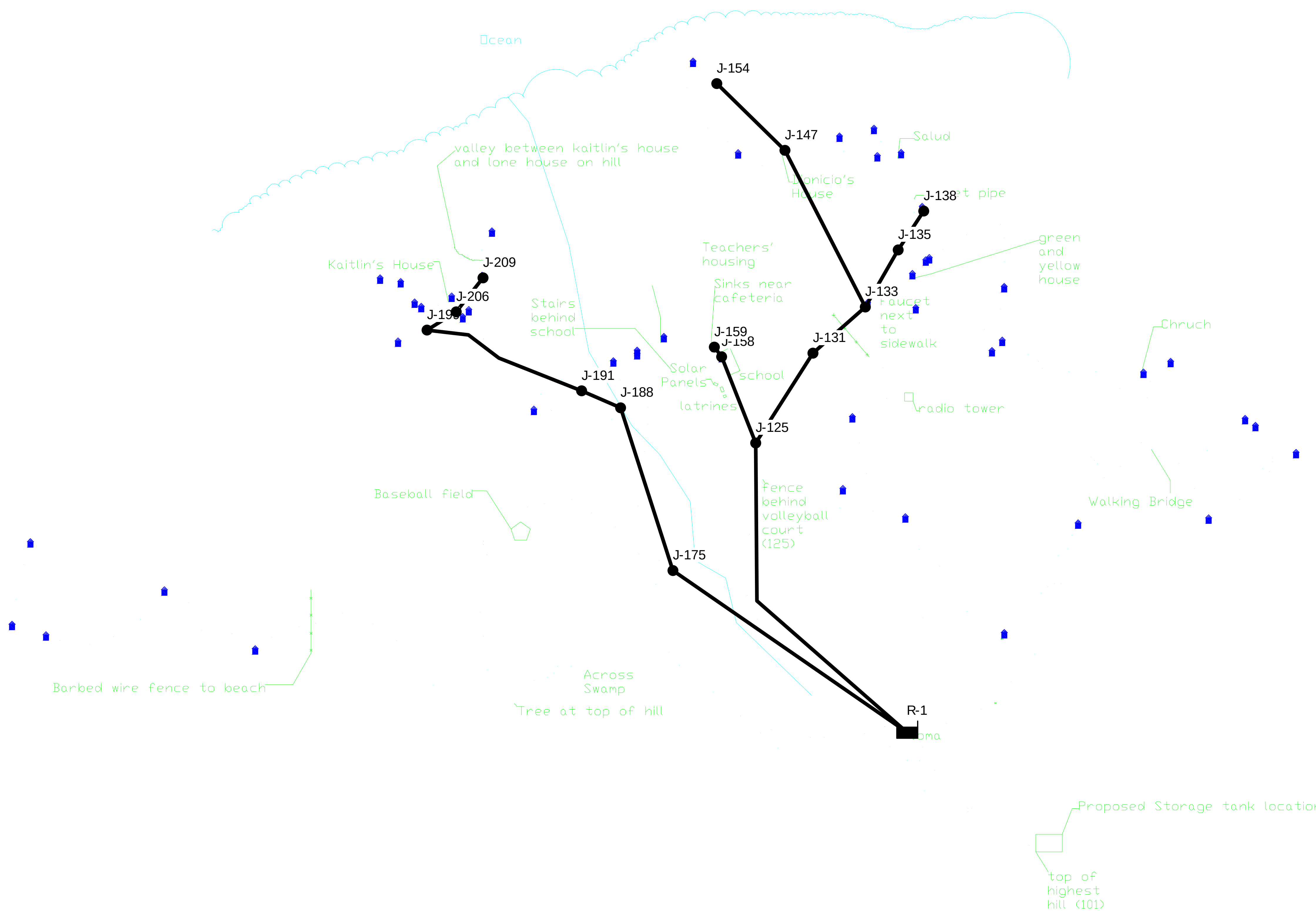
```
                                        %account for losses

   %solar panel array sizing
    array_amps = ah/sun_hrs;            %current needed from the pv array


    %battery bank sizing
    batt_ah_req = ((ah/batt_charge_percent)*batt_temp_effect)*batt_percent;

end

if ideal_pump_rate == 7
    power = 250;                         %pump load power in Watts
    energy = power*(pump_time/60);       %(Watt~Hours)/day
    ah = (energy/pump_volt)*1.2;         %system (amp~hours)/day, 1.2 is to
                                         %account for losses

   %solar panel array sizing
    array_amps = ah/sun_hrs;             %current needed from the pv array


    %battery bank sizing
    batt_ah_req = ((ah/batt_charge_percent)*batt_temp_effect)*batt_percent

end
```

10.3 Appendix C: EPANET simulations

Punta Sirain Distribution Network - Existing System

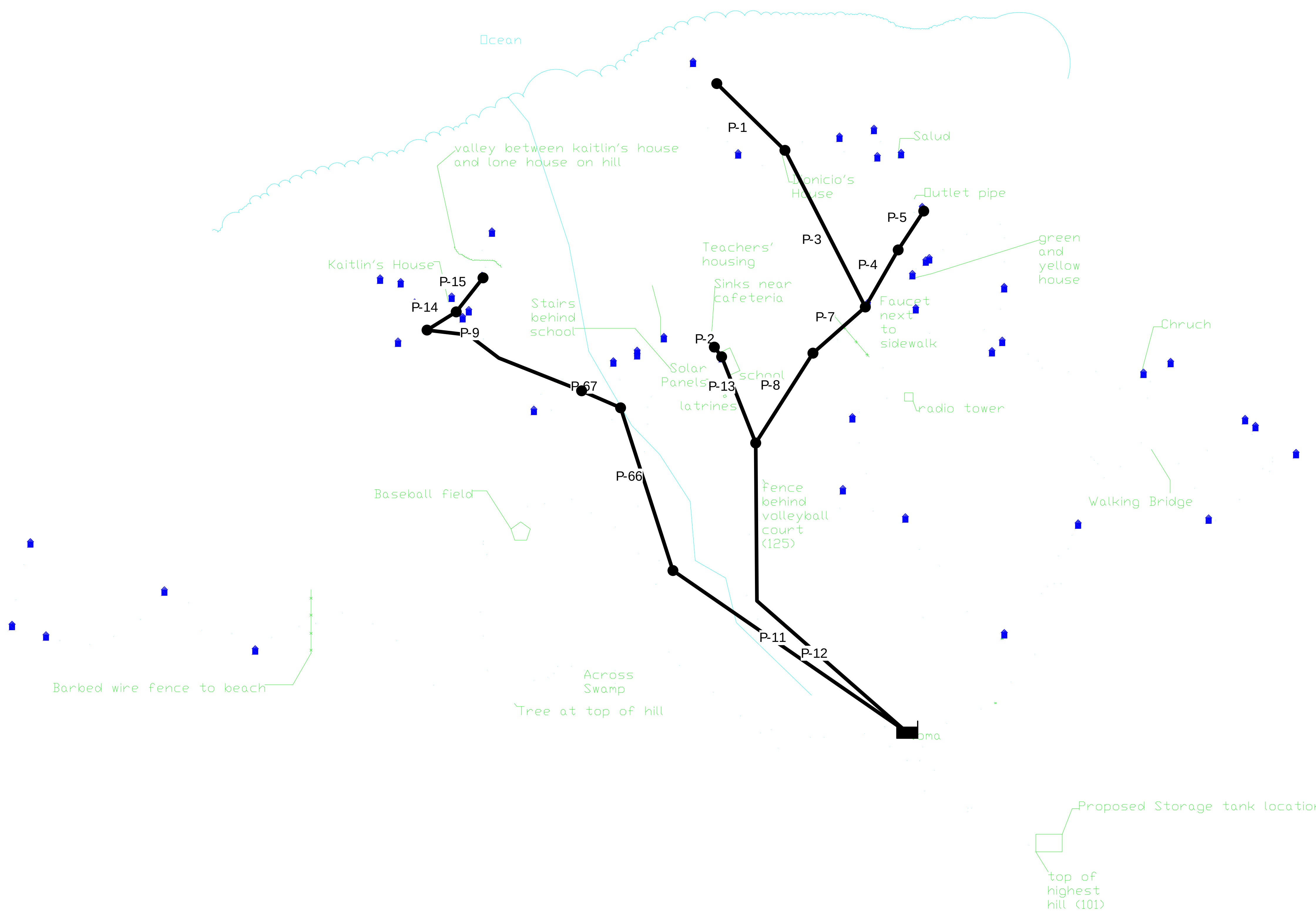


Punta Sirain Distribution Network - Existing Plus Option



Node Labels

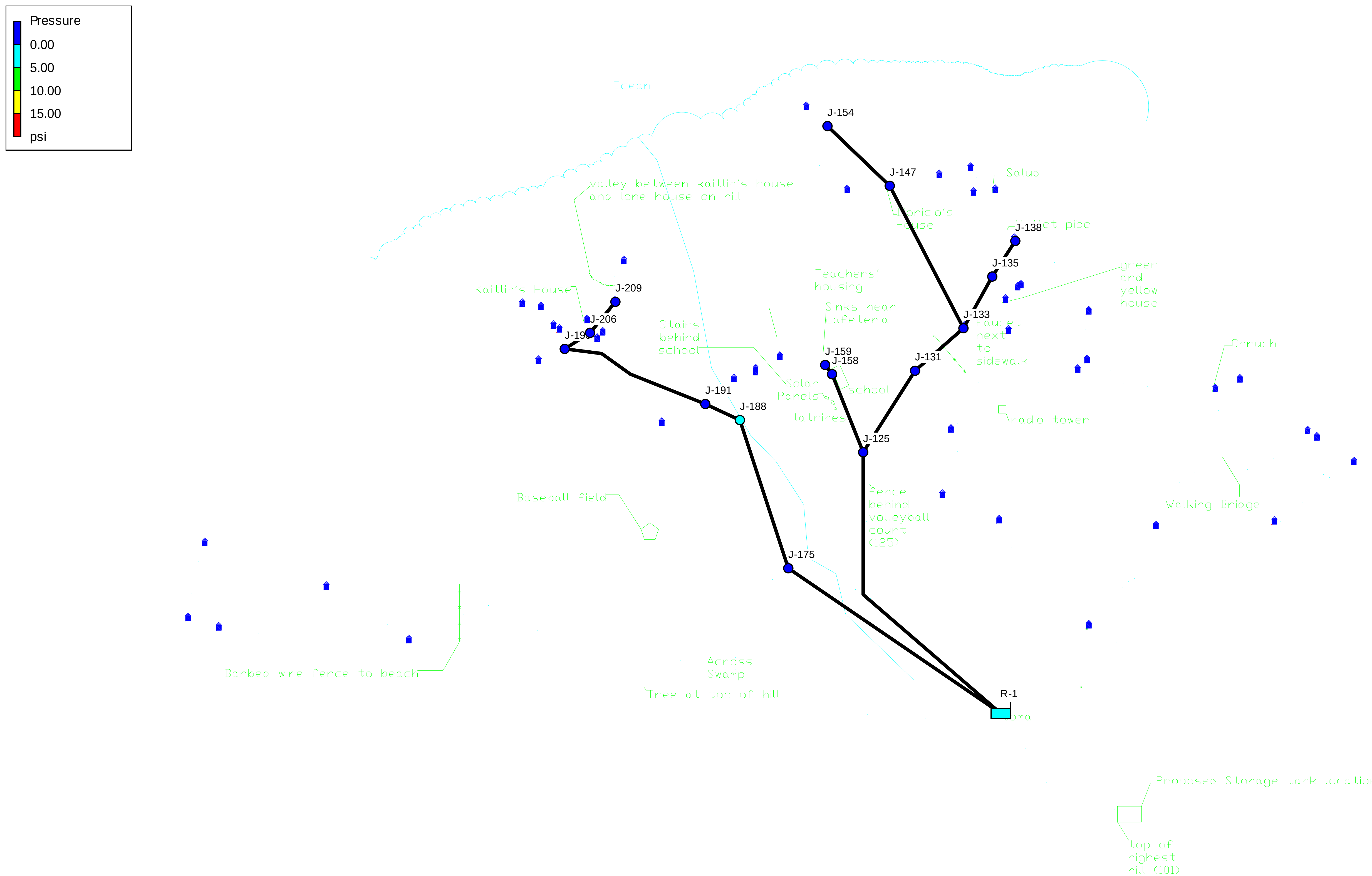
Punta Sirain Distribution Network - Existing Plus Option



Pipe Labels

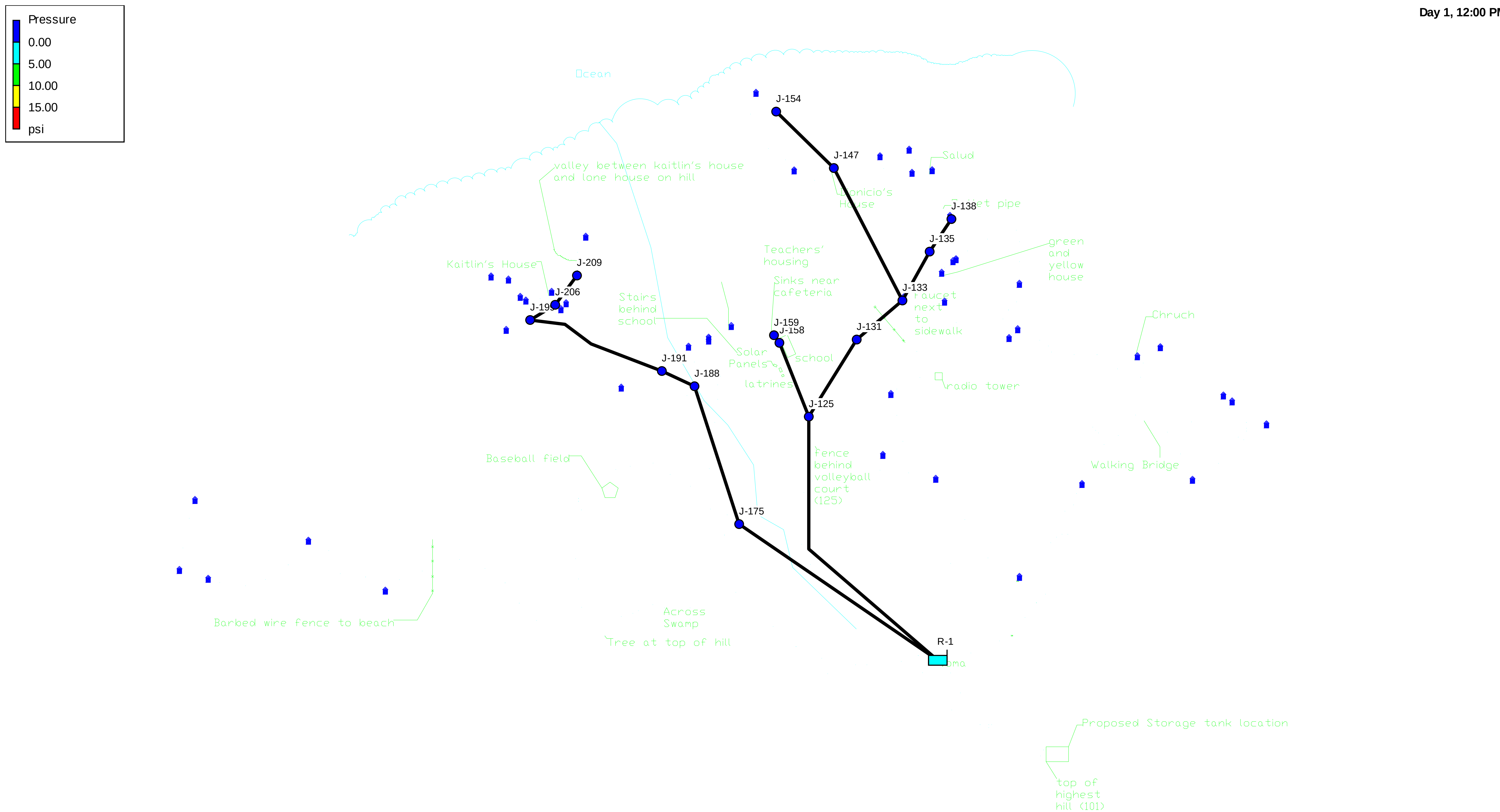
Punta Sirain Distribution Network - Existing Plus Option

Day 1, 7:00 AM



System performance under demand curve 1; peak demand, 2X demand multiplier

Punta Sirain Distribution Network - Existing Plus Option

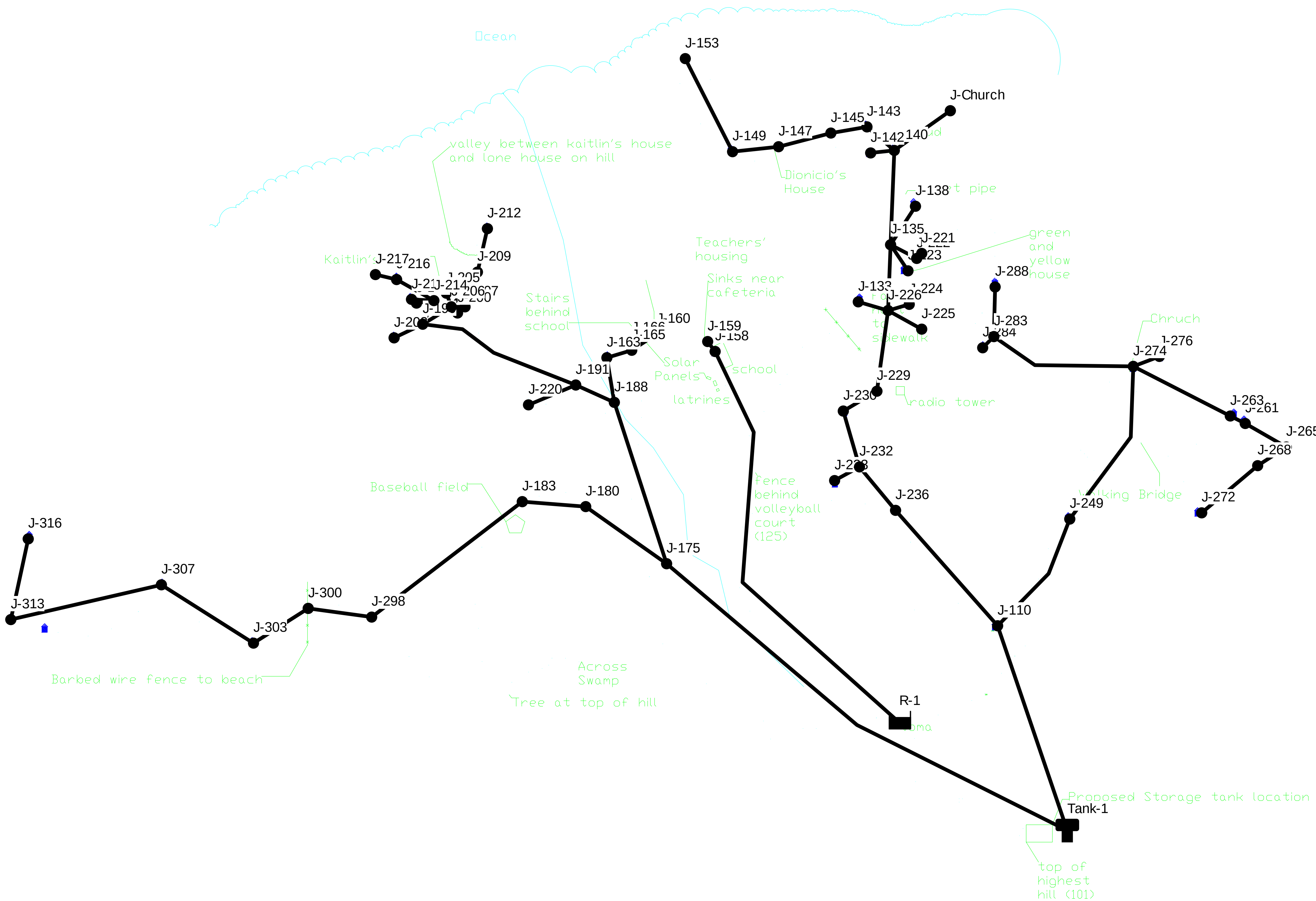


System performance under demand curve 2; peak demand, 2X demand multiplier

Nodes Under Peak Demand - Existing Plus Option				
			Curve 1	Curve 2
	Elevation	Base Demand	Pressure	Pressure
Node ID	ft	GPM	psi	psi
Junc J-125	437	0	-38.12	-51.31
Junc J-131	434	0	-54.37	-73.11
Junc J-133	436	0	-59.61	-79.74
Junc J-135	437	0.665	-60.35	-80.57
Junc J-138	441	0	-62.08	-82.3
Junc J-147	436	0.665	-67.12	-89.59
Junc J-154	421	0.665	-62.1	-85.03
Junc J-158	441	0.16055	-40.27	-53.58
Junc J-159	441	0.16055	-40.28	-53.6
Junc J-175	443	0	-3.37	-4.68
Junc J-188	421	0	3.48	1.34
Junc J-191	429	0	-0.64	-2.98
Junc J-199	441	0	-8.25	-11.33
Junc J-206	440	0	-8.26	-11.47
Junc J-209	431	0.665	-4.95	-8.35
Resvr R-1	445	#N/A	0	0

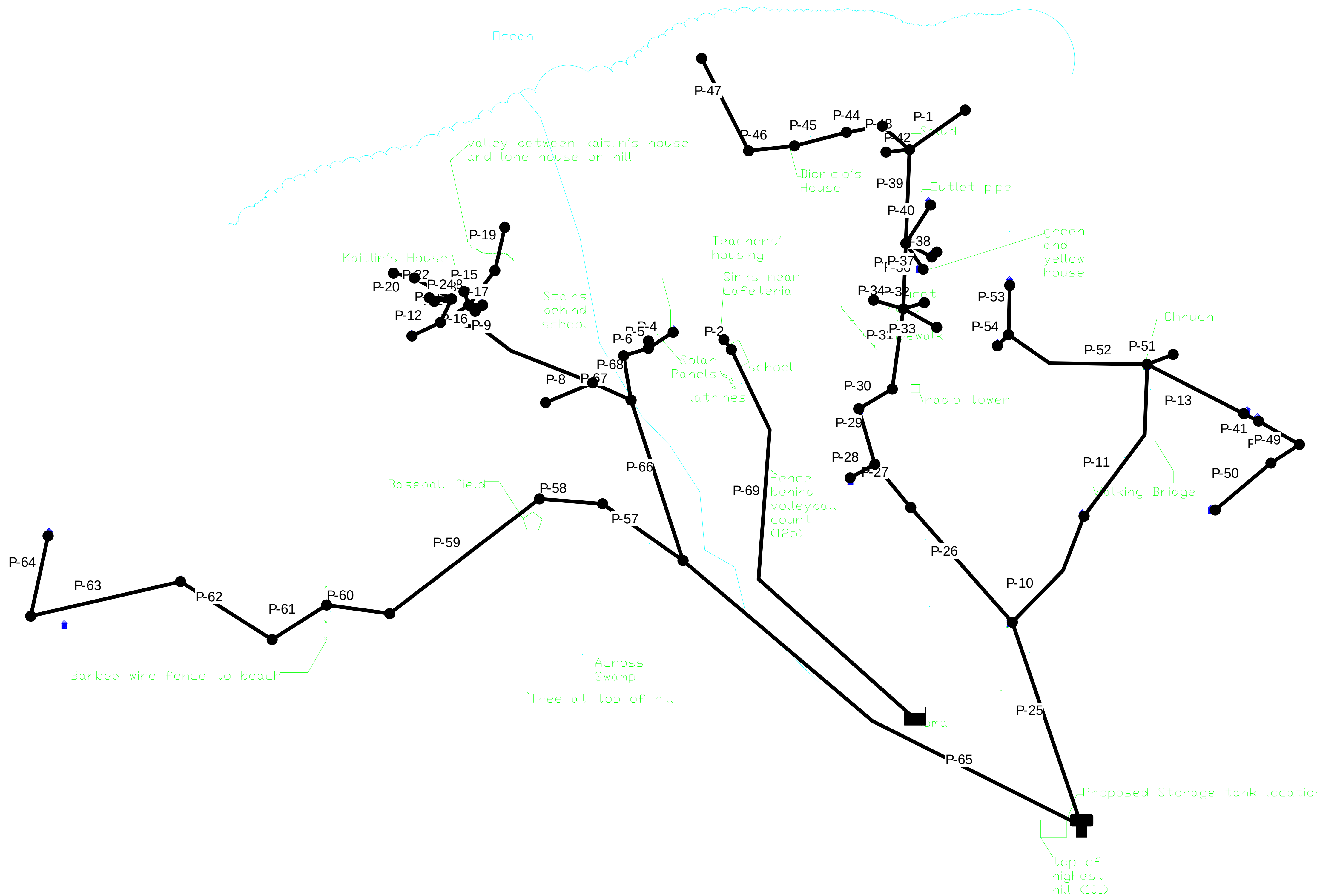
Links Under Maximum Demand - Existing Plus Option								
					Curve 1		Curve 2	
	Start	End	Length	Diameter	Flow	Velocity	Flow	Velocity
Link ID	Node	Node	ft	in	GPM	fps	GPM	fps
Pipe P-1	J-154	J-147	171	1	-4.79	1.96	-5.59	2.28
Pipe P-2	J-158	J-159	22	1	1.16	0.47	1.35	0.55
Pipe P-3	J-147	J-133	257	1	-9.58	3.91	-11.17	4.56
Pipe P-4	J-133	J-135	35	1	4.79	1.96	5.59	2.28
Pipe P-5	J-135	J-138	185	1	0	0	0	0
Pipe P-7	J-133	J-131	73	1	-14.36	5.87	-16.76	6.85
Pipe P-8	J-131	J-125	293	1	-14.36	5.87	-16.76	6.85
Pipe P-9	J-191	J-199	278	1	4.79	1.96	5.59	2.28
Pipe P-11	R-1	J-175	490	1	4.79	1.96	5.59	2.28
Pipe P-12	R-1	J-125	532	1	16.68	6.81	19.46	7.95
Pipe P-13	J-125	J-158	168	1	2.31	0.94	2.7	1.1
Pipe P-14	J-199	J-206	51	1	4.79	1.96	5.59	2.28
Pipe P-15	J-206	J-209	69	1	4.79	1.96	5.59	2.28
Pipe P-66	J-175	J-188	310	1	4.79	1.96	5.59	2.28
Pipe P-67	J-188	J-191	76	1	4.79	1.96	5.59	2.28

Punta Sirain Distribution Network - Linear Option



Node Labels

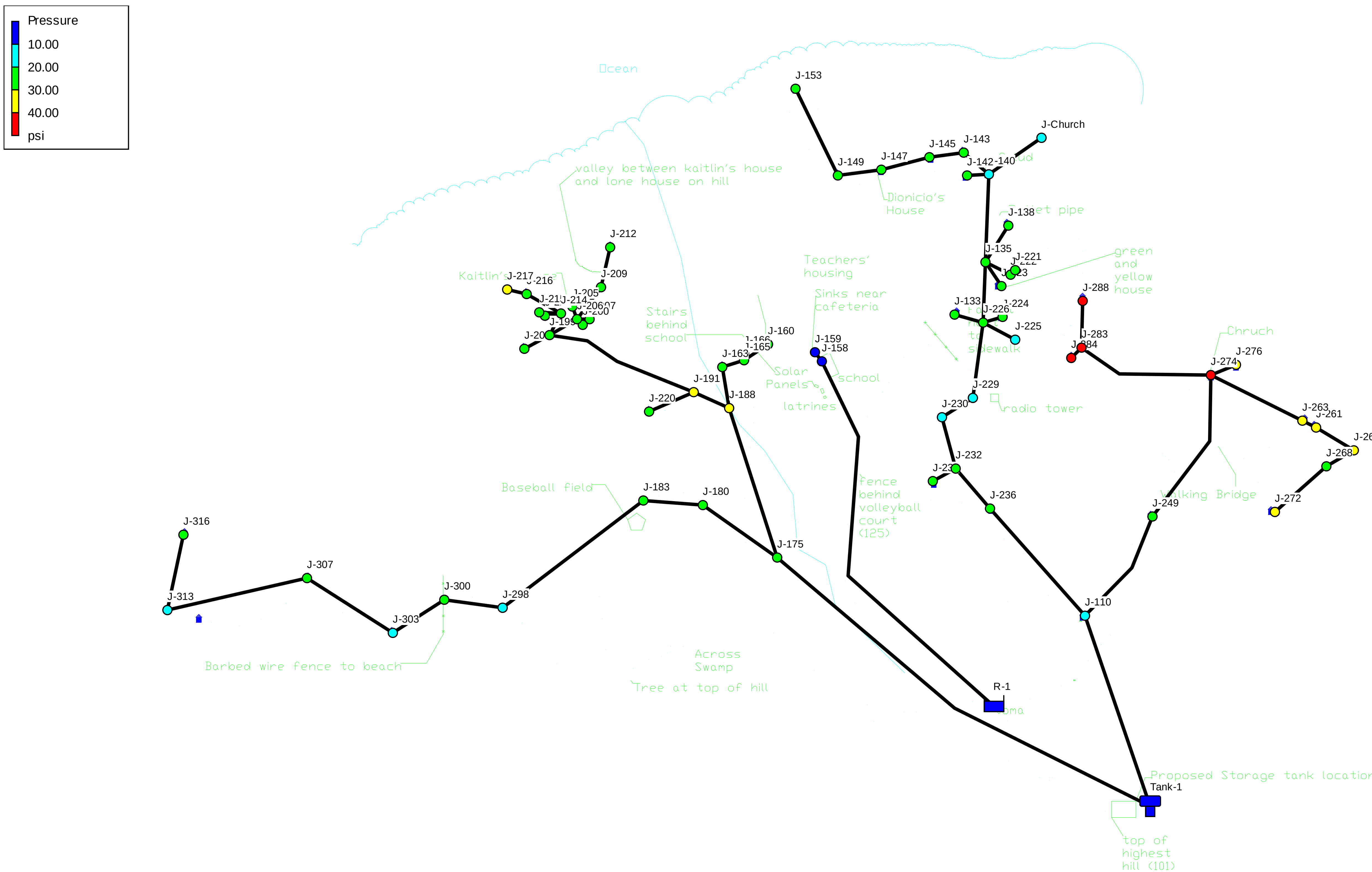
Punta Sirain Distribution Network - Linear Option



Pipe Labels

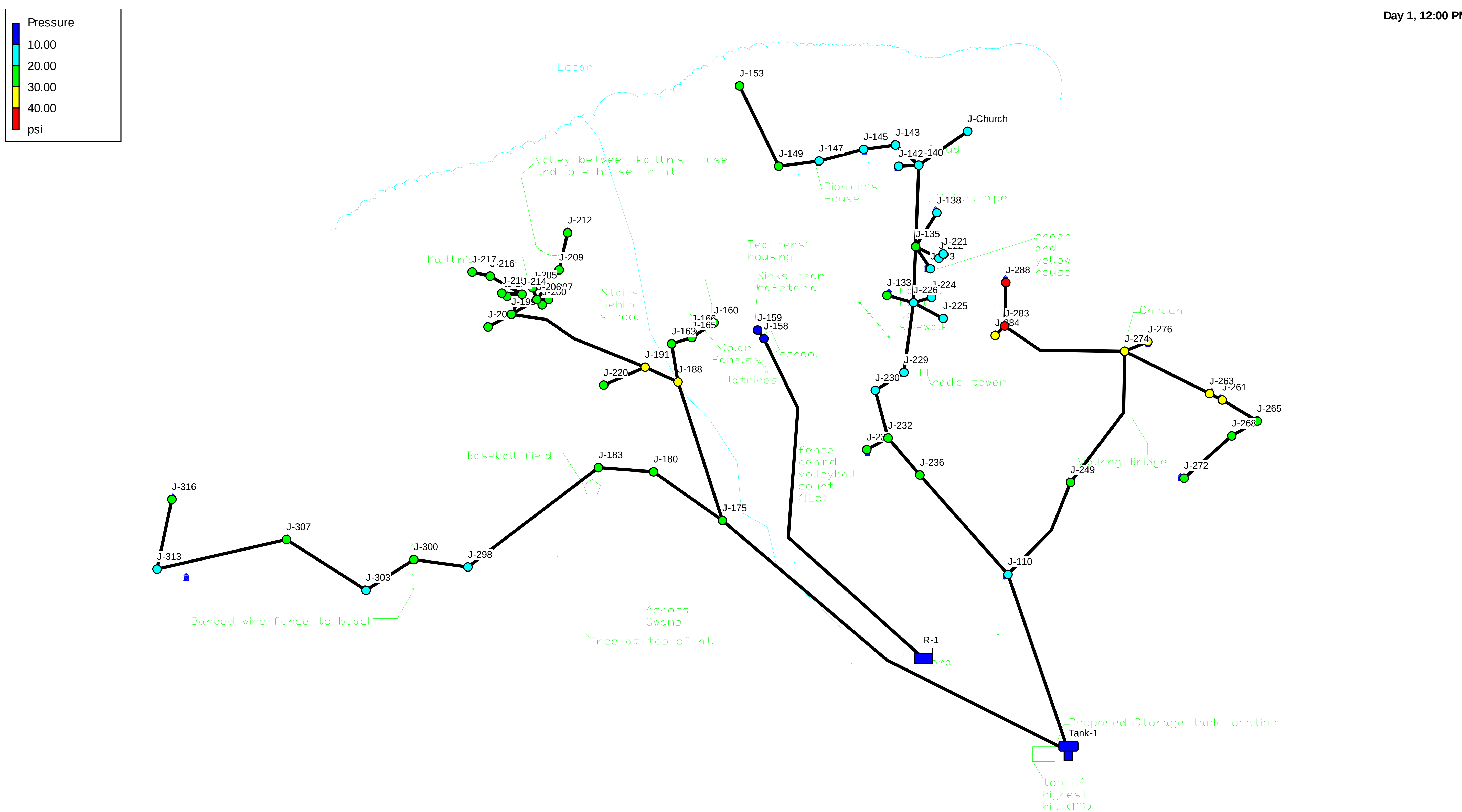
Punta Sirain Distribution Network - Linear Option

Day 1, 7:00 AM



System performance under demand curve 1; peak demand, 2X multiplier

Punta Sirain Distribution Network - Linear Option



System performance under demand curve 2; peak demand, 2X multiplier

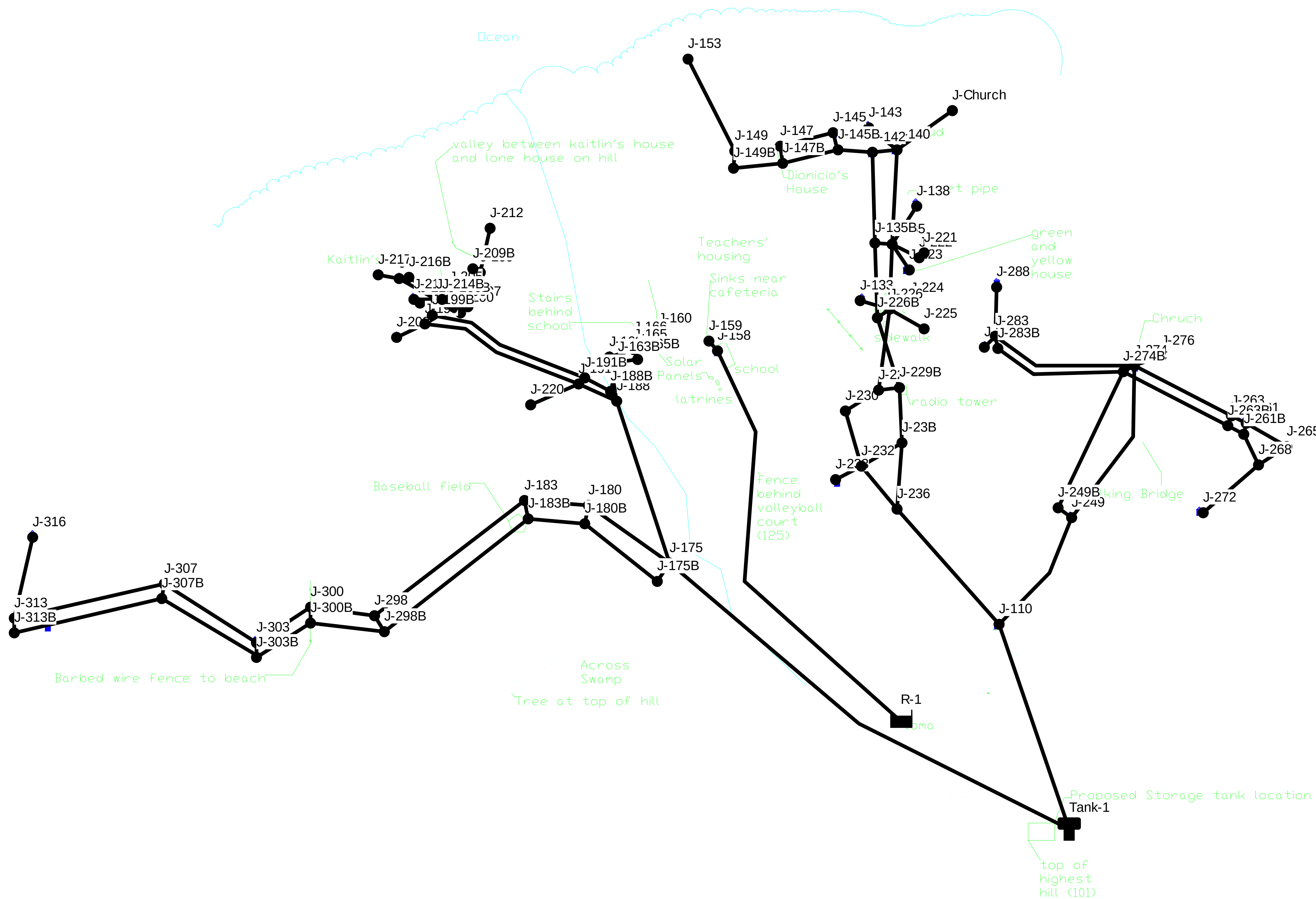
Nodes Under Peak Demand - Linear Option				
			Curve 1	Curve 2
	Elevation	Base Demand	Pressure	Pressure
Node ID	ft	GPM	psi	psi
Junc J-110	460	0.0554	19.5	19.3
Junc J-133	436	0.0554	23.9	21.8
Junc J-135	437	0	22.7	20.4
Junc J-138	441	0.0554	21.0	18.7
Junc J-140	444	0.0554	18.8	16.2
Junc J-142	440	0.0554	20.5	18.0
Junc J-143	440	0.0554	20.4	17.8
Junc J-145	438	0.0554	21.2	18.6
Junc J-147	436	0.0554	22.0	19.3
Junc J-149	427	0.0554	25.9	23.2
Junc J-153	423	0.0554	27.6	24.9
Junc J-158	441	0.16055	1.7	1.7
Junc J-159	441	0.16055	1.7	1.6
Junc J-160	444	0.0554	25.9	25.6
Junc J-163	436	0.0554	29.4	29.0
Junc J-165	442	0.0554	26.8	26.4
Junc J-166	442	0.0554	26.8	26.4
Junc J-175	443	0.0554	26.6	26.3
Junc J-180	444	0	25.9	25.5
Junc J-183	454	0	21.3	20.9
Junc J-188	421	0	36.0	35.7
Junc J-191	429	0	32.0	31.5
Junc J-199	441	0	25.0	24.0
Junc J-200	441	0.0554	24.9	23.9
Junc J-202	448	0.0554	22.0	20.9
Junc J-205	438	0.0554	26.2	25.2
Junc J-206	440	0	25.4	24.3
Junc J-207	441	0.0554	24.9	23.9
Junc J-209	431	0.0554	29.2	28.2
Junc J-212	432	0.0554	28.8	27.7
Junc J-213	440	0.0554	25.4	24.3
Junc J-214	437	0	26.7	25.6
Junc J-215	433	0.0554	28.4	27.3
Junc J-216	432	0.0554	28.8	27.7
Junc J-217	429	0.0554	30.1	29.0
Junc J-220	448	0.0554	23.7	23.2
Junc J-221	440	0.0554	21.4	19.1
Junc J-222	438	0.0554	22.3	20.0
Junc J-223	439	0.0554	21.9	19.5
Junc J-224	442	0.0554	21.3	19.2
Junc J-225	450	0.0554	17.8	15.7
Junc J-226	443	0	20.8	18.8
Junc J-229	456	0	17.7	16.3

Junc J-230	456	0.0554	18.0	16.8
Junc J-232	452	0	21.1	20.3
Junc J-233	452	0.0554	21.1	20.3
Junc J-236	453	0.0554	22.3	22.0
Junc J-249	436	0.0554	29.8	29.6
Junc J-261	424	0.0554	33.0	32.2
Junc J-263	420	0.0554	34.8	33.9
Junc J-265	430	0.0554	30.4	29.5
Junc J-268	444	0	24.3	23.4
Junc J-272	429	0.0554	30.8	29.9
Junc J-274	408	0.0554	40.2	39.5
Junc J-276	418	0.0554	35.9	35.1
Junc J-283	402	0.0554	42.6	41.8
Junc J-284	408	0.0554	40.0	39.2
Junc J-288	402	0.0554	42.6	41.8
Junc J-298	460	0	18.5	18.0
Junc J-300	452	0	21.8	21.3
Junc J-303	468	0.0554	14.7	14.1
Junc J-307	451	0.0554	22.0	21.3
Junc J-313	456	0.0554	19.7	19.0
Junc J-316	447	0.0554	23.6	22.9
Junc J-Church	450	0.0554	16.2	13.6
Resvr R-1	445	#N/A	0.0	0.0
Tank Tank-1	500	#N/A	2.6	2.5

Links Under Maximum Demand - Linear Option								
					Curve 1		Curve 2	
	Start	End	Length	Diameter	Flow	Velocity	Flow	Velocity
Link ID	Node	Node	ft	in	GPM	fps	GPM	fps
Pipe P-1	J-Church	J-140	150	1	-0.4	0.16	-0.47	0.19
Pipe P-2	J-158	J-159	22	1	1.16	0.47	1.35	0.55
Pipe P-4	J-160	J-165	57	1	-0.4	0.16	-0.47	0.19
Pipe P-5	J-165	J-166	6	1	0.4	0.16	0.47	0.19
Pipe P-6	J-163	J-165	44	2	1.2	0.12	1.4	0.14
Pipe P-8	J-191	J-220	96	1	0.4	0.16	0.47	0.19
Pipe P-9	J-191	J-199	278	1	3.99	1.63	4.65	1.9
Pipe P-10	J-110	J-249	297	2	3.99	0.41	4.65	0.48
Pipe P-11	J-249	J-274	325	1	3.59	1.47	4.19	1.71
Pipe P-12	J-199	J-202	34	1	0.4	0.16	0.47	0.19
Pipe P-13	J-274	J-263	221	1	1.6	0.65	1.86	0.76
Pipe P-14	J-199	J-206	51	1	1.99	0.81	2.33	0.95
Pipe P-15	J-206	J-209	69	1	0.8	0.33	0.93	0.38
Pipe P-16	J-206	J-200	19	1	0.4	0.16	0.47	0.19
Pipe P-17	J-206	J-207	19	1	0.4	0.16	0.47	0.19
Pipe P-18	J-206	J-205	22	1	0.4	0.16	0.47	0.19
Pipe P-19	J-209	J-212	110	1	0.4	0.16	0.47	0.19
Pipe P-20	J-217	J-216	37	1	-0.4	0.16	-0.47	0.19
Pipe P-21	J-199	J-214	76	1	1.6	0.65	1.86	0.76
Pipe P-22	J-214	J-216	68	1	0.8	0.33	0.93	0.38
Pipe P-23	J-214	J-213	30	1	0.4	0.16	0.47	0.19
Pipe P-24	J-214	J-215	27	1	0.4	0.16	0.47	0.19
Pipe P-25	Tank-1	J-110	276	2	11.57	1.18	13.5	1.38
Pipe P-26	J-110	J-236	328	2	7.18	0.73	8.38	0.86
Pipe P-27	J-236	J-232	103	1	6.78	2.77	7.91	3.23
Pipe P-28	J-232	J-233	60	1	0.4	0.16	0.47	0.19
Pipe P-29	J-232	J-230	96	1	6.38	2.61	7.45	3.04
Pipe P-30	J-230	J-229	26	1	5.98	2.44	6.98	2.85
Pipe P-31	J-229	J-226	192	1	5.98	2.44	6.98	2.85
Pipe P-32	J-226	J-224	18	1	0.4	0.16	0.47	0.19
Pipe P-33	J-226	J-225	60	1	0.4	0.16	0.47	0.19
Pipe P-34	J-226	J-133	65	1	0.4	0.16	0.47	0.19
Pipe P-35	J-226	J-135	84	1	4.79	1.96	5.58	2.28
Pipe P-36	J-135	J-223	37	1	0.4	0.16	0.47	0.19
Pipe P-37	J-135	J-222	54	1	0.8	0.33	0.93	0.38
Pipe P-38	J-222	J-221	13	1	0.4	0.16	0.47	0.19
Pipe P-39	J-135	J-140	205	1	3.19	1.3	3.72	1.52
Pipe P-40	J-135	J-138	185	1	0.4	0.16	0.47	0.19
Pipe P-41	J-263	J-261	22	1	1.2	0.49	1.4	0.57
Pipe P-42	J-140	J-142	43	1	0.4	0.16	0.47	0.19
Pipe P-43	J-261	J-265	109	1	0.8	0.33	0.93	0.38
Pipe P-44	J-143	J-145	61	1	1.6	0.65	1.86	0.76
Pipe P-45	J-145	J-147	99	1	1.2	0.49	1.4	0.57

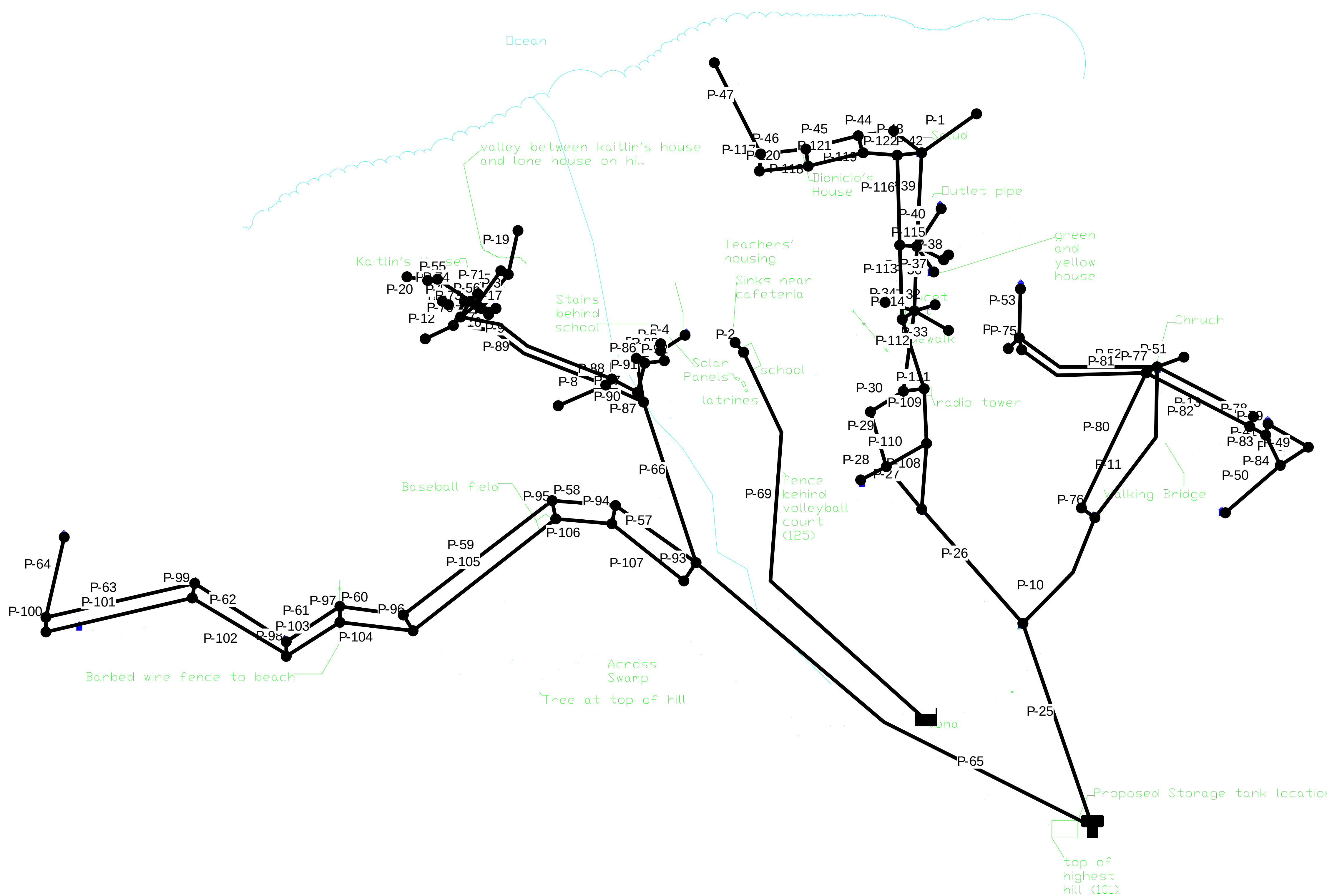
Pipe P-46	J-147	J-149	84	1	0.8	0.33	0.93	0.38
Pipe P-47	J-149	J-153	181	1	0.4	0.16	0.47	0.19
Pipe P-48	J-140	J-143	64	1	1.99	0.81	2.33	0.95
Pipe P-49	J-265	J-268	49	1	0.4	0.16	0.47	0.19
Pipe P-50	J-268	J-272	146	1	0.4	0.16	0.47	0.19
Pipe P-51	J-274	J-276	51	1	0.4	0.16	0.47	0.19
Pipe P-52	J-274	J-283	255	1	1.2	0.49	1.4	0.57
Pipe P-53	J-283	J-288	103	1	0.4	0.16	0.47	0.19
Pipe P-54	J-283	J-284	26	1	0.4	0.16	0.47	0.19
Pipe P-57	J-175	J-180	219	1	1.6	0.65	1.86	0.76
Pipe P-58	J-180	J-183	172	1	1.6	0.65	1.86	0.76
Pipe P-59	J-183	J-298	180	1	1.6	0.65	1.86	0.76
Pipe P-60	J-298	J-300	102	1	1.6	0.65	1.86	0.76
Pipe P-61	J-300	J-303	127	1	1.6	0.65	1.86	0.76
Pipe P-62	J-303	J-307	192	1	1.2	0.49	1.4	0.57
Pipe P-63	J-307	J-313	277	1	0.8	0.33	0.93	0.38
Pipe P-64	J-313	J-316	142	1	0.4	0.16	0.47	0.19
Pipe P-65	Tank-1	J-175	820	2	7.98	0.81	9.31	0.95
Pipe P-66	J-175	J-188	310	2	5.98	0.61	6.98	0.71
Pipe P-67	J-188	J-191	76	1	4.39	1.79	5.12	2.09
Pipe P-68	J-188	J-163	81	1	1.6	0.65	1.86	0.76
Pipe P-69	R-1	J-158	700	2	2.31	0.24	2.7	0.28

Punta Sirain Distribution Network - Gridded Option



Node Labels

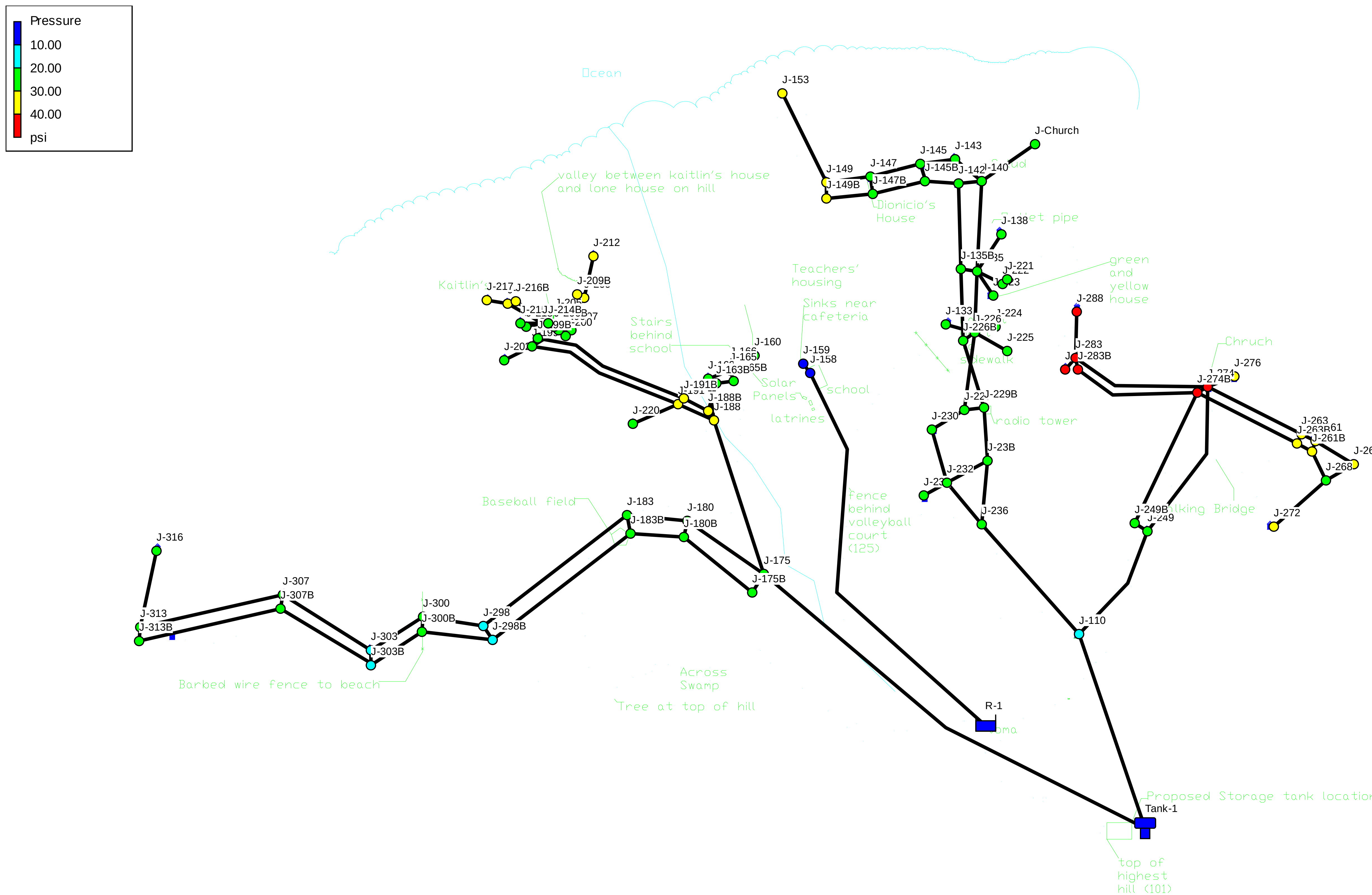
Punta Sirain Distribution Network - Gridded Option



Pipe Labels

Punta Sirain Distribution Network - Gridded Option

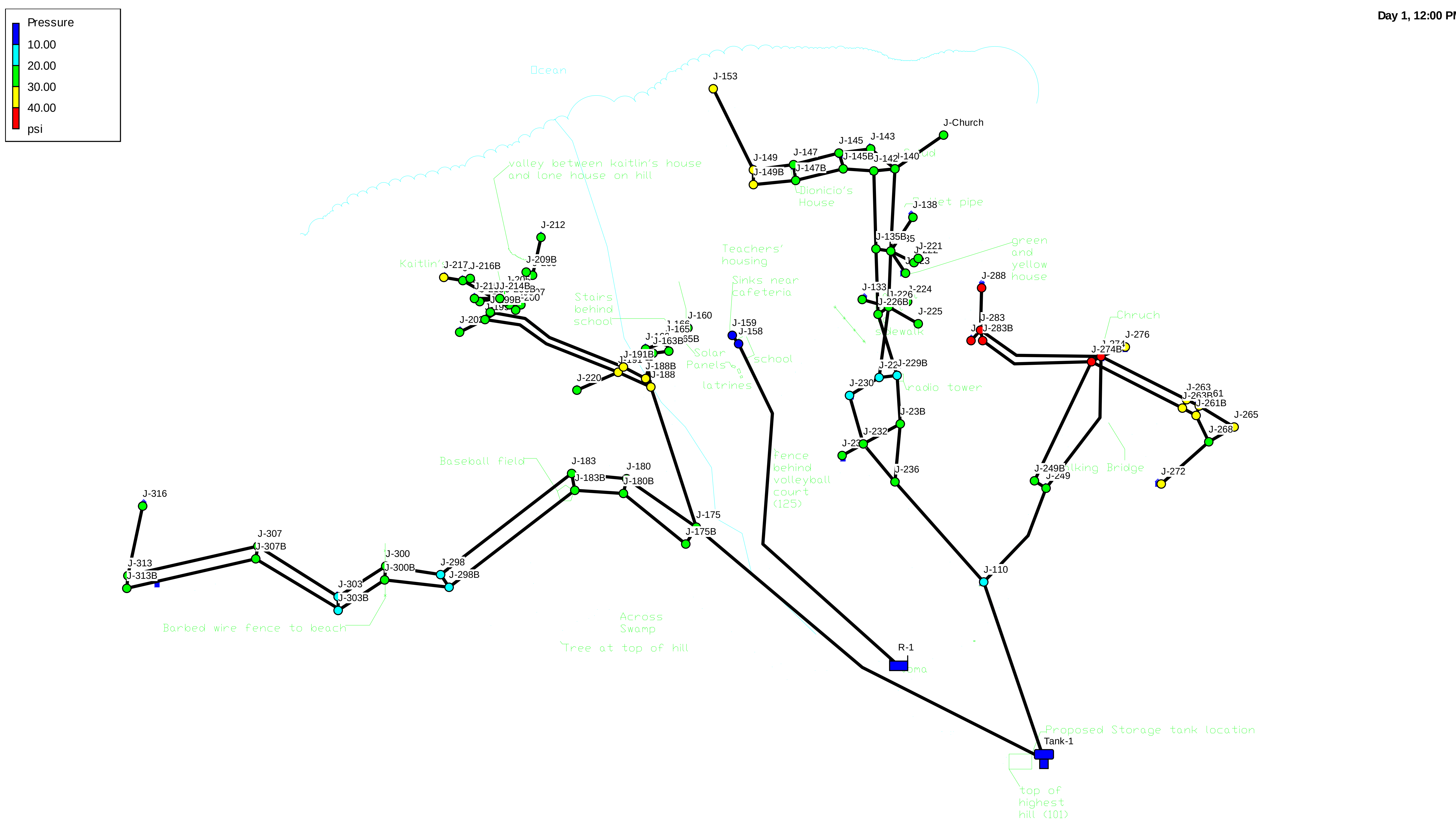
Day 1, 7:00 AM



System performance under demand curve 1; peak demand, 2X demand multiplier

Punta Sirain Distribution Network - Gridded Option

Day 1, 12:00 PM



System performance under demand curve 2; peak demand, 2X demand multiplier

Nodes Under Peak Demand - Gridded Option				
			Curve 1	Curve 2
	Elevation	Base Demand	Pressure	Pressure
Node ID	ft	GPM	psi	psi
Junc J-110	460	0.0554	19.46	19.29
Junc J-133	436	0.0554	27.95	27.20
Junc J-135	437	0	27.30	26.48
Junc J-135B	437	0	27.31	26.49
Junc J-138	441	0.0554	25.55	24.73
Junc J-140	444	0.0554	24.00	23.11
Junc J-142	440	0.0554	25.74	24.84
Junc J-143	440	0.0554	25.71	24.80
Junc J-145	438	0.0554	26.57	25.65
Junc J-145B	438	0	26.57	25.65
Junc J-147	436	0.0554	27.42	26.50
Junc J-147B	436	0	27.42	26.50
Junc J-149	427	0.0554	31.31	30.39
Junc J-149B	427	0	31.31	30.39
Junc J-153	423	0.0554	33.02	32.10
Junc J-158	441	0.16055	1.67	1.65
Junc J-159	441	0.16055	1.67	1.65
Junc J-160	444	0.0554	25.82	25.49
Junc J-163	436	0.0554	29.31	28.97
Junc J-163B	436	0	29.31	28.97
Junc J-165	442	0.0554	26.70	26.36
Junc J-165B	442	0	26.70	26.36
Junc J-166	442	0.0554	26.70	26.36
Junc J-175	443	0.0554	26.53	26.27
Junc J-175B	443	0	26.52	26.26
Junc J-180	444	0	26.04	25.75
Junc J-180B	444	0	26.04	25.75
Junc J-183	454	0	21.66	21.36
Junc J-183B	454	0	21.66	21.36
Junc J-188	421	0	35.88	35.56
Junc J-188B	421	0	35.81	35.48
Junc J-191	429	0	32.15	31.76
Junc J-191B	429	0	32.15	31.76
Junc J-199	441	0	26.23	25.61
Junc J-199B	441	0	26.23	25.61
Junc J-200	441	0.0554	26.17	25.54
Junc J-202	448	0.0554	23.19	22.58
Junc J-205	438	0.0554	27.47	26.84
Junc J-206	440	0	26.61	25.98
Junc J-206B	440	0.0554	26.61	25.98
Junc J-207	441	0.0554	26.17	25.54
Junc J-209	431	0.0554	30.49	29.86
Junc J-209B	431	0.0554	30.49	29.86

Junc J-212	432	0.0554	30.05	29.42
Junc J-213	440	0.0554	26.64	26.01
Junc J-214	437	0	27.94	27.32
Junc J-214B	437	0	27.94	27.32
Junc J-215	433	0.0554	29.67	29.05
Junc J-216	432	0.0554	30.10	29.47
Junc J-216B	432	0	30.10	29.48
Junc J-217	429	0.0554	31.39	30.77
Junc J-220	448	0.0554	23.91	23.51
Junc J-221	440	0.0554	25.99	25.16
Junc J-222	438	0.0554	26.85	26.03
Junc J-223	439	0.0554	26.43	25.61
Junc J-224	442	0.0554	25.35	24.60
Junc J-225	450	0.0554	21.88	21.13
Junc J-226	443	0	24.92	24.17
Junc J-226B	443	0	24.93	24.18
Junc J-229	456	0	20.02	19.50
Junc J-229B	456	0	20.03	19.50
Junc J-230	456	0.0554	20.11	19.61
Junc J-232	452	0	22.22	21.84
Junc J-233	452	0.0554	22.21	21.83
Junc J-236	453	0.0554	22.28	22.04
Junc J-23B	452	0	22.22	21.84
Junc J-249	436	0.0554	29.76	29.56
Junc J-249B	436	0	29.72	29.51
Junc J-261	424	0.0554	34.15	33.70
Junc J-261B	424	0	34.15	33.70
Junc J-263	420	0.0554	35.88	35.43
Junc J-263B	420	0	35.89	35.43
Junc J-265	430	0.0554	31.54	31.08
Junc J-268	444	0	25.47	25.02
Junc J-272	429	0.0554	31.95	31.50
Junc J-274	408	0.0554	41.14	40.72
Junc J-274B	408	0.0554	41.14	40.72
Junc J-276	418	0.0554	36.80	36.38
Junc J-283	402	0.0554	43.68	43.22
Junc J-283B	402	0.0554	43.68	43.22
Junc J-284	408	0.0554	41.07	40.62
Junc J-288	402	0.0554	43.66	43.21
Junc J-298	460	0	19.02	18.69
Junc J-298B	460	0	19.02	18.69
Junc J-300	452	0	22.46	22.12
Junc J-300B	452	0	22.46	22.12
Junc J-303	468	0.0554	15.49	15.14
Junc J-303B	468	0	15.49	15.14
Junc J-307	451	0.0554	22.83	22.47
Junc J-307B	451	0	22.83	22.47

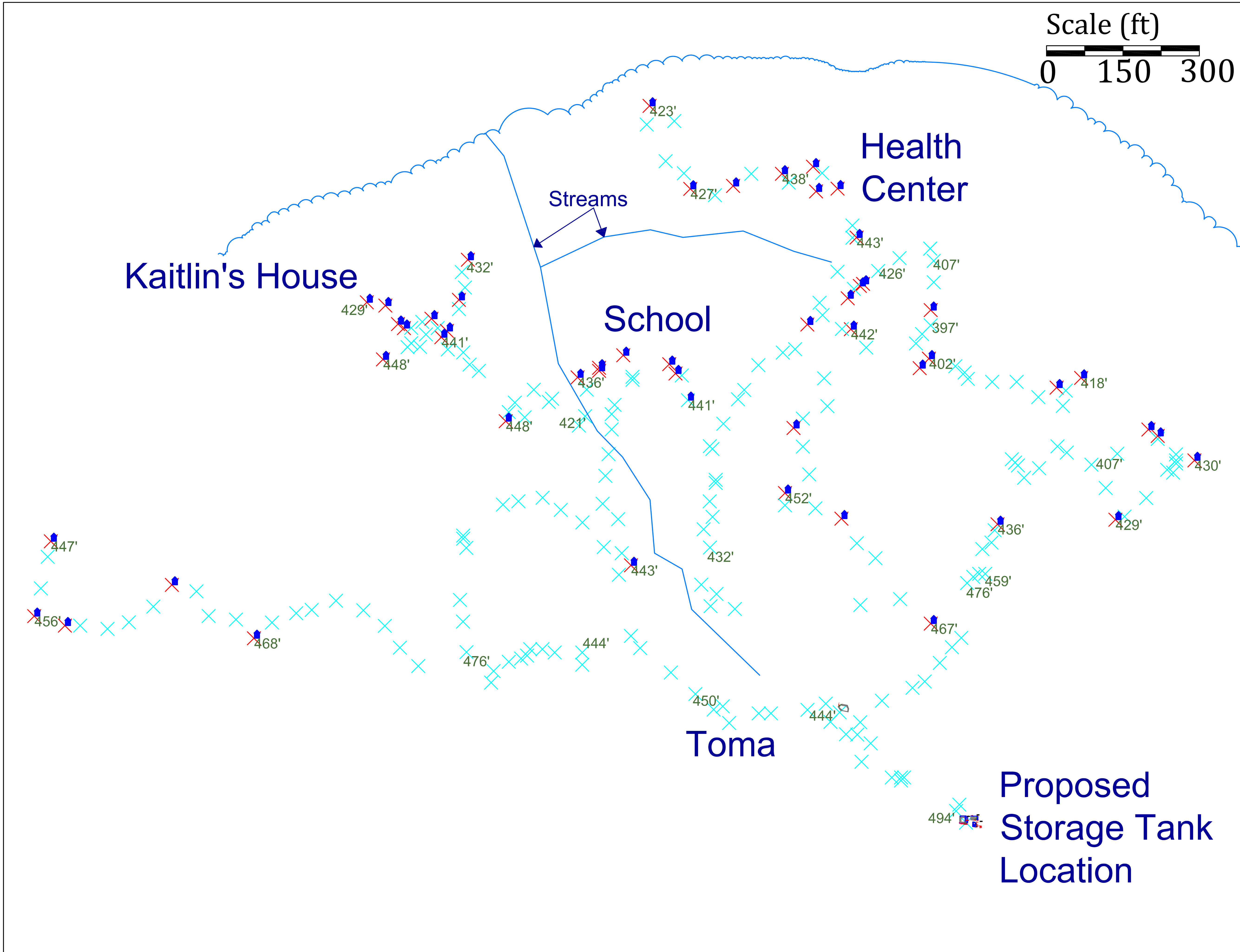
Junc J-313	456	0.0554	20.63	20.26
Junc J-313B	456	0	20.63	20.27
Junc J-316	447	0.0554	24.51	24.14
Junc J-Church	450	0.0554	21.38	20.49
Resvr R-1	445	#N/A	0.00	0.00
Tank Tank-1	500	#N/A	2.59	2.57

Links Under Maximum Demand - Gridded Option								
					Curve 1		Curve 2	
	Start	End	Length	Diameter	Flow	Velocity	Flow	Velocity
Link ID	Node	Node	ft	in	GPM	fps	GPM	fps
Pipe P-1	J-Church	J-140	150	1	-0.4	0.16	-0.47	0.19
Pipe P-2	J-158	J-159	22	2	1.16	0.12	1.35	0.14
Pipe P-3	J-209B	J-209	20	1	0.22	0.09	0.25	0.1
Pipe P-4	J-160	J-165	57	1	-0.4	0.16	-0.47	0.19
Pipe P-5	J-165	J-166	6	1	0.4	0.16	0.47	0.19
Pipe P-6	J-163	J-165	44	1	0.73	0.3	0.81	0.33
Pipe P-7	J-206B	J-206	20	1	0.37	0.15	0.44	0.18
Pipe P-8	J-191	J-220	96	1	0.4	0.16	0.47	0.19
Pipe P-9	J-191	J-199	278	1	2.39	0.98	2.79	1.14
Pipe P-10	J-110	J-249	297	2	4.79	0.49	5.58	0.57
Pipe P-11	J-249	J-274	325	1	2.23	0.91	2.6	1.06
Pipe P-12	J-199	J-202	34	1	0.4	0.16	0.47	0.19
Pipe P-13	J-274	J-263	221	1	0.8	0.33	0.93	0.38
Pipe P-14	J-199	J-206	51	1	1.4	0.57	1.64	0.67
Pipe P-15	J-206	J-209	69	1	0.57	0.23	0.68	0.28
Pipe P-16	J-206	J-200	19	1	0.4	0.16	0.47	0.19
Pipe P-17	J-206	J-207	19	1	0.4	0.16	0.47	0.19
Pipe P-18	J-206	J-205	22	1	0.4	0.16	0.47	0.19
Pipe P-19	J-209	J-212	110	1	0.4	0.16	0.47	0.19
Pipe P-20	J-217	J-216	37	1	-0.4	0.16	-0.47	0.19
Pipe P-21	J-199	J-214	76	1	0.81	0.33	0.94	0.38
Pipe P-22	J-214	J-216	68	1	0.4	0.16	0.47	0.19
Pipe P-23	J-214	J-213	30	1	0.4	0.16	0.47	0.19
Pipe P-24	J-214	J-215	27	1	0.4	0.16	0.47	0.19
Pipe P-25	Tank-1	J-110	276	2	12.37	1.26	14.43	1.47
Pipe P-26	J-110	J-236	328	2	7.18	0.73	8.38	0.86
Pipe P-27	J-236	J-232	103	1	3.39	1.39	3.96	1.62
Pipe P-28	J-232	J-233	60	1	0.4	0.16	0.47	0.19
Pipe P-29	J-232	J-230	96	1	3.05	1.25	3.56	1.46
Pipe P-30	J-230	J-229	26	1	2.65	1.08	3.1	1.27
Pipe P-31	J-229	J-226	192	1	2.99	1.22	3.49	1.43
Pipe P-32	J-226	J-224	18	1	0.4	0.16	0.47	0.19
Pipe P-33	J-226	J-225	60	1	0.4	0.16	0.47	0.19
Pipe P-34	J-226	J-133	65	1	0.4	0.16	0.47	0.19
Pipe P-35	J-226	J-135	84	1	2.41	0.98	2.81	1.15
Pipe P-36	J-135	J-223	37	1	0.4	0.16	0.47	0.19
Pipe P-37	J-135	J-222	54	1	0.8	0.33	0.93	0.38
Pipe P-38	J-222	J-221	13	1	0.4	0.16	0.47	0.19
Pipe P-39	J-135	J-140	205	1	1.59	0.65	1.85	0.76
Pipe P-40	J-135	J-138	185	1	0.4	0.16	0.47	0.19
Pipe P-41	J-263	J-261	22	1	0.59	0.24	0.69	0.28
Pipe P-42	J-140	J-142	43	1	-0.17	0.07	-0.21	0.09
Pipe P-43	J-261	J-265	109	1	0.38	0.16	0.45	0.18

Pipe P-44	J-143	J-145	61	1	0.57	0.23	0.67	0.27
Pipe P-45	J-145	J-147	99	1	0.58	0.24	0.68	0.28
Pipe P-46	J-147	J-149	84	1	0.42	0.17	0.49	0.2
Pipe P-47	J-149	J-153	181	1	0.4	0.16	0.47	0.19
Pipe P-48	J-140	J-143	64	1	0.96	0.39	1.14	0.46
Pipe P-49	J-265	J-268	49	1	-0.01	0.01	-0.02	0.01
Pipe P-50	J-268	J-272	146	1	0.4	0.16	0.47	0.19
Pipe P-51	J-274	J-276	51	1	0.4	0.16	0.47	0.19
Pipe P-52	J-274	J-283	255	1	0.8	0.33	0.93	0.38
Pipe P-53	J-283	J-288	103	1	0.4	0.16	0.47	0.19
Pipe P-54	J-283	J-284	26	1	0.4	0.16	0.47	0.19
Pipe P-55	J-216B	J-216	20	1	0.4	0.16	0.46	0.19
Pipe P-56	J-214B	J-214	20	1	0.39	0.16	0.46	0.19
Pipe P-57	J-175	J-180	219	1	0.81	0.33	0.95	0.39
Pipe P-58	J-180	J-183	172	1	0.8	0.33	0.93	0.38
Pipe P-59	J-183	J-298	180	1	0.8	0.33	0.93	0.38
Pipe P-60	J-298	J-300	102	1	0.8	0.33	0.93	0.38
Pipe P-61	J-300	J-303	127	1	0.8	0.33	0.94	0.38
Pipe P-62	J-303	J-307	192	1	0.6	0.24	0.7	0.29
Pipe P-63	J-307	J-313	277	1	0.41	0.17	0.47	0.19
Pipe P-64	J-313	J-316	142	1	0.4	0.16	0.47	0.19
Pipe P-65	Tank-1	J-175	820	2	8.78	0.9	10.24	1.05
Pipe P-66	J-175	J-188	310	2	6.78	0.69	7.91	0.81
Pipe P-67	J-188	J-191	76	1	2.81	1.15	3.27	1.34
Pipe P-68	J-188	J-163	81	1	1.27	0.52	1.47	0.6
Pipe P-69	R-1	J-158	700	2	2.31	0.24	2.7	0.28
Pipe P-70	J-199B	J-199	20	1	0.21	0.09	0.25	0.1
Pipe P-71	J-206B	J-209B	69	1	0.62	0.25	0.72	0.29
Pipe P-72	J-206B	J-199B	51	1	-1.39	0.57	-1.62	0.66
Pipe P-73	J-199B	J-214B	76	1	0.79	0.32	0.92	0.38
Pipe P-74	J-214B	J-216B	68	1	0.4	0.16	0.46	0.19
Pipe P-75	J-283B	J-283	20	1	0.4	0.16	0.46	0.19
Pipe P-76	J-249	J-249B	20	1	2.15	0.88	2.51	1.03
Pipe P-77	J-274B	J-274	20	1	0.16	0.07	0.19	0.08
Pipe P-78	J-263B	J-263	20	1	0.2	0.08	0.23	0.09
Pipe P-79	J-261B	J-261	20	1	0.19	0.08	0.22	0.09
Pipe P-80	J-249B	J-274B	325	1	2.15	0.88	2.51	1.03
Pipe P-81	J-274B	J-283B	255	1	0.79	0.32	0.93	0.38
Pipe P-82	J-274B	J-263B	221	1	0.8	0.33	0.93	0.38
Pipe P-83	J-263B	J-261B	22	1	0.6	0.25	0.7	0.29
Pipe P-84	J-261B	J-268	109	1	0.41	0.17	0.48	0.2
Pipe P-85	J-165B	J-165	20	1	0.47	0.19	0.58	0.24
Pipe P-86	J-163B	J-163	20	1	-0.14	0.06	-0.19	0.08
Pipe P-87	J-188B	J-188	20	1	-2.71	1.11	-3.17	1.29
Pipe P-88	J-191B	J-191	20	1	-0.01	0.01	-0.02	0.01
Pipe P-89	J-199B	J-191B	278	1	-2.39	0.98	-2.79	1.14
Pipe P-90	J-191B	J-188B	76	1	-2.38	0.97	-2.78	1.13

Pipe P-91	J-188B	J-163B	81	1	0.33	0.13	0.39	0.16
Pipe P-92	J-163B	J-165B	44	1	0.47	0.19	0.58	0.24
Pipe P-93	J-175B	J-175	20	1	-0.78	0.32	-0.92	0.37
Pipe P-94	J-180B	J-180	20	1	-0.02	0.01	-0.01	0.01
Pipe P-95	J-183B	J-183	20	1	0	0	0	0
Pipe P-96	J-298B	J-298	20	1	0	0	0	0
Pipe P-97	J-300B	J-300	20	1	0.01	0	0	0
Pipe P-98	J-303B	J-303	20	1	0.19	0.08	0.23	0.09
Pipe P-99	J-307B	J-307	20	1	0.21	0.08	0.24	0.1
Pipe P-100	J-313B	J-313	20	1	0.39	0.16	0.46	0.19
Pipe P-101	J-313B	J-307B	277	1	-0.39	0.16	-0.46	0.19
Pipe P-102	J-307B	J-303B	192	1	-0.6	0.24	-0.7	0.28
Pipe P-103	J-303B	J-300B	127	1	-0.79	0.32	-0.93	0.38
Pipe P-104	J-300B	J-298B	102	1	-0.8	0.33	-0.93	0.38
Pipe P-105	J-298B	J-183B	180	1	-0.8	0.33	-0.93	0.38
Pipe P-106	J-183B	J-180B	172	1	-0.8	0.33	-0.93	0.38
Pipe P-107	J-180B	J-175B	219	1	-0.78	0.32	-0.92	0.37
Pipe P-108	J-236	J-238	103	1	3.39	1.38	3.95	1.62
Pipe P-109	J-238	J-229B	100	1	3.33	1.36	3.88	1.59
Pipe P-110	J-232	J-23B	46	1	-0.06	0.02	-0.07	0.03
Pipe P-111	J-229B	J-229	20	1	0.34	0.14	0.4	0.16
Pipe P-112	J-229B	J-226B	192	1	2.99	1.22	3.49	1.42
Pipe P-113	J-226B	J-135B	85	1	2.38	0.97	2.77	1.13
Pipe P-114	J-226B	J-226	25	1	0.61	0.25	0.71	0.29
Pipe P-115	J-135B	J-135	25	1	0.78	0.32	0.9	0.37
Pipe P-116	J-135B	J-142	205	1	1.6	0.65	1.87	0.76
Pipe P-117	J-149	J-149B	25	1	-0.38	0.16	-0.44	0.18
Pipe P-118	J-147	J-147B	25	1	-0.24	0.1	-0.28	0.11
Pipe P-119	J-145	J-145B	25	1	-0.41	0.17	-0.48	0.2
Pipe P-120	J-149B	J-147B	85	1	-0.38	0.16	-0.44	0.18
Pipe P-121	J-147B	J-145B	100	1	-0.62	0.25	-0.71	0.29
Pipe P-122	J-145B	J-142	70	1	-1.03	0.42	-1.19	0.49

10.4 Appendix D: Construction drawings



General Notes:

Red X = Existing house

Blue X = Surveyed point with known relative elevation

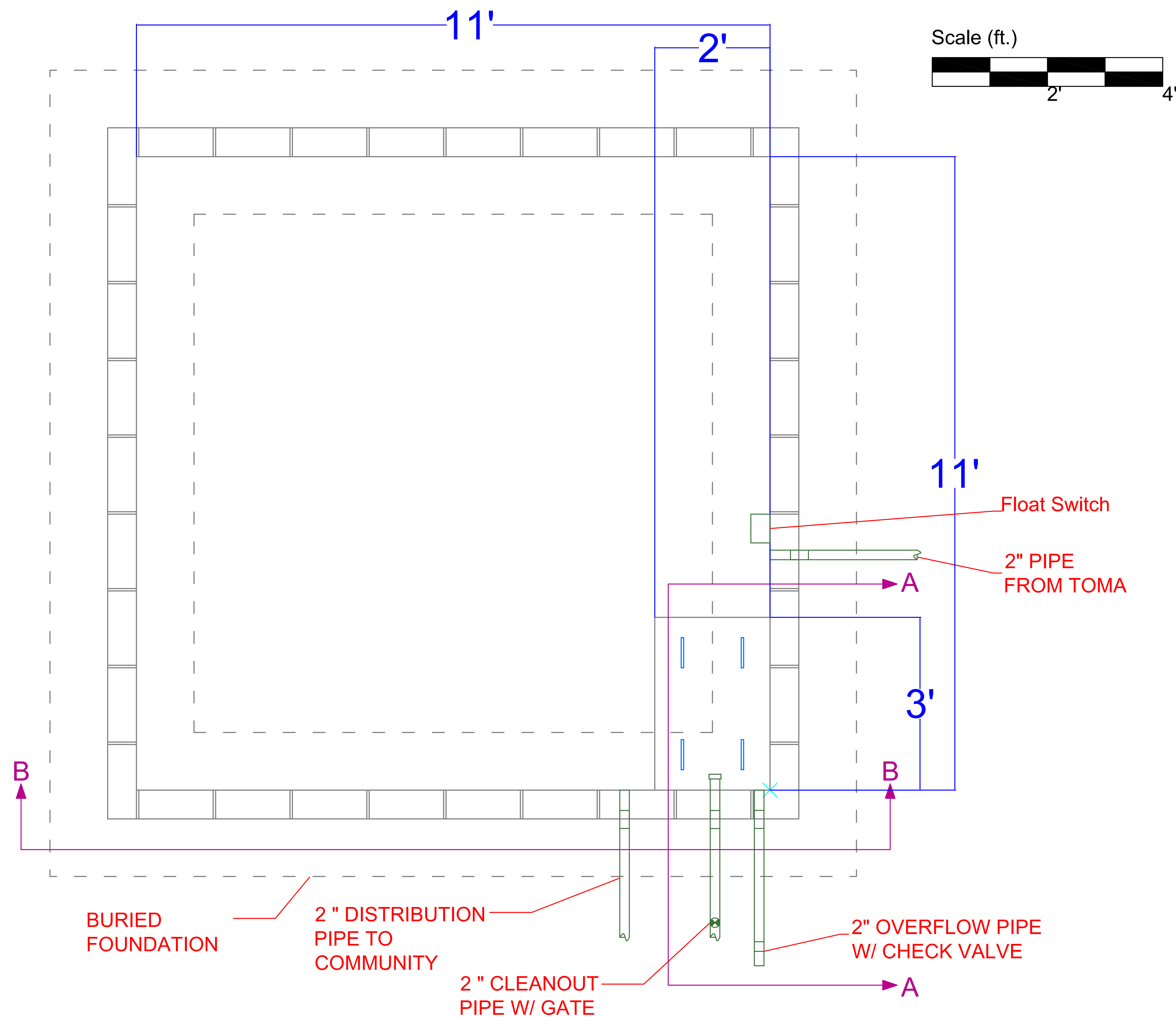
Green labels = Measured relative elevation

Date: 2 Dec 2009

Dwg No: 1

Dwg Name: Community Map

Project: Punta Sirain Water Distribution System



General Notes:

All pipes are 2" PVC SDR26.

Rapear (Panamanian technique to seal with mortar) inner surfaces to seal

8 - 2" PVC Elbows required

1 - Gate Valve required

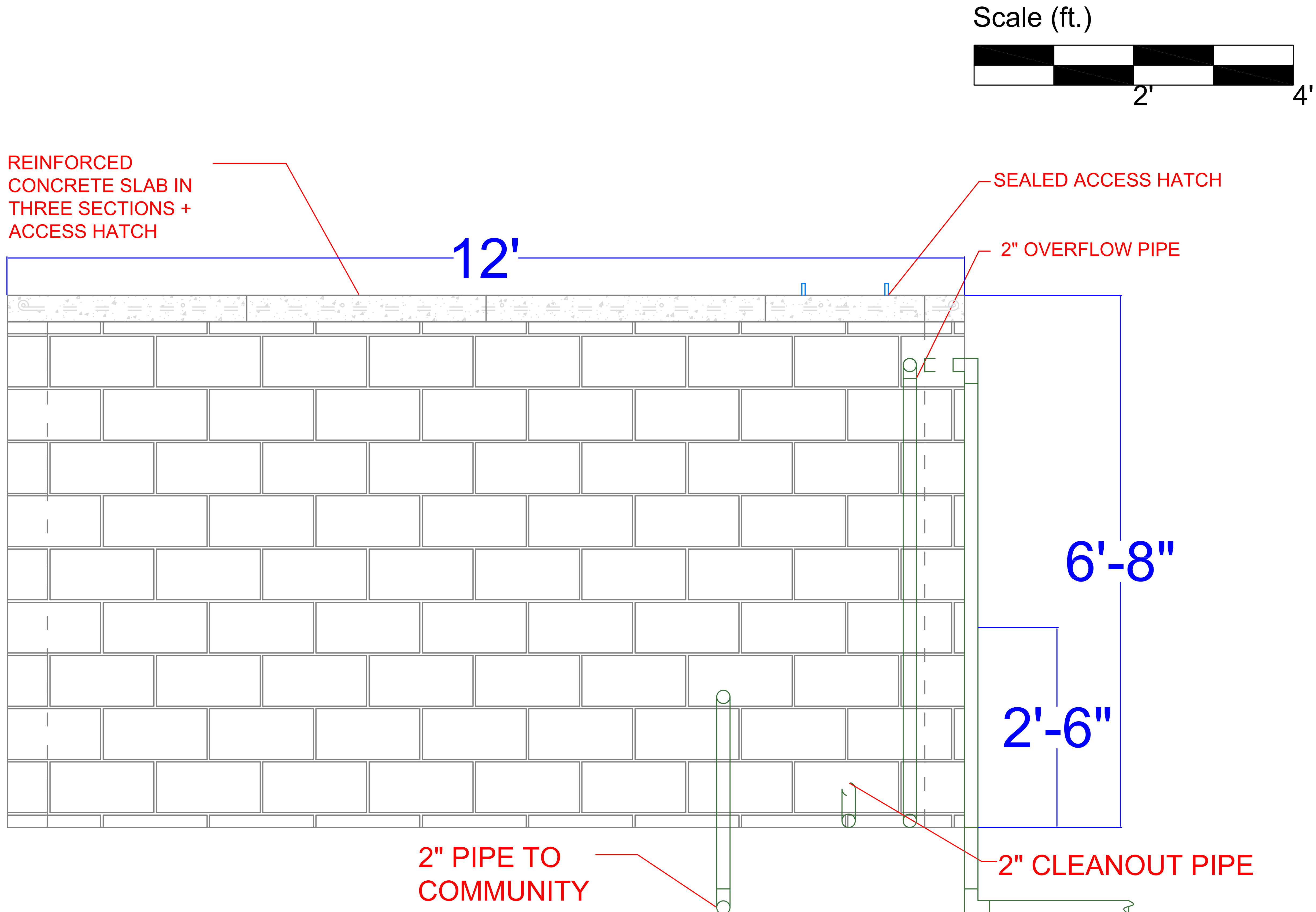
1- Check valve required

Date: 2 Dec 2009

Dwg No: 2

Dwg Name:
Tank - Plan View

Project: Punta Sirain Water Distribution System



Section B-B

General Notes:

Roof will be constructed in four sections for ease in construction.

All joints and gaps must be sealed.

Bury pipe at least 12' under ground level.

Install check valve in overflow pipe.

Access hatch needs to be resealed every time that it is opened.

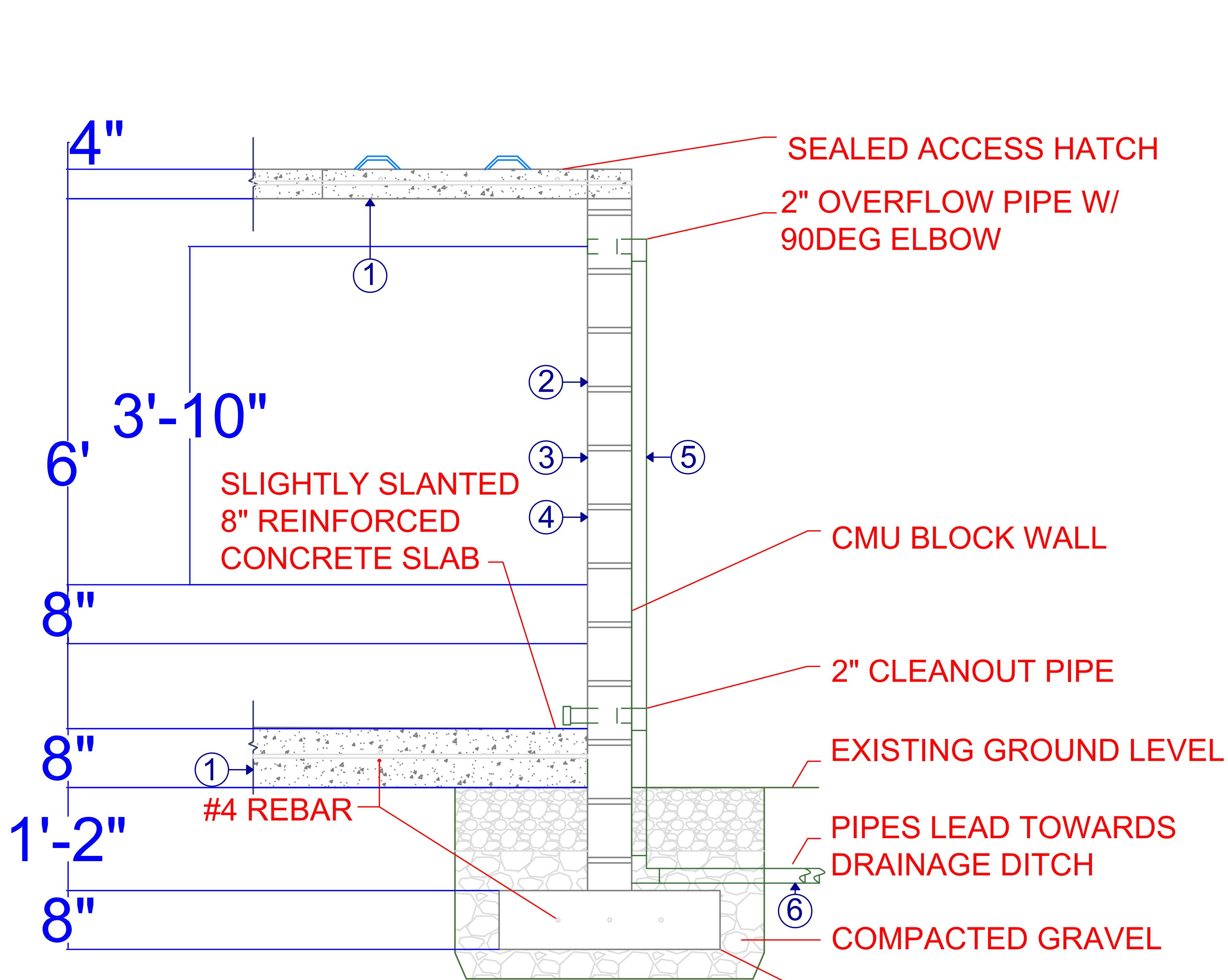
Bä Noire Designs

Date: 18 Nov 2009

Dwg No: 3

Dwg Name: Tank - Elevation

Project: Punta Sirain Water Distribution System



Section A-A

Notes:

1. #4 Rebar in roof and floor slabs spaced 24" oc
2. #4 vertical Rebar in CMU block wall spaced 8" oc
3. 9 gage ladder style reinforcing wire at 16" oc vertically
4. Rapear (Panamanian technique to seal with mortar) inner surfaces to seal
5. All pipes are 2" PVC SDR26
6. Drainage ditch located downhill from footing

General Notes:

Bury overflow and cleonout pipes 12" and direct at least 12' from foundation in gravel ditch.

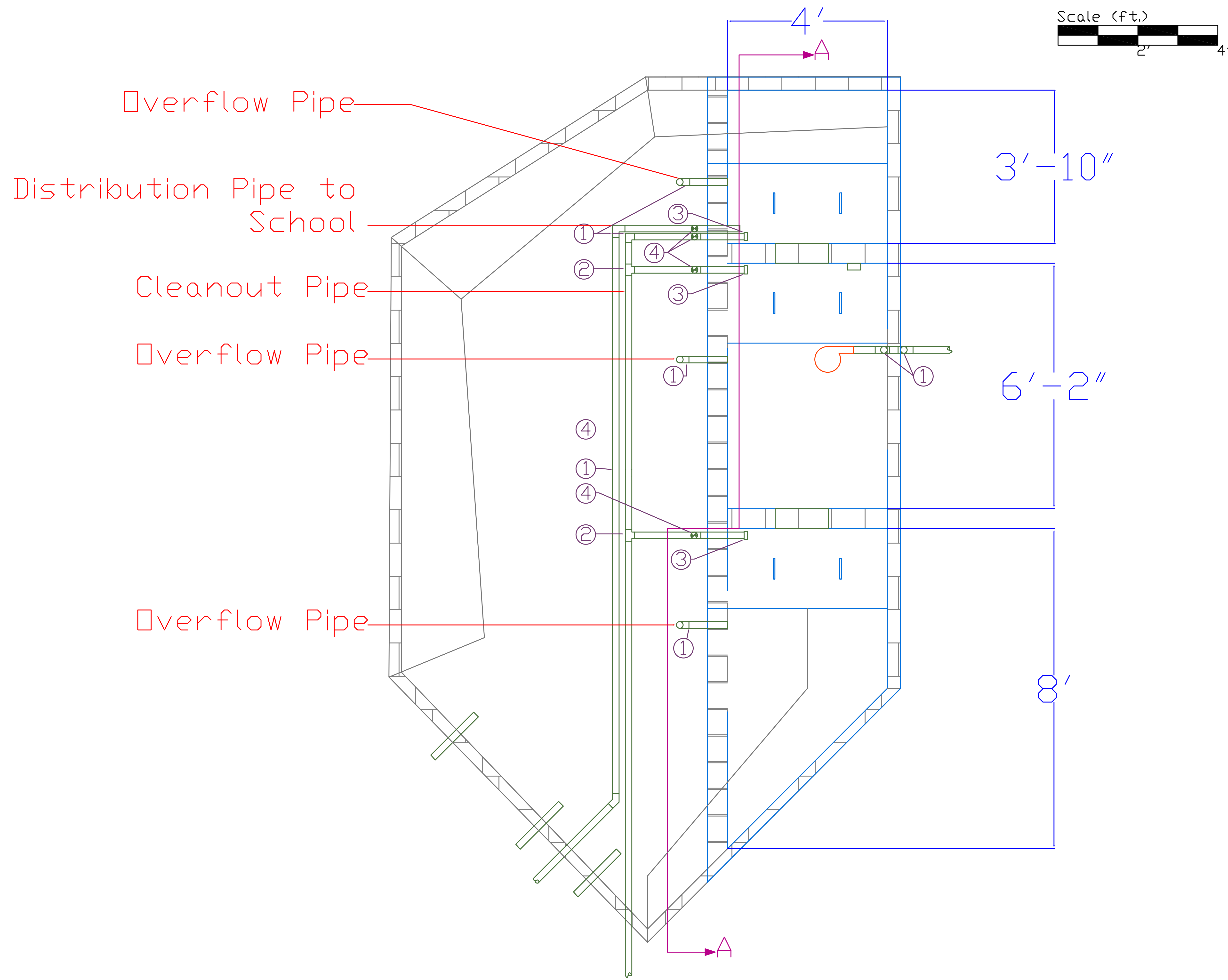
4 - 2" PVC elbows shown

Date: 18 Nov 2009

Dwg No: 4

Dwg Name: Tank - Profile

Project: Punta Sirain Water Distribution System



General Notes:

1 = 2" Elbow
2 = 2" Tee
3 = 2" Pipe Cap
4 = Gate Valve

Connections and valves needed:

15 - 2" Elbows
2 - 2" Tees
3 - 2" Caps
4 - Gate Valves

Each of the three boxes has a cleanout pipeand overflow pipe.

Cleanout pipes will exit outside of toma into the existing swamp.

Access hatches are 2' x 4'.

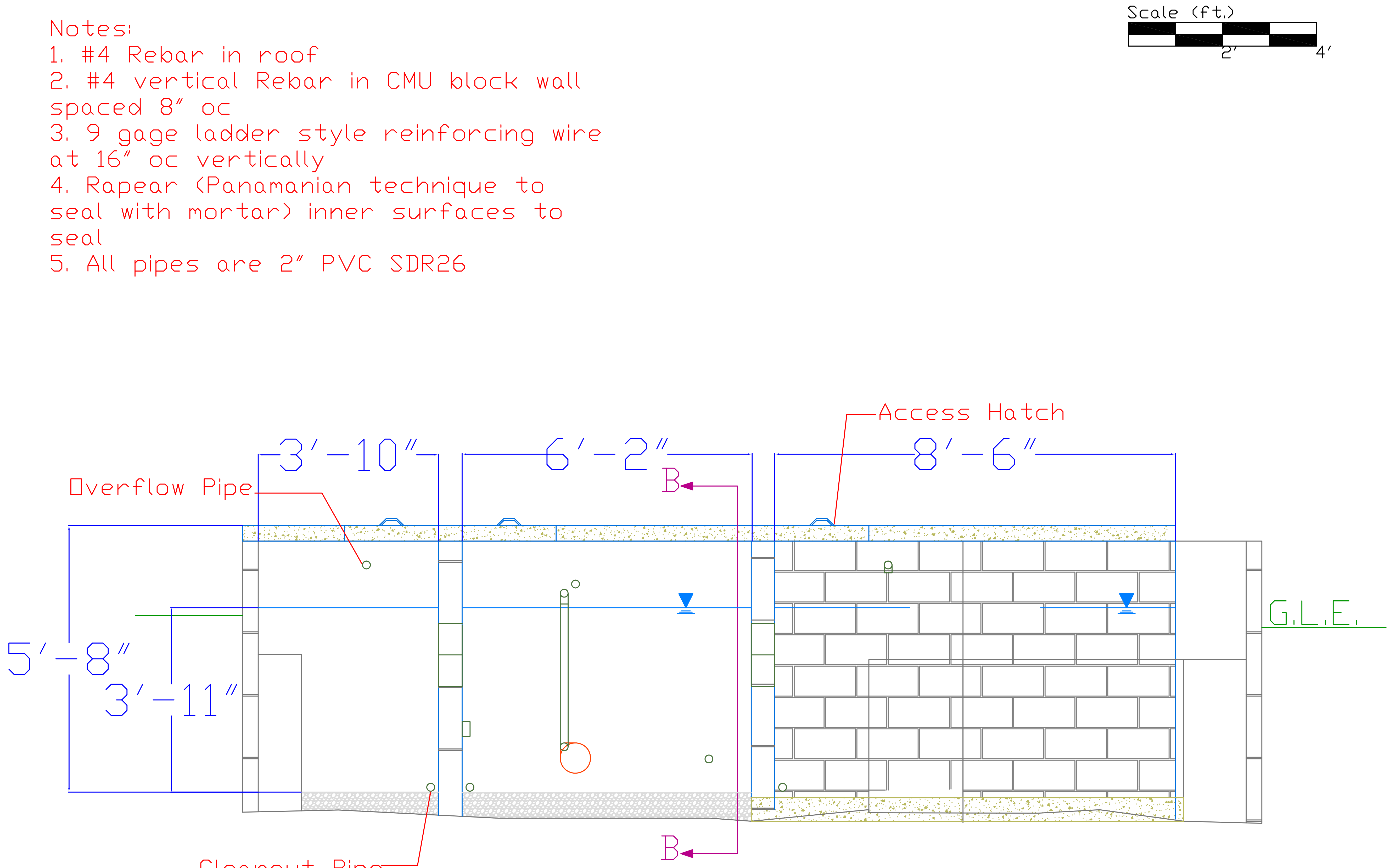
Date: 2 Dec 2009

Dwg No: 5

Dwg Name: Toma Plan View

Project: Punta Sirain Water Distribution System

Notes:
1. #4 Rebar in roof
2. #4 vertical Rebar in CMU block wall spaced 8" oc
3. 9 gage ladder style reinforcing wire at 16" oc vertically
4. Rapear (Panamanian technique to seal with mortar) inner surfaces to seal
5. All pipes are 2" PVC SDR26



Section A-A

General Notes:

CMU Concrete blocks lined with mortar to seal and prevent leaks

Add gravel as needed and grade towards the cleanout pipes

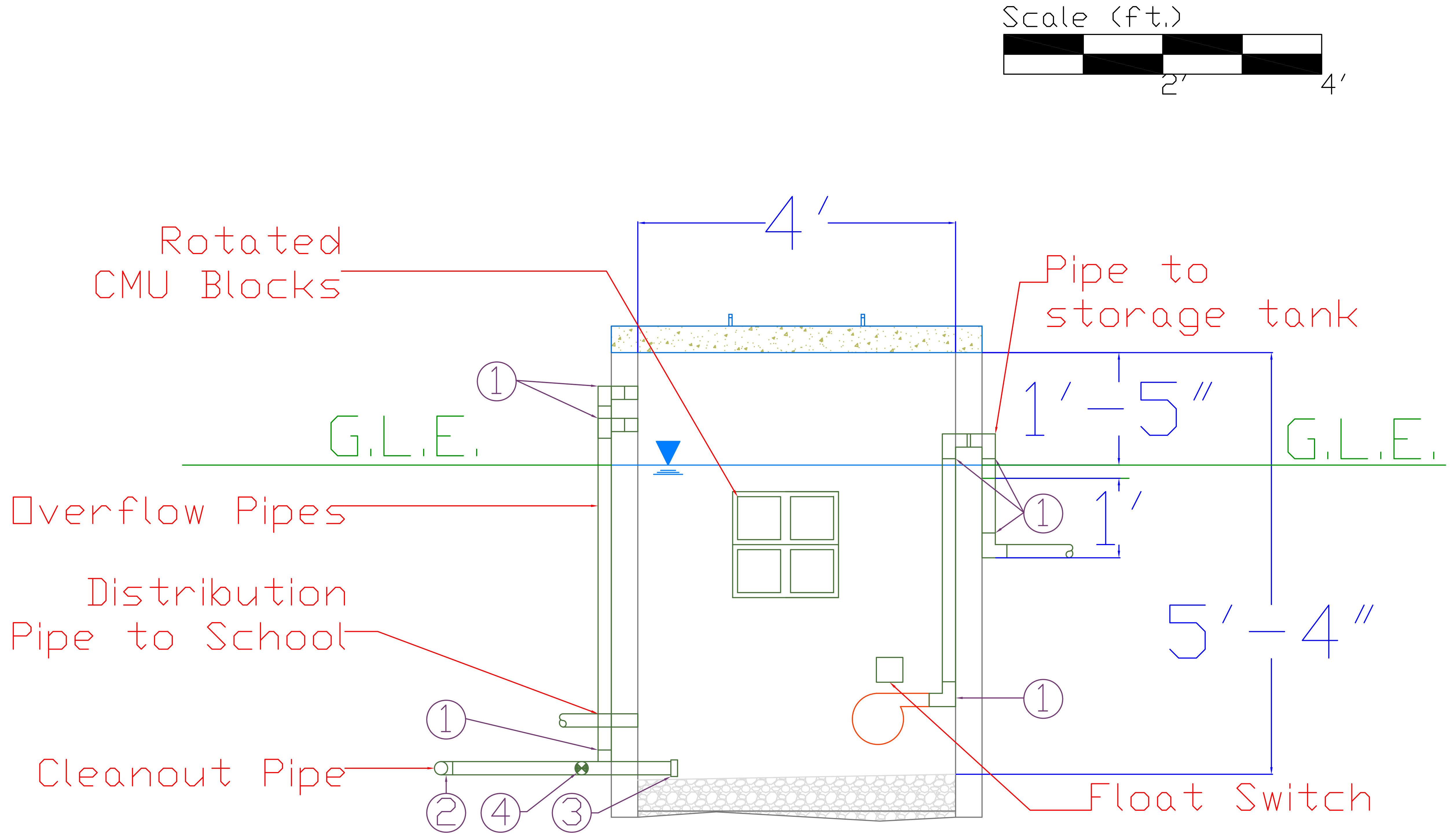
Form and pour concrete 6" base to have level surface for CMU blocks

Date: 2 Dec 2009

Dwg No: 6

Dwg Name: Toma Profile

Project: Punta Sirain Water Distribution System



Section B-B

General Notes:

Water overflows from each springbox chamber into the pump chamber by rotating two CMU blocks. Water will flow through the openings in the blocks.

Date: 2 Dec 2009

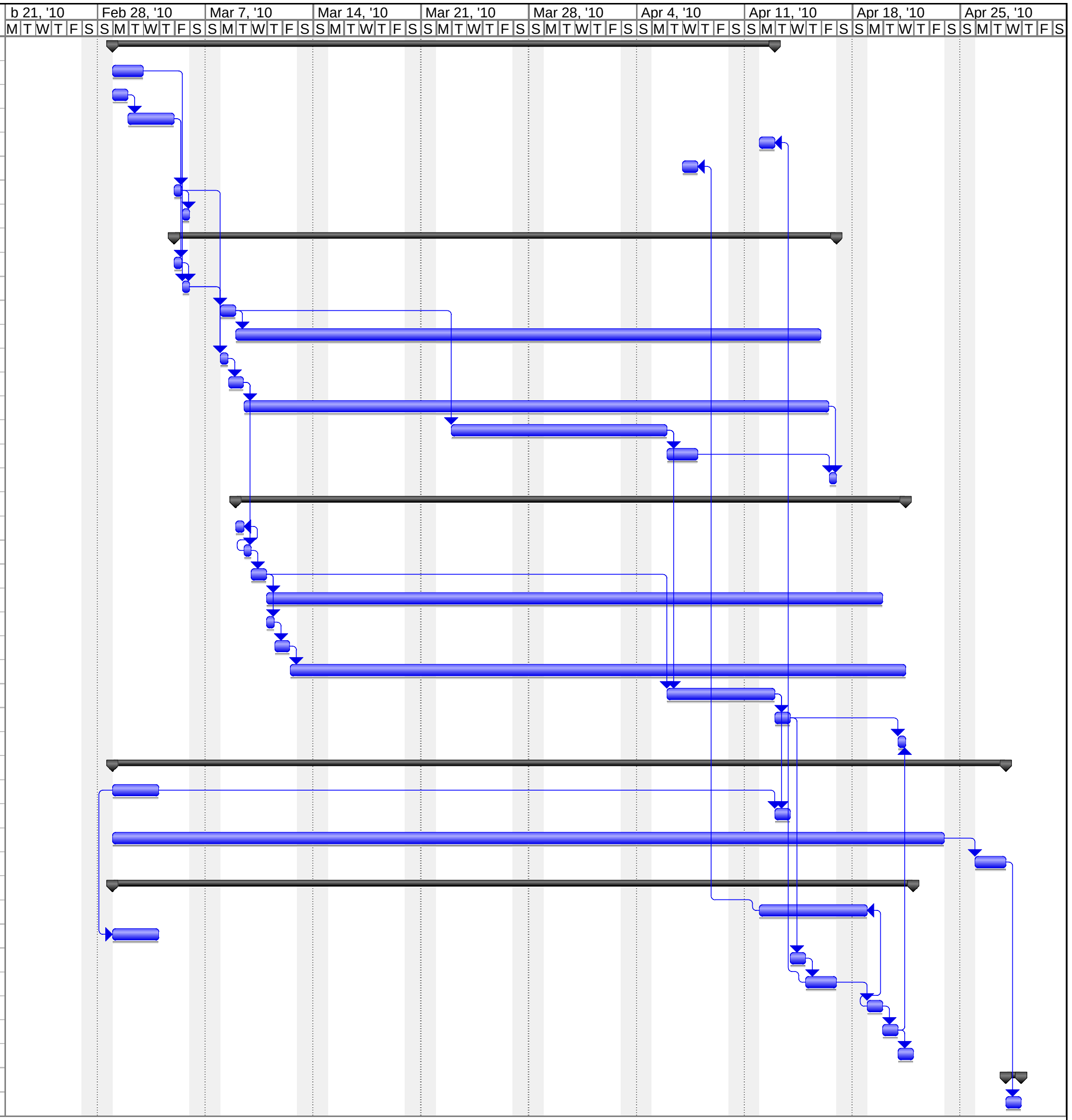
Dwg No: 7

Dwg Name: Toma - Pump Chamber Prof.

Project: Punta Sirain Water Distribution System

10.5 Appendix E: Construction schedule

ID		Task Name	Duration	Start	Finish	Predecessors
1		**Site Preparation**	**31 days**	**Mon 3/1/10**	**Tue 4/13/10**	
2		Cut lumber for forms	2 days	Mon 3/1/10	Tue 3/2/10	
3		Clear storage tank area	1 day	Mon 3/1/10	Mon 3/1/10	
4		Excavate site for storage tank	3 days	Tue 3/2/10	Thu 3/4/10	3
5		Clear solar panel area	1 day	Mon 4/12/10	Tue 4/13/10	40SF-2 days
6		Clear area for electrical storage shelter	1 day	Wed 4/7/10	Thu 4/8/10	37SF-2 days
7		Select and clear area for storage tank roof slab pour	0.5 days	Fri 3/5/10	Fri 3/5/10	4
8		Select and clear area for toma roof slab pour	0.5 days	Fri 3/5/10	Fri 3/5/10	7
9		**Storage Tank Construction**	**31 days**	**Fri 3/5/10**	**Fri 4/16/10**	
10		Put down gravel bed below tank	0.5 days	Fri 3/5/10	Fri 3/5/10	4
11		Put forms and steel in place for floor slab and foundation	0.5 days	Fri 3/5/10	Fri 3/5/10	10,2
12		Pour floor slab and foundation	1 day	Mon 3/8/10	Mon 3/8/10	11
13		Cure concrete	28 days	Tue 3/9/10	Thu 4/15/10	12
14		Put forms and steel in place for roof slabs	0.5 days	Mon 3/8/10	Mon 3/8/10	11,7
15		Pour roof slabs	1 day	Mon 3/8/10	Tue 3/9/10	14
16		Cure concrete	28 days	Tue 3/9/10	Fri 4/16/10	15
17		Build tank walls	10 days	Tue 3/23/10	Mon 4/5/10	12FS+10 days
18		Seal walls and floor	2 days	Tue 4/6/10	Wed 4/7/10	17
19		Place tank roof sections	0.5 days	Fri 4/16/10	Fri 4/16/10	18,16
20		**Toma Construction**	**31.5 days**	**Tue 3/9/10**	**Wed 4/21/10**	
21		Drain, clean and prep toma	0.5 days	Tue 3/9/10	Tue 3/9/10	22SF
22		Put forms and steel in place for foundation	0.5 days	Tue 3/9/10	Tue 3/9/10	15
23		Pour foundation	1 day	Wed 3/10/10	Wed 3/10/10	22
24		Cure concrete	28 days	Thu 3/11/10	Mon 4/19/10	23
25		Put forms and steel in place for roof slabs	0.5 days	Thu 3/11/10	Thu 3/11/10	23
26		Pour roof slabs	1 day	Thu 3/11/10	Fri 3/12/10	25
27		Cure concrete	28 days	Fri 3/12/10	Wed 4/21/10	26
28		Build new toma walls	5 days	Tue 4/6/10	Mon 4/12/10	23FS+10 days,17
29		Seal walls	1 day	Tue 4/13/10	Tue 4/13/10	28
30		Place toma roof sections	0.5 days	Wed 4/21/10	Wed 4/21/10	29,42
31		**Pipe Installation**	**42 days**	**Mon 3/1/10**	**Tue 4/27/10**	
32		Lay pipe between tank and toma	3 days	Mon 3/1/10	Wed 3/3/10	
33		Connect pipe between tank and toma	1 day	Tue 4/13/10	Tue 4/13/10	32,28
34		Lay pipe for new network	40 days	Mon 3/1/10	Fri 4/23/10	
35		Connect network to storage tank	2 days	Mon 4/26/10	Tue 4/27/10	34
36		**Solar Power System and Pump Installation**	**38 days**	**Mon 3/1/10**	**Wed 4/21/10**	
37		Build electrical storage shelter	5 days	Mon 4/12/10	Mon 4/19/10	41SF
38		Lay conduit	3 days	Mon 3/1/10	Wed 3/3/10	32SS
39		Build pump stand	1 day	Wed 4/14/10	Wed 4/14/10	29
40		Install pump	2 days	Thu 4/15/10	Fri 4/16/10	39
41		Install solar panel	1 day	Mon 4/19/10	Mon 4/19/10	40
42		Install control components	1 day	Tue 4/20/10	Tue 4/20/10	41
43		Connect all electrical components	1 day	Wed 4/21/10	Wed 4/21/10	42
44		**Project Closeout**	**1 day**	**Wed 4/28/10**	**Wed 4/28/10**	
45		Final inspection of system	1 day	Wed 4/28/10	Wed 4/28/10	35



Project: Construction Schedule
Date: Fri 12/4/09

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

10.6 Appendix F: Cost estimate

Cost Estimate - Design Option Summary

Summary "Linear System" - Recommended Design	
	Cost
Distribution System - Linear Option	$ 3,800
Toma and Tank Materials	$ 2,400
Solar Power System Pricing	$ 8,600
Shipping from David to Chiriqui Grande	$ 500
Total:	**$ 15,300**

Summary "Grid System" - Alternative Design	
	Cost
Distribution System - Grid Option	$ 4,900
Toma and Tank Materials	$ 2,400
Solar Power System Pricing	$ 8,600
Shipping from David to Chiriqui Grande	$ 500
Total:	**$ 16,400**

Summary "Existing Plus System" - Alternative Design	
	Cost
Distribution System - Existing Plus	$ 500
Toma Materials	$ 1,900
Shipping from David to Chiriqui Grande	$ 500
Total:	**$ 2,900**

Cost Estimate - Detailed Breakdown

Punta Sirain Gravity-fed Distribution System, Linear Option					
Item	Amount	Unit	Unit Cost	Total Cost	Notes:
Distribution Piping					
1" SDR 26 PVC Pipe	303	20 Feet	$ 4.25	$ 1,287.75	EPANET: 5754 ft; 5% extra added
2" SDR 26 PVC Pipe	148	20 Feet	$ 6.50	$ 962.00	EPANET: 2797 ft; 5% extra added
2" -> 1" reducer	6	Each	$ 0.89	$ 5.34	
2" Tee	4	Each	$ 1.75	$ 7.00	
1" Tee	56	Each	$ 0.45	$ 25.20	
1" 90° Elbow	10	Each	$ 0.20	$ 2.00	
2" 90° Elbow	3	Each	$ 0.85	$ 2.55	
House Hook-ups					55 taps
Plastic Faucet	55	Each	$ 2.99	$ 164.45	
1" 90° Elbow	110	Each	$ 0.20	$ 22.00	
1" SDR 26 PVC Pipe	91	20 Feet	$ 4.25	$ 386.75	Assume 8 ft vertical to reach house plus
					25 ft lateral pipe; 55 taps
From Toma to Tank					
2" SDR 26 PVC Pipe	18	20 Feet	$ 6.50	$ 117.00	EPANET: 316 ft: 5% extra added
2" 90° Elbow	9	Each	$ 0.85	$ 7.65	
Metal Screen	1	Each	$ 2.55	$ 2.55	Assumes 1 screen can cover 4 overflows
#32 Hose Clamp	4	Each	$ 1.03	$ 4.12	2.5" max diameter, worm drive
					(price from www.msc.com)
2" PVC Cap	4	Each	$ 1.00	$ 4.00	
PVC Glue	7	Gallon	$ 6.20	$ 43.40	
0.5" SDR 13.5 PVC Pipe	32	20 Feet	$ 1.75	$ 56.00	597 ft from GPS data; 5% extra added
0.5" 90° Elbow	6	Each	$ 0.19	$ 1.14	
0.5" Tee	1	Each	$ 0.25	$ 0.25	
2" Metal Gate Valve	2	Each	$ 32.95	$ 65.90	
1" Metal Gate Valve	4	Each	$ 19.95	$ 79.80	
Skilled Labor	1	Person/Day	$ 10.00	$ 420.00	42 Days
Unskilled Labor	5	Person/Day	$ -	$ -	42 Days, volunteer labor
Boat Shipping	4	Roundtrip	$ 40.00	$ 160.00	
Total:				**$ 3,826.85**	

Cost Estimate - Detailed Breakdown

Punta Sirain Gravity-fed Distribution System, Grid Option					
Item	Amount	Unit	Unit Cost	Total Cost	Notes:
Distribution Piping					
1" SDR 26 PVC Pipe	543	20 Feet	$ 4.25	$ 2,307.75	EPANET: 10313 ft; 5% extra added
2" SDR 26 PVC Pipe	148	20 Feet	$ 6.50	$ 962.00	EPANET: 2797 ft; 5% extra added
2" -> 1" reducer	6	Each	$ 0.89	$ 5.34	
2" Tee	4	Each	$ 1.75	$ 7.00	
1" Tee	81	Each	$ 0.45	$ 36.45	
1" 90° Elbow	22	Each	$ 0.20	$ 4.40	
2" 90° Elbow	3	Each	$ 0.85	$ 2.55	
House Hook-ups					55 taps
Plastic Faucet	55	Each	$ 2.99	$ 164.45	
1" 90° Elbow	110	Each	$ 0.20	$ 22.00	
1" SDR 26 PVC Pipe	91	20 Feet	$ 4.25	$ 386.75	Assume 8 ft vertical to reach house plus
					25 ft lateral pipe; 55 taps
From Toma to Tank					
2" SDR 26 PVC Pipe	18	20 Feet	$ 6.50	$ 117.00	EPANET: 316 ft: 5% extra added
2" 90° Elbow	9	Each	$ 0.85	$ 7.65	
Metal Screen	1	Each	$ 2.55	$ 2.55	
#32 Hose Clamp	4	Each	$ 1.03	$ 4.12	2.5" max diameter, worm drive
2" PVC Cap	4	Each	$ 1.00	$ 4.00	
PVC Glue	9	Gallon	$ 6.20	$ 55.80	
0.5" SDR 13.5 PVC Pipe	32	20 Feet	$ 1.75	$ 56.00	597 ft from GPS data; 5% extra added
0.5" 90° Elbow	6	Each	$ 0.19	$ 1.14	
0.5" Tee	1	Each	$ 0.25	$ 0.25	
2" Metal Gate Valve	2	Each	$ 32.95	$ 65.90	
1" Metal Gate Valve	4	Each	$ 19.95	$ 79.80	
Skilled Labor	1	Person/Day	$ 10.00	$ 420.00	42 Days
Unskilled Labor	5	Person/Day	$ -	$ -	42 Days, volunteer labor
Boat Shipping	5	Roundtrip	$40.00	$200.00	
Total:				**$ 4,912.90**	

Cost Estimate - Detailed Breakdown

Toma and Tank Materials					
Item	Amount	Unit	Unit Cost	Total Cost	Notes:
Concrete Block	505	Each	$ 1.31	$ 661.55	
Cement	97	Each	$ 7.80	$ 756.60	assumed that bags listed in David prices are standard bags of cement
Sand	8	CY		$ -	assume that this is available on-site
Aggregate	12	CY		$ -	assume that this is available on-site
Horizontal Reinforcing	353	feet	$ 0.21	$ 74.13	
#4 Reinforcing Steel	30	30' length	$ 1.90	$ 57.00	
Cement Sealant	12	gallon	$ 6.20	$ 74.40	
Skilled Labor	2	Person/Day	$ 10.00	$ 560.00	28 Days
Unskilled Labor	5	Person/Day	$ -	$ -	28 Days, volunteer labor
Boat Shipping	5	Roundtrip	$40.00	$200.00	
Total				**$2,383.68**	

Solar Power System Pricing					
Item	Amount	Unit	Unit Price	Total Cost	Notes:
Batteries	4	Each	$ 178.00	$ 712.00	MK/8A27
Solar Panels	8	Each	$ 532.00	$ 4,256.00	Evergreen Solar/ES-A-200-fa3
Pump	1	Each	$ 1,795.00	$ 1,795.00	Grundfos/P-SQ Flex 11 SQF-2
Charge Controller	1	Each	$ 120.00	$ 120.00	Xantrex/C40
Control Unit	1	Each	$ 320.00	$ 320.00	Grundfos/C200
Level Switch	1	Each	$ 36.00	$ 36.00	Grundfos
Interface Box	1	Each	$ 95.00	$ 95.00	Grundfos/IO 100
Intermodule Connectors					
Branch coupler (to make parallel)	1	Each	$ 19.00	$ 19.00	MC/M to 2F
Branch coupler (to make parallel)	1	Each	$ 19.00	$ 19.00	MC/F to 2M
Module to Control Box Connectors	2	Each	$ 35.00	$ 70.00	MC2/30' #10 AWG
Battery Interconnect Cable	3	Each	$ 12.00	$ 36.00	Sunwize/8'' cable , 2/0
Battery to Charge Controller	2	Each	$ 30.00	$ 60.00	5' #6 AWG cable
Pump Wiring Splice Kit	1	Each	$ 15.00	$ 15.00	Grundfos
Submersible Wire	10	ft.	$ 1.46	$ 14.60	Sun Pumps/#10 AWG
Wire from Controls to Pump	3	Each	$ 160.00	$ 480.00	USE-2/RHW-2 500' #10 AWG
Additional Wire for Float Switch		Each		$ 150.00	
Solar Panel Mount Kit		Each		$ 400.00	
Skilled Labor	1	Person/Day	$ 20.00	$ 560.00	10 Days
Unskilled Labor	1	Person/Day	$ -	$ -	10 Days, volunteer labor
Boat Shipping	1	Roundtrip	$40.00	$40.00	
Total				$ 8,597.60	

Cost Estimate - Detailed Breakdown

Punta Sirain Gravity-fed Distribution System, Existing Plus					
Item	Amount	Unit	Unit Cost	Total Cost	Notes:
Distribution Piping					
1" SDR 26 PVC Pipe	67	20 Feet	$ 4.25	$ 284.75	EPANET: 1274 ft; 5% extra added
1" 90° Elbow	6	Each	$ 0.20	$ 1.20	
Metal Faucet	1	Each	$ 4.59	$ 4.59	
Metal Screen	1	Each	$ 2.55	$ 2.55	Assumes 1 screen can cover 4 overflows
#32 Hose Clamp	4	Each	$ 1.03	$ 4.12	2.5" max diameter, worm drive
PVC Glue	1	Gallon	$ 6.20	$ 6.20	
1" Metal Gate Valve	2	Each	$ 19.95	$ 39.90	
Skilled Labor	1	Person/Day	$ 10.00	$ 150.00	15 Days
Unskilled Labor	5	Person/Day	$ -	$ -	15 Days, volunteer labor
Boat Shipping	1	Roundtrip	$40.00	$40.00	
Total:				**$ 533.31**	

Toma Materials					
Item	Amount	Unit	Unit Cost	Total Cost	Notes:
Concrete Block	505	ea	$ 1.31	$ 661.55	
Cement	97	ea	$ 7.80	$ 756.60	assumed that bags listed in David prices are standard bags of cement
Sand	8	CY		$ -	assume that this is available on-site
Aggregate	12	CY		$ -	assume that this is available on-site
Horizontal Reinforcing	353	feet	$ 0.21	$ 74.13	
#4 Reinforcing Steel	30	30' length	$ 1.90	$ 57.00	
Cement Sealant	12	gallon	$ 6.20	$ 74.40	
Skilled Labor	2	Person/Day	$ 10.00	$ 220.00	11 days
Unskilled Labor	5	Person/Day	$ -	$ -	11 days, volunteer labor
Shipping	2	Roundtrip	$ 40.00	$ 80.00	
Total				**$1,923.68**	

Solar Power System Pricing - Recommended Design

Component	Brand/Model	Price/Unit (or /ft)	# of units or ft	Total Cost
Batteries	MK/8A27	178	4	712
Solar Panels	Evergreen Solar/ES-A-200-fa3	532	8	4,256
Pump	Grundfos/P-SQ Flex 11 SQF-2	1,795	1	1,795
Charge Controller	Xantrex/C40	120	1	120
Control Unit	Grundfos/C200	320	1	320
Level Switch	Grundfos	36	1	36
Interface Box	Grundfos/IO 100	95	1	95
Intermodule Connectors				
Branch coupler (to make parallel)	MC/M to 2F	19	1	19
Branch coupler (to make parallel)	MC/F to 2M	19	1	19
Module to Control Box Connectors	MC2/30' #10 AWG	35	2	70
Battery Interconnect Cable	Sunwize/8'' cable , 2/0	12	3	36
Battery to Charge Controller	5' #6 AWG cable	30	2	60
Pump Wiring Splice Kit	Grundfos	15	1	15
Submersible Wire	Sun Pumps/#10 AWG	1	10	15
Wire from Controls to Pump	USE-2/RHW-2 500' #10 AWG	160	3	480
Additional Wire for Float Switch				150
Solar Panel Mount Kit		400	1	400
			Total:	**$ 8,598**

Solar Power System Pricing - Researched Options

Pump Requirements (48 Volts)			
Pump Rate (gpm)	**Power (Watts)**	**Amps (PV)**	**Ah (battery)**
9	325	16.4	77.3
8	280	15.9	66.6
7	250	16.2	59.5
Note: Battery Ah is determined based on ability to pump for 6 hours on battery power			

Solar System Battery Choices									
Brand	Model	Voltage	Ah	Discharge Rate	Price/Unit ($)	Pump Rate	# of batteries	Battery Cost ($)	Source
Universal	UB30H	12	97	20	240	9	4	960	mrsolar.com
						8	4	960	
						7	4	960	
MK	8A27	12	92	20	181	9	4	724	mrsolar.com
						8	4	724	
						7	4	724	
Universal	UB27	12	86	20	210	9	4	840	mrsolar.com
						8	4	840	
						7	4	840	
MK	8A24	12	79	20	178	9	4	712	mrsolar.com
						8	4	712	
						7	4	712	
Sun Xtender	PVX-890T	12	79	8	238	9	4	952	mrsolar.com
						8	4	952	
						7	4	952	
Universal	UB24	12	73	20	185	9	8	1,480	mrsolar.com
						8	4	740	
						7	4	740	
Sun Xtender	PVX-690T	12	60	8	192	9	8	1,536	mrsolar.com
						8	8	1,536	
						7	4	768	
MK	8A22NF	12	55	20	141	9	8	1,128	mrsolar.com
						8	8	1,128	
						7	8	1,128	
Sun Xtender	PVX-560T	12	49	8	184	9	8	1,472	mrsolar.com
						8	8	1,472	
						7	8	1,472	
Sun Xtender	PVX-490T	12	43	8	163	9	8	1,304	mrsolar.com
						8	8	1,304	
						7	8	1,304	
							Minimum Cost: $	712	

Solar Power System Pricing - Researched Options

Photo Voltaic Panel Choices								
Brand	Model	Voltage	Current	Maximum Power	Price/Panel	# of panels	Array Cost ($)	Source
Evergreen Solar	ES-A-200-fa3	12	11.05	200	532	8	4,256	altestore.com
Kyocera	KD 135GX-LPU	12	7.63	135	435	12	5,220	altestore.com
BP Solar	SX 3140J	12	8	140	660	12	7,920	mrsolar.com
Kyocera	KC 130TM	12	7.39	130	470	12	5,640	affordable-solar.com
BP Solar	BP375J	12	4.35	75	390	16	6,240	mrsolar.com
BP Solar	SX-3190B	16	7.82	190	606	9	5,454	affordable-solar.com
Mitsubishi	PV-UD175MF5	16	7.32	175	558	9	5,022	affordable-solar.com
						Minimum Cost:	$ 4,256	

Solar System Control Electronics Choices				
Component	Brand	Model	Price	Source
Pump	Grundfos	P-SQ Flex 11 SQF-2	1,795	backwoodssolar.com
	Grundfos	P-SQ Flex 11 SQF-2	1,799	wholesalesolar.com
Control Unit	Grundfos	CU 200	320	backwoodssolar.com
	Grundfos	CU 200	444	wholesalesolar.com
Charge Controller	Xantrex	C40	143	solar4power.com
	Xantrex	C40	141	wholesalesolar.com
	Xantrex	C40	120	infinigi.com
Level Switch	Grundfos	for use w/ CU 200	36	wholesalesolar.com
Interface Box	Grundfos	IO 100	109	wholesalesolar.com
	Grundfos	IO 100	95	backwoodssolar.com
	Total Electronics Cost (Minimum):	$	2,366	

Cables and Wires for Minimum Cost Array/Batteries						
Component	Brand	Model	Price/Unit or ft	# of units or ft	Total Cost	Source
Intermodule Connectors						
Branch coupler (to make parallel)	MC	M to 2F	19	1	19	altestore.com
Branch coupler (to make parallel)	MC	F to 2M	19	1	19	altestore.com
Module to Control Box Connectors	MC2	30' #10 AWG	35	2	70	altestore.com
Battery Interconnect Cable	Sunwize	8'' cable , 2/0	12	3	36	altestore.com
Battery to Charge Controller		5' #6 AWG cable	30	2	60	mrsolar.com
Pump Wiring Splice Kit	Grundfos		15	1	15	wholesalesolar.com
Submersible Wire	Sun Pumps	#10 AWG	1	10	15	altestore.com
Wire from Controls to Pump		USE-2/RHW-2 500' #10 A	160	3	480	altestore.com
Additional Wire for Float Switch					150	
Solar Panel Mount Kit					400	altestore.com
				Total Wiring Cost:	$ 1,264	

Minimum Total Solar Pumping System Cost :	$	8,598

10.7 Appendix G: Cleaning guide

Toma and Storage Tank Cleaning Guide

To ensure proper function of the *toma* and storage tank, and to promote clean drinking water the following recommendations should be adhered to.

Clean each chamber every six months

1. Break seal on access hatch
2. Remove hatch and place in safe area
3. Drain water from chamber by opening gate valve or removing cap from drain pipe
4. Safely enter chamber and scrub walls and floor to remove excess grime and soil
5. Exit chamber and replace hatch
6. Reseal access hatch to ensure that debris and animals are prevented from entering chamber

Note: Check areas to which overflow pipes divert the water. Remove brush and debris to ensure that the water can effectively escape the *toma* and storage tank.

Chlorination of drinking water

Chlorination should take place in *toma* rather than storage tank, since the water provided to the school comes directly from the storage tank. To treat the water, a chlorination tablet should be placed in the north spring box every week. The overflow pipe can be used as a path for delivery by removing the screen and pushing the tablet through the pipe until it drops into the chamber.

Flash chlorination of system

Before operating new system flash chlorinate all chambers and pipes to ensure that the distribution system will provide clean drinking water once fully operational. To flash chlorinate, increase the chlorine concentration by adding either chlorine tablets or bleach to all chambers of the *toma*. Allow this highly chlorinated water to flow through the entire distribution system. All taps in the distribution system should be open to ensure treated water flushes through every tap. It is important to communicate to the entire community that the highly chlorinated water should not be consumed. Repeat process every year to ensure that contaminants do not build up throughout system.