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Potable Water For a Volcanic Community In Rural Guatemala

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SENIOR DESIGN PROJECT REPORT
PREPARED UNDER MY SUPERVISION BY

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ENTITLED

Potable Water For a Volcanic Community In Rural Guatemala

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

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IN
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POTABLE WATER FOR A VOLCANIC COMMUNITY IN RURAL GUATEMALA

By

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SENIOR DESIGN PROJECT REPORT

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Potable Water for a Volcanic Community In Guatemala

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ABSTRACT

The project, in partnership with Santa Clara University Frugal Innovation Hub and Instituto de Investigacion y Proyeccion sobre Ciencia y Tecnología (INCYT) at Universidad Rafael Landivar, aimed to provide Panimache II, a small volcanic Guatemalan community, with access to clean and affordable water. The team designed a water treatment plant and distribution system, consisting of a hydraulic flocculator, sedimentation basin, slow-sand filter, and chlorination chamber, to remove the high levels of ash and other suspended solids. Components of the project included analyzing water source and quality, availability of construction materials, and recommended construction to effectively design and implement the community's water treatment and distribution system. Due to restrictions caused by the COVID-19 pandemic, this project was theoretical and will only be considered for implementation when conditions permit.

Keywords: Civil Engineering, Water Resources Engineering, Water Filtration, Hydraulic Flocculator, Sedimentation Basin, Slow-sand Filter, Distribution System, Chlorination, Guatemala, Panimache II, Volcanic Ash, Volcan de Fuego, Economic Material Analysis

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1. Introduction

Guatemala, the most populous country in Central America, has the highest child mortality rate of Central American countries, largely due to the lack of access to clean drinking water (Centers for Disease Control and Prevention, 2021). According to UNICEF, only 44% of people in rural communities have access to basic water services (World Health Organization, 2017).

1.1 Project Location

Panimache II, located 85 km South-West of Guatemala City, is located in the Department of Chimaltenango and has a population of 55 families whose occupation focus is on agriculture and farming (Hernandez, 2003).

Figure 1: Panimache II Location Within Guatemala.

Crops cultivated in Panimache II include corn, beans, pacaya, guineo, and sugar cane that are subsequently consumed by the community or sold to neighboring communities. In addition to the community's agricultural landscape, the village is situated at the foot of Volcan de Fuego, one of Guatemala's most active volcanoes that experienced significant eruptions in 1974 and 2002, and over 62 eruptions in its documented history (Ramirez, 2011). There are 25,000 other individuals from 20 communities who also live near Volcan de Fuego, but at only seven km from the volcano's crater, Panimache II (**Figure 2).**

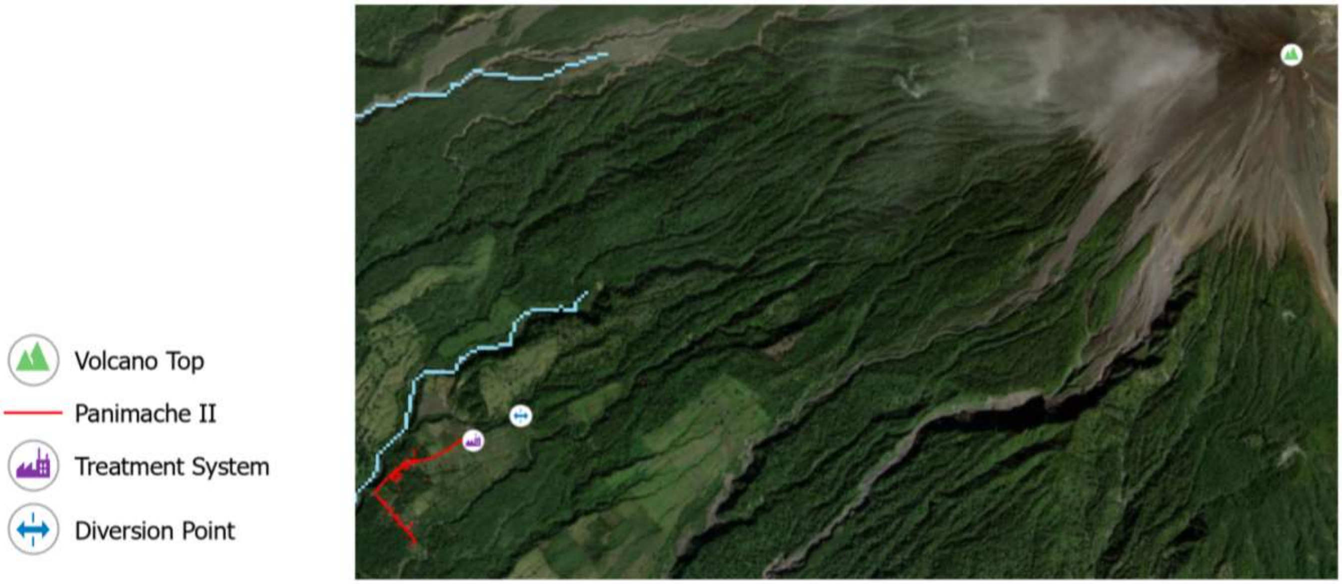


Figure 2: Panimache II Location Relative to Volcan de Fuego

The gases, such as carbon monoxide, sulfur dioxide, and hydrogen sulfide, and ash that are produced in the aftermath of the volcanic eruptions pose danger to the small town's agriculture-based economy, damage to the physical health of its inhabitants, and damage to their homes and water resources. Panimache II's close proximity to the volcano places it in a region where an estimated 30 centimeters (cm) of ash could accumulate after an eruption, as illustrated in Figure 3.

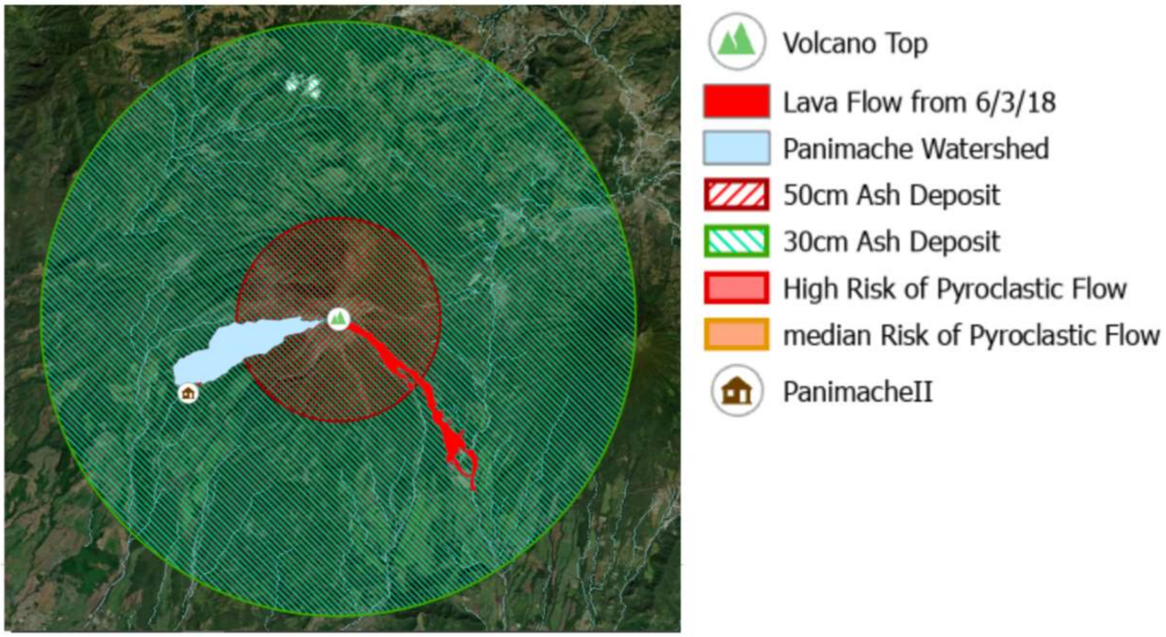


Figure 3: Panimache II Ash Fall from the Volcan De Fuego.

A survey conducted in 2011 found that 72% of the community members living in Panimache reported that they were afraid to live there (Ramirez, 2011). Aside from the dangers of the volcano destroying their homes, the contamination caused by the ash in their surface water has worried many. Families in Panimache II currently collect and use water from Rio Quixaya, as shown in Figure 4**.** Rio Quixaya originates from a natural spring and consistently provides water.

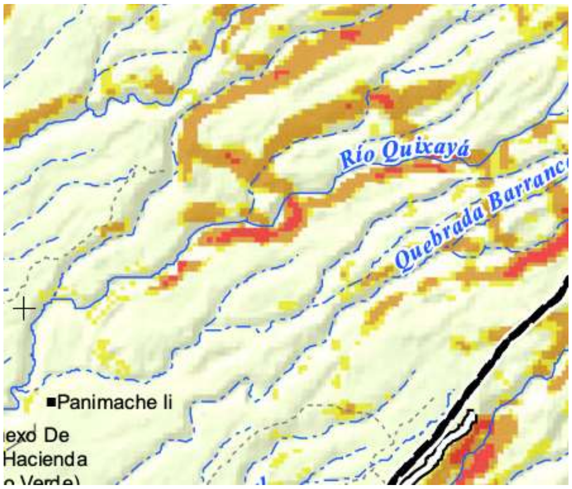


Figure 4: Panimache II's Water Source (Juarros, 2015).

1.2 Demonstrated Need for Project

Panimache II’s proximity and exposure to Volcan de Fuego make it vulnerable to ash falls after a volcanic eruption. According to Stewart et al. (2006), volcanic ashfall on natural waters can negatively affect turbidity, pH levels and concentrations of metals, leaving water non-potable. Many community members have expressed concerns to the community leaders regarding the ash and other contaminants emitted from the volcano in their drinking water supply (J. Mendez, personal communication, January 20, 2021). Data and anecdotal evidence suggest that there are high levels of suspended solids, contamination from the ash and algal growth in the river that is their drinking source. Although the community currently chlorinates the water, it does not completely remove the heavy metals and suspended solids from the water and runs the risk of creating disinfection byproducts that can be hazardous to the community members. The team’s goal was to meet the international potable water standards to produce and deliver reliable and clean water that also meets the aesthetic factors of taste, color, and odor.

2. Analysis of Alternatives

When determining possible solutions to resolve Panimache II’s ash-polluted water, the team considered four options: a community treatment and distribution system, household filters, a spring box at the water source, and trucking in water with an organization known as Agua Pura Salvavidas. Each alternative was rated on criteria such as efficiency, maintenance, ease of use, and durability, as outlined in the criteria column below. A scale from one to three was utilized, one being not meeting the criteria and three being it met or exceeded it.

Table 1: Alternative Evaluation Matrix.

	Score			
Criteria	**Community Treatment & Distribution System**	**Household Filters**	**Spring Box**	**Trucking in Water (Agua Pura Salvavidas)**
Safety (Water Quality)	3	2	1	3
Efficiency (Amount of clean water produced in certain time frame)	3	2	1	2
Maintenance	2	1	2	2
Ease of Use	3	2	2	3
Accessibility	3	3	1	1
Economical	2	1	3	1
Durability	3	1	2	1
Material Availability	2	1	2	1
Total	21	13	14	14

1=does not meet criteria, 2= meet criteria less well, 3= Meets or exceeds criterion

Using the alternative evaluation matrix to sum the ratings of each category, the design team concluded that the community treatment and distribution system would be the best solution for the community of Panimache II. However, the team acknowledges that the community's preference, with regard to the criteria included and the weighting of different criteria, is unaccounted for due to the virtual environment and the inability to facilitate community surveys.

3. Data Collected by Partner Organization

The challenges of working with an international partner amidst the Global COVID-19 pandemic were numerous and included receiving insufficient data about the project site. With COVID-19 traveling restrictions, the SCU student team was unable to conduct or receive any water quality assessments and the INCYT team's travel to the site was also limited. Therefore, the design was limited and based on anecdotal evidence. The anecdotal evidence provided by INCYT originated from their communication with Panimache II community leaders, but not the community residents themselves. However, INCYT representatives were able to provide the team with two reports that included the water's pH, water temperature, and map coordinates of important locations.

Figure 5: Panimache II water samples taken by José Luis Méndez on January 20th 2021.

The four water samples used for pH measurements (Figure 5) were taken from two different water sources from the same river. The pH levels ranged from 6.28 to 6.87 with a temperature of approximately 20 degrees C. Map coordinates of their existing water storage tank, Water Pond A and Water Pond B, were provided to help the team understand their existing water infrastructure.

4. Design Criteria

According to the U.S. Army Corps of Engineers, "Guatemala has an abundance of water, with 18 major rivers originating in the volcanic highlands and adequate rainfall; however, proper management to develop and maintain the water supply requirements is lacking, (2000)." Guatemala currently lacks enforceable water standards, leading many communities to consume unsafe drinking water. Therefore, to create a water treatment system that provides sufficiently safe and clean water to the community of Panimache II, the World Health Organization (WHO) and United States Environmental Protection Agency (US EPA) water quality standards were used.

The team used the WHO water quality standards for total dissolved solids, turbidity, and pH levels. Values for each requirement are in Table 2. The US EPA guidelines for disinfection of giardia were used. Giardia was chosen to be the baseline for disinfection because a 4-log inactivation, or 99.99% disinfection, of giardia will be sufficient in disinfecting most other pathogens.

Table 2: Water quality guidelines.

Parameter	Recommended Range	Source
Total Dissolved Solids	600 mg/l	WHO
Turbidity	4 NTU	WHO
pH	6.5 - 8.5	WHO
Giardia	4-log inactivation	EPA

5. Design Parameters of Selected Alternative

To improve Panimache II's current water quality and meet the World Health Organization's requirements for safe drinking potable water, the design team designed a water treatment and distribution system for the community. The system consists of a hydraulic flocculator, a sedimentation tank, a slow-sand filter, and a chlorination chamber within a clean water storage tank (**Figure 6)**.

The water treatment and distribution systems were designed to produce 96,250 Liter (L) of clean water per day to the approximate 300 individuals who live in Panimache II. This volume was calculated by referring to the standard water use per person and providing individuals with sufficient water for drinking, basic necessities, and recreational use. The water treatment system works on a three (3) hour operation period to the flow rate required by the hydraulic flocculator.

A distribution system was designed to deliver the clean water to each household. A description of the purpose of each component is given below:

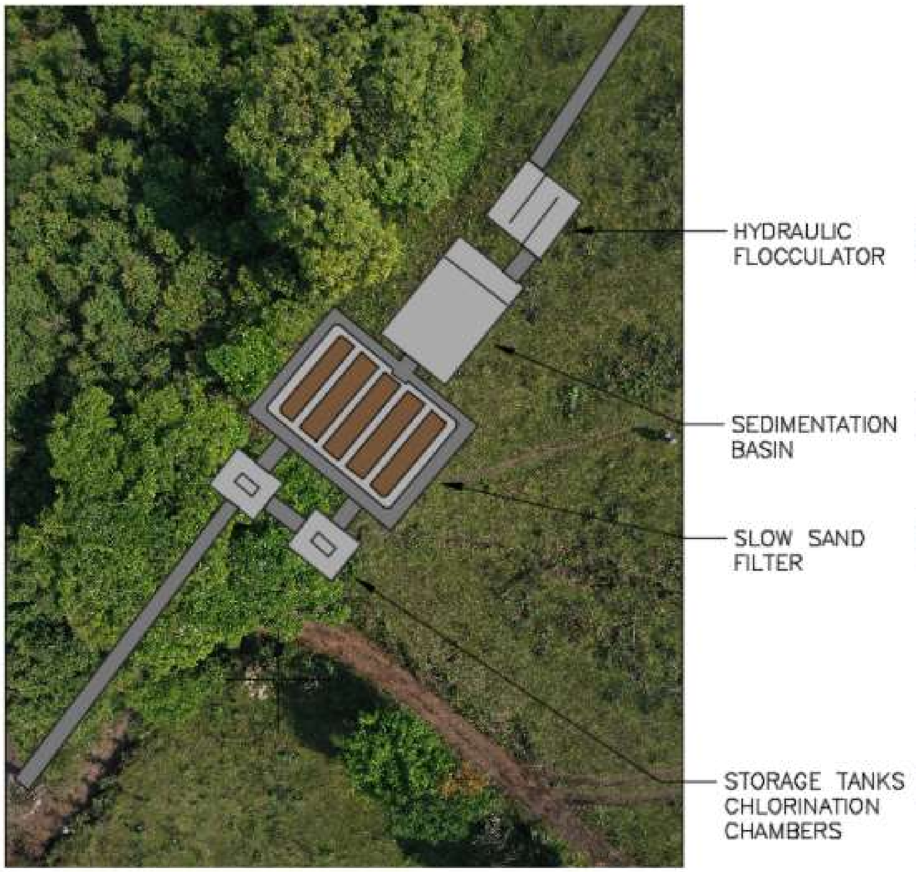


Figure 6: Water Treatment System Overview.

5.1 *Water Diversion*

The goal of the water diversion is to control the flow rate that enters the water treatment system. As the community had already diverted a portion of the river water into structures they call Water Ponds A and B, the design team chose to modify those structures in order to eliminate the cost of constructing another diversion. Water Pond A is where the water will be diverted from to be sent to the hydraulic flocculator. Water Pond A is located in the diversion in Figure 2 and shown in Figure 7.

Water Pond A is located further up the volcano and approximately 500 meters (m) from the next step in the treatment system. Using the Darcy-Weisbach equation, the design team determined that a difference in head of 47 m between Water Pond A and the hydraulic flocculator, and a pipe diameter of 65 millimeter (mm) was necessary to achieve a flow rate of 770 cubic meters per day (m^3/day). The entire system will operate for three hours every day and will require a trained member of the community to regulate the flow of water. A gate valve will be installed between Water Pond A and the hydraulic flocculator to achieve this goal. An important detail to note is that due to the topography of the area, the water diversion is gravity fed and does not require pumps or mechanical systems in order to operate.

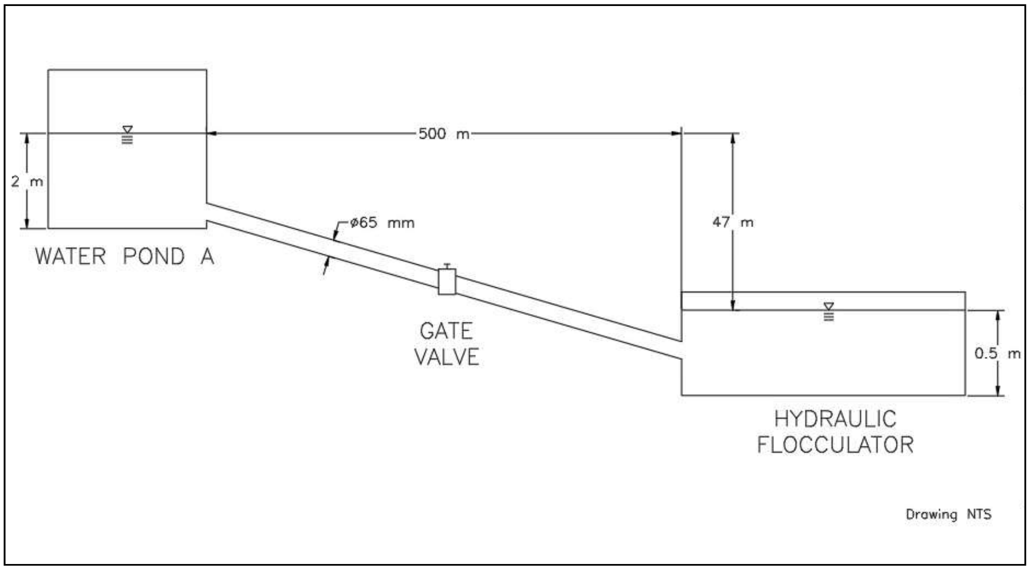


Figure 7: Side view of the water diversion (not to scale).

5.2 *Hydraulic Flocculator*

The purpose of the hydraulic flocculator, shown in Figure 8 is to provide the physical environment, such that the ash particles and other suspended solids can form large flocs that can be effectively removed. A chemical coagulant is added before water enters the flocculator to enhance floc formation. The flocs formed in the hydraulic flocculator are removed via settling in the sedimentation basin. The hydraulic flocculator was chosen in place of other flocculator designs, such as paddle or turbine flocculators, because Panimache II does not have reliable access to electricity. Other designs would require a power source to effectively flocculate the sediments in the water.

The hydraulic flocculator is a 4.62 m by 4.62 m structure with a height of 0.8 m and a water depth of 0.5 m. It was partitioned into three stages with baffles spaced 75 centimeters (cm) apart in the first and third stages and 88 cm in the second. The baffles were separated from the stage walls and the outside wall of the entire structure by a distance of 12 cm. The baffles were spaced in such a way as to allow the water to experience a residence time of 20 minutes and a cross-sectional area such that the water met the 1.5 meters per second (m/s) minimum velocity required for floc formation.

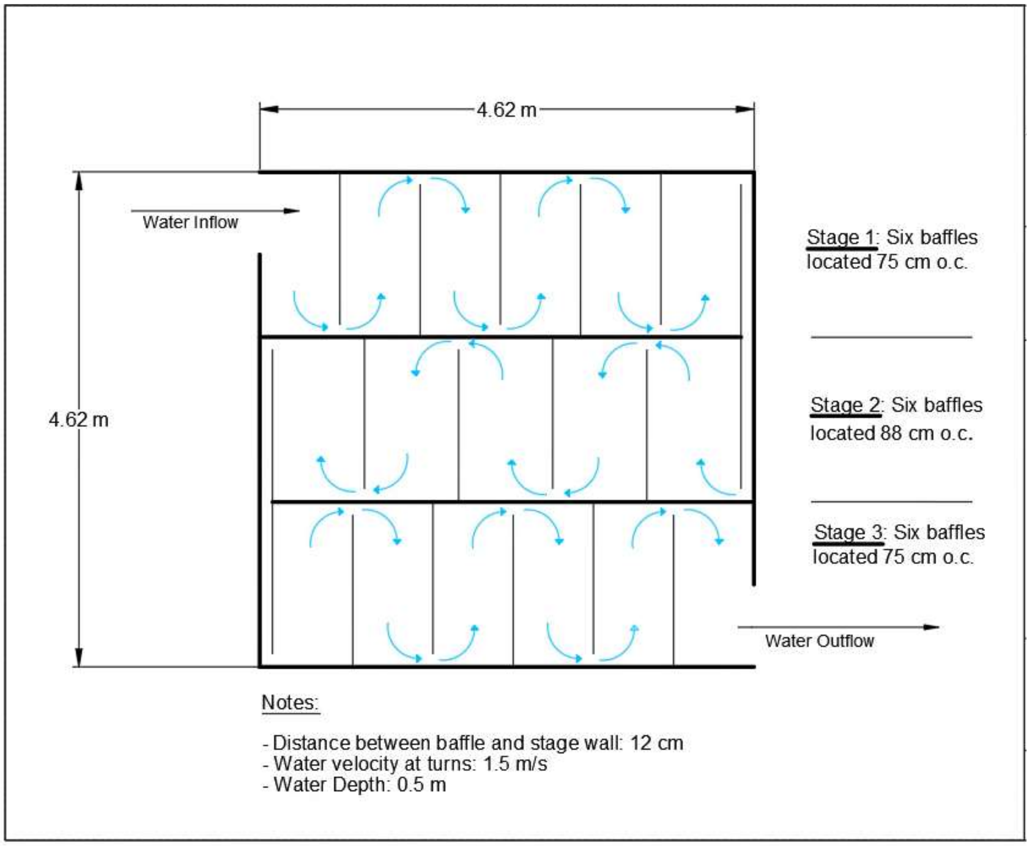


Figure 8: Top view of hydraulic flocculator.

The coagulant chosen for this design was aluminum sulfate (alum, $Al_2(SO_4)_3.14H_2O$). As the design team was unable to conduct jar tests to determine the optimal concentration of alum for the water in Panimache II, a concentration of 30 mg/L was chosen as it is within the optimum sweep range shown in **Figure 9**. The optimum sweep is a range within which alum can produce the most flocs with the smallest concentration possible. However, this is only an approximation and jar tests with local water provide more accurate results.

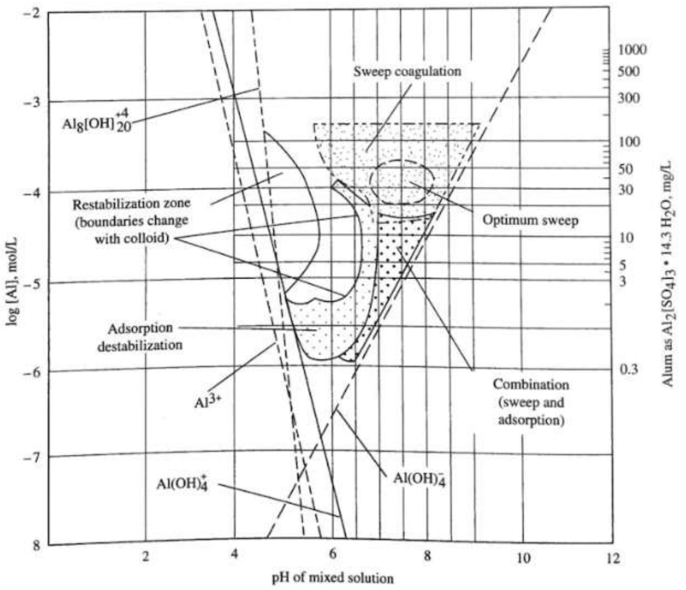


Figure 9: A graph showing the optimum sweep range of aluminum based coagulants (Davis, 2020).

5.3 *Sedimentation Basin*

Due to the high turbidity and suspended solids caused by the ashfall, the horizontal sedimentation basin (Figure 10) is used to settle the flocs formed in the hydraulic flocculator. The sedimentation basin was designed as a 2 by 3 by 12.4 meter rectangular tank with a perforated baffle to spread the flow across the inlet of the tank and prevent short circuiting (Zerihun, 2012). The perforated baffle, a 2 by 3.1 by 0.25 meter wall, is located at the basin's inlet zone, 0.5 meters from the inlet pipe. It contains a total of 28 holes that are 0.4 m apart from one another and are all 0.10 meters in diameter. These perforated baffle dimensions effectively control the incoming flow and follow the recommendations outlined in *Water and Wastewater Engineering* (Davis, 2020). Furthermore, the bottom of the tank, referred to as a 0.8 meter tall sludge zone, was designed with a 1:600 ratio slope to collect the sunk sediment particles. A sludge bucket would be regularly used to discard the accumulated sludge.

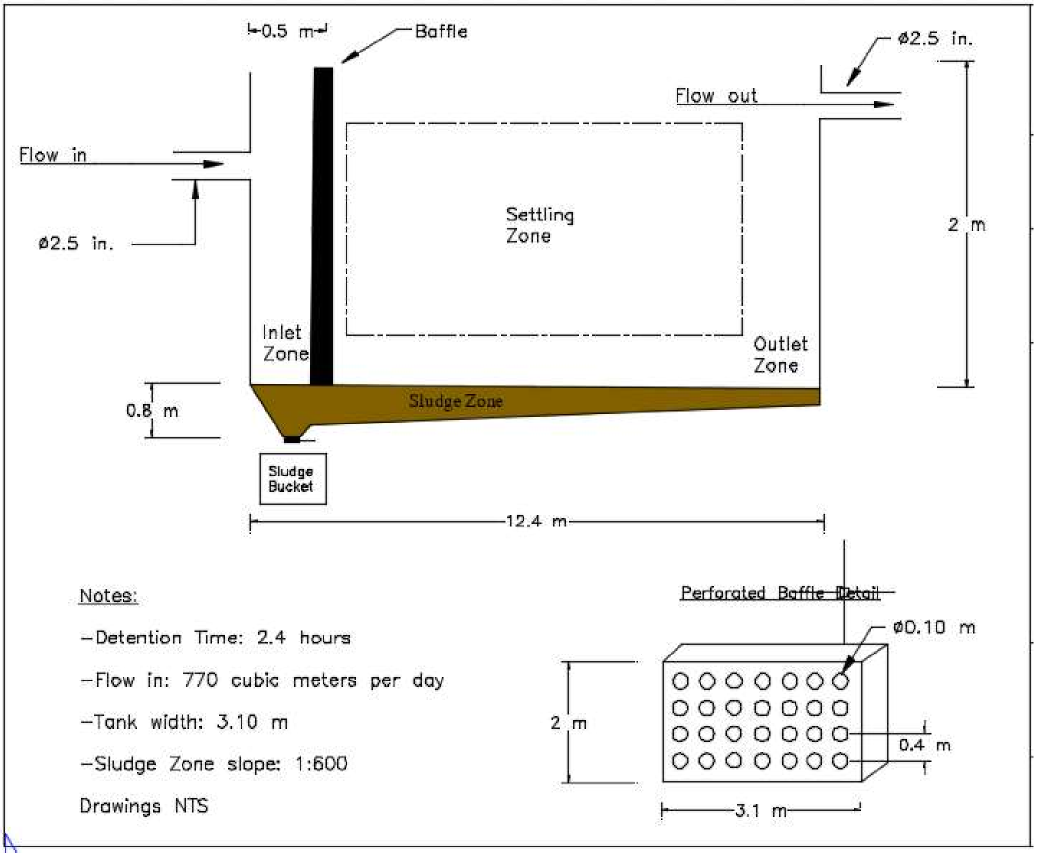


Figure 10: Side view of the sedimentation basin and related details.

Due to the system's three-hour operation time and an incoming flow rate of 770 m^3/day, the dimensions of the sedimentation basin were chosen to allow for a 2.4 hour detention time. The typical design criteria for small to medium horizontal-flow rectangular sedimentation basins is outlined in Table 10-5 in Appendix D. The overflow rate, which is equal to the settling velocity of the smallest particle that is completely removed in the sedimentation tank, was chosen to be 20 meters per day since it was below the 10,000 cubic meter per day flow criteria. The surface area and subsequent dimensions were calculated using the overall flow rate and the overflow rate.

5.4 *Slow-Sand Filter*

The slow-sand filter (Figure 11 and 12), which consists of layers of sand and gravel, follows the sedimentation basin to further remove the suspended solids that were not retained in the sedimentation basin. It has a total volume of 403 m^3, with a sand depth of 1 meter and a 0.3 meter depth of supporting 30 mm diameter gravel. The sand and gravel size specification, in regards to its effective size of 0.2 mm and uniformity coefficient of 2 (Heber, 1985). Its design was dictated by the hydraulic loading rate, which was determined to be 0.2 m/hr on average (Crittenden et. al, 2012).

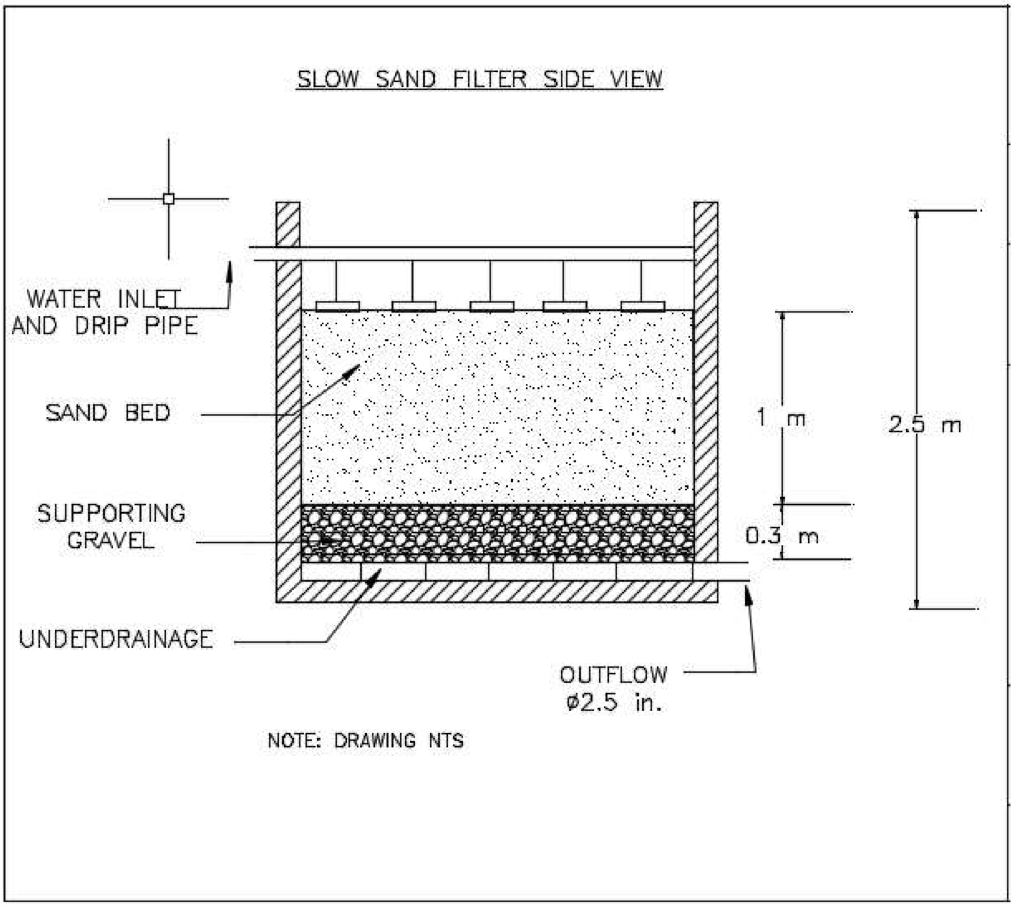


Figure 11: Side view of the slow-sand filter.

The filter bed area, which was determined by dividing the daily demand flow rate of 770 m^3/day by the hydraulic loading rate of 0.2 m/hr, was used to find the length, width, and height of the slow-sand filtration system.

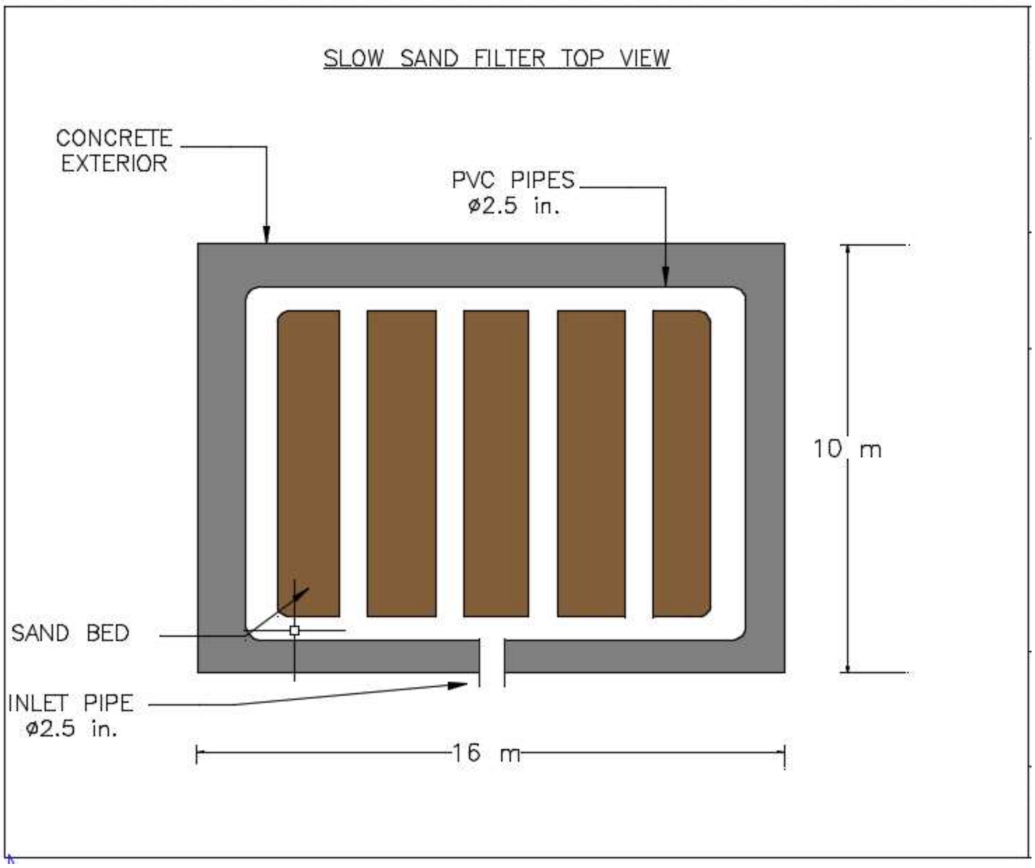


Figure 12: Top view of the slow-sand filter.

In addition, to ensure that water was uniformly distributed over the sand filter, six vertical and two horizontal 2.5 inch PVC pipes were added to act as a drip system. Impact pads were integrated to help disperse the water as well (Figure 13).

Figure 13: An example of a slow-sand filtration system.

5.5 *Chlorination Chamber and Storage Tank*

The storage tank (Figure 14), which is the last component in the treatment system, contains the filtered water that must be chlorinated before distribution to effectively disinfect the water of pathogenic organisms that were not removed in the previous steps.

Two tanks will be used to store the water delivered from the other treatment components. It should be noted that one of the tanks already exists on site and that the other will be constructed two meters away from the existing tank and will be connected by a 2.5 inch diameter pipe. The existing tank has a volume of 48 cubic meters (m^3) and the proposed tank will have a volume of 56 m^3 in order to hold the 96.3 m^3 volume of water that the treatment system will clean each day.

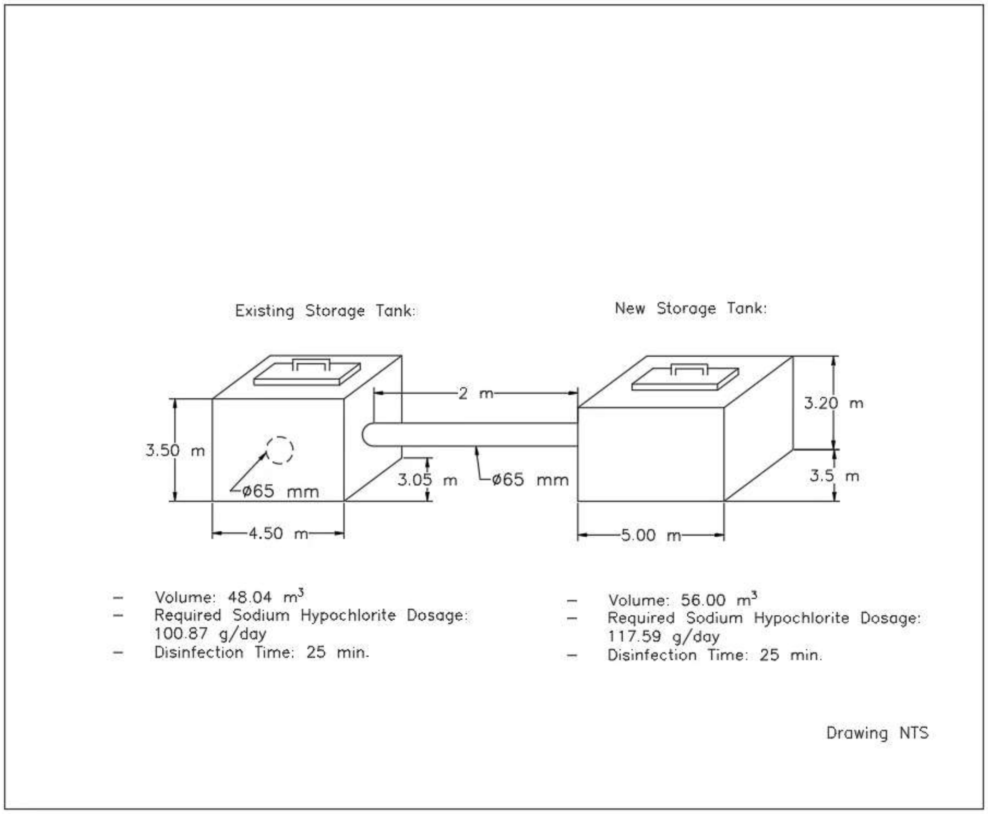


Figure 14: The existing and new storage tank design.

Chlorination will occur within each storage tank for a duration of at least 25 minutes for adequate disinfection of the drinking water. Calcium hypochlorite will be the disinfection chemical used within each tank and 209.8 grams will be injected each day within the 3-hour operation time; an amount of 96.9 grams calcium hypochlorite will be injected into the existing tank and 112.9 grams will be injected into the new tank. The injection of calcium hypochlorite will achieve a chlorine concentration of one (1) mg/L of water. As stated previously, one of the goals of the treatment system is to achieve a 4-log inactivation, or 99.99% disinfection, of giardia, and the chlorine concentration and the contact time that the team chose will accomplish that.

It should be noted that in the cost analysis, the design team incorporated the pricing for sodium hypochlorite as reference only, as the team was unable to find pricing for calcium hypochlorite in Guatemala. Calcium hypochlorite has the advantage of being available in solid form that can be easily transported to the site.

5.6 *Distribution System*

The distribution system controls the flow rate and the pressure at which the water reaches each household within the community. This process is executed by designing the pipe layout, dependent on the elevation of the water source as well as the households. No pumps were used throughout the entire distribution system, as the entire layout was gravity-fed. This was possible due to the 78 m difference in elevation between the start of the system at the storage tanks to the end of the system at the entrance to Panimache II.

All of the pipes were PVC with diameters of 0.5 in to 4 in and Hazen Williams roughness coefficient of 150, meaning it was assumed to be smooth on the inner diameter with minimal friction loss. Table C-1 in Appendix of *Water and Wastewater Engineering* book was referenced for Hazen-Williams coefficient value (Davis, 2020).

There were junctions placed at each house/building to indicate a faucet available at every household. Minimum pressure was set to 20 psi and maximum pressure was set to 72.5 psi. These pressure values were in line with 2019 California Plumbing Code on US requirement values.

Most pipe sizes used were Class DR 32.5 rated for 125psi; more detailed pipe breakdown is shown on Appendix page E 7. This pipe rating is more than adequate to serve the community while still taking into account the safety factor of 2 according to American Water Works Association Standard C900 (AWWA, 2017). When running the simulations through Darwin Designer on WaterGEMS to get the pipe sizing and prices, only a third of junctions were left active at a time to best simulate real-life water usage. An article on Neatworks, a free software for designing gravity-fed water distribution systems, recommended that around 30% of faucets be open per simulation (Babonneau). If all of the junctions were left on, that would suggest that every house would be using water at the same time, which is not realistic (Babonneau).

A starting flow of 770 m^3/day (0.00891m^3/s) was used as a starting flow at the first pipe, as calculated in flocculation design.

Software packages used for the distribution system design included AutoCAD, ArcGIS, WaterGEMS, and NeatWorks.

5.6.1 *AutoCAD*

AutoCAD was the software of choice to draw the community outline, as well as the main road that connected every household together.

5.6.2 *ArcGIS*

ArcGIS was used in identifying the elevation/topography of the community and the nearby areas. A Digital Elevation Model (DEM) from USGS's EarthExplorer was downloaded and converted into a raster, with each tile the size of 5x5 meters showing elevation. SRTM 1 arc-second DEM data with entity ID of SRTM1N14W091V3 was used. With the topography of the area identified, tools within ArcGIS, such as Flow Direction and Flow Accumulation, were used to determine the locations of streams within Panimache II. Information such as detailed stream data, watershed data, and other Geographic Information Systems (GIS) files were readily available for locations within the United States, but because the community was located in Guatemala, extra steps such as defining river locations using elevation data and their watershed were required. ArcGIS was further used to delineate the watershed serving the Panimache II community and its characteristics.

5.6.3 *WaterGEMS*

WaterGEMS (Bentley Software Package) was used in designing the pipe distribution/layout of the filtered water. Throughout the design no pumps were used as the community lacked a constant power source. This restricted the project to being purely gravity-fed, but the elevation difference throughout the community allowed for the project purely relying on gravity. Starting flow of 770 m^3/day (0.00891m^3/s) was used at the first pipe, as determined during the calculations for the hydraulic flocculator. Piping started at the storage tanks and ended at the entrance of the community (storage tanks are the northernmost point on Figure 15 and the entrance of the community is the southernmost point on Figure 15); between the two points the elevation difference was 78 m. There were junctions placed at each house in the community.

Polyvinyl chloride (PVC) pipes were chosen as the pipe material due to availability and affordability. A Hazen Williams coefficient of 150 for smooth pipes was used (Davis, 2020), meaning the pipe was assumed to be smooth to reduce friction and pressure. Pipe specifications were entered into Darwin Designer on WaterGEMS. Pipe diameters ranging from 0.5 in to 4 in, and a maximum operating pressure of 125 psi were used in the design. The minimum pressure at junctions was set to 20 psi, with the maximum pressure at 72.5 psi (140 kilopascal [kpa] to 500 kpa). According to the California Plumbing Code 2019 sections 608.1 and 608.2, water pressure cannot be below 15 psi and above 80 psi; these values are in line with the pressure values used as minimum and maximum for Darwin Designer.

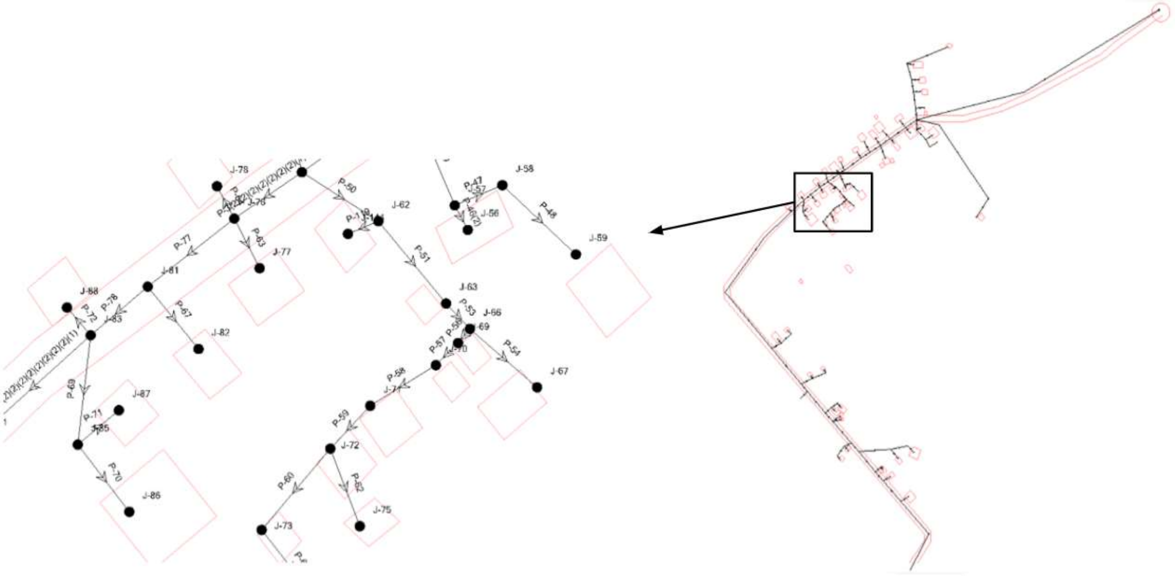


Figure 15: WaterGEMS design layout.

6. Related Non-Technical Issues

Panimache II, a community without reliable electricity and with limited funds, required the team's design to be gravity-based and constructed using affordable materials. In regards to how this affected the design of the water treatment and distribution system, the team was unable to incorporate pumps or technology that monitored water flow and distribution. The team analyzed the area's topography to adequately install the PVC piping and the location of the water treatment system. Additionally, the possible locations for the water treatment system provided by INCYT landed on private property, which would result in additional cost if the land needed to be purchased.

Figure 16: Possible location of the water purification system.

The goal of the water treatment and distribution systems was to be operated and maintained by appointing a local individual who would be trained. The operator's role would be to add the necessary chemicals to the hydraulic flocculator and the storage tanks, as well as open and close the gate valve for the three hour operation time. The largest obstacle to understanding the community needs was the language barrier and clearly communicating maintenance procedures, such as pouring the correct quantities of chlorine and alum. The operator would be responsible for creating alum and chlorine slurries on a daily basis to add to the respective water treatment system components.

The water treatment system also requires routine maintenance. This would be the periodic cleaning of the hydraulic flocculator (flocs can collect at the bottom that need to be removed), drainage of the sludge zone of the sedimentation basin, and removal of the Schmutzdecke from the slow-sand filter, carried out when the standing water accumulates on the surface of the filter at a certain depth.

7. Recommended Materials

7.1 *PVC Pipes*

PVC pipes are widely used in the developing world because they are affordable, readily available, durable, and do not have concerns of corrosion and pipe degradation like their metal counterparts. They do, however, have some disadvantages, such as being less heat/flame and UV resistant. Pipes run the risk of being damaged if in contact with the lava, but designing for protection against lava was outside of our scope. Even though the placement of the piping was outside the design team's scope, both the advantages and disadvantages were considered for buried pipes and exposed pipes. Buried pipes would have the benefit of longer life spans because they are protected from the elements, but would be more difficult to maintain due to the community's lack of resources for locating and excavating the pipes in a remote location. With exposed pipes, the community would have fewer issues locating a break and fixing it, but would have the downside of a shorter life span. With these thoughts in mind, the design team would recommend exposed pipes, but understands that the decision is ultimately with the community and the construction team.

7.2 *Construction of the water treatment plant*

The cinder blocks used to construct the exterior of the hydraulic flocculator, the sedimentation basin, the slow-sand filter, and the storage tanks will be the standard two-hole 8x8x16 inch blocks. Concrete cinder blocks will be sourced from Guatemala City and delivered to Panimache II during the dry season.

To ensure the stability of the cinder block walls, corrugated #3 (Grade 40) steel rebars would be added to every other hole of the cinder blocks and set in place with the poured concrete. The rebar would be purchased in Guatemala City to then be shipped to Panimache II and cut accordingly to size depending on the wall height.

Mortar, a mixture of sand and cement, will be used to glue the layers of cinder blocks together and ensure the cinder block cistern is water-tight and sealed. The bags of ready-to-go mortar will be purchased at Novex (a Guatemala City store) along with the bags of premixed concrete.

Bags of 50 kg concrete with 3000 psi and gravel size of ⅜ will be shipped to Panimache II, where construction workers will need to add water and then pour it inside of the cinder blocks.

8. Recommended Construction

Panimache II's remote location and small population results in the lack of paved roads. As a result, Panimache II's rainy season between May and October causes the unpaved roads to be unsafe to drive and transport materials into the town (Curtis, 2004). It is recommended that the water treatment and distribution system be constructed during the dry season between November and April to ensure the safety of the construction crew.

Figure 17: An example of cinder block construction.

The INCYT partners mentioned that Panimache II residents would subsidize the cost of construction by volunteering their construction labor since the project would benefit their community members. Furthermore, the proposed design will create an affordable and long-term solution for the community, which led to cinder blocks as the primary construction material. The cinder blocks will be affixed using a layer of mortar between each block and will subsequently be filled with concrete and rebar to ensure structural integrity.

9. Cost Analysis for Fixed Construction Cost

The team's goal was to design an affordable and reliable water treatment and distribution system to provide community members with sufficient clean water for daily necessities. The accessibility of potable water will permit individuals to use it for drinking purposes, bathing, laundry, and farming, and will enhance their quality of life and productivity.

While this project was not expected to be constructed in 2021, a cost analysis that examined the materials required, the construction methods, and an estimate of the maintenance costs determined whether the project was feasible to construct and maintain. Figure X demonstrates the breakdown of the materials costs, and are outlined in more detail in Appendix E. Upon completing the cost estimate with Guatemalan sourced and priced materials, the total cost of the project was estimated to be 25,663 U.S. dollars.

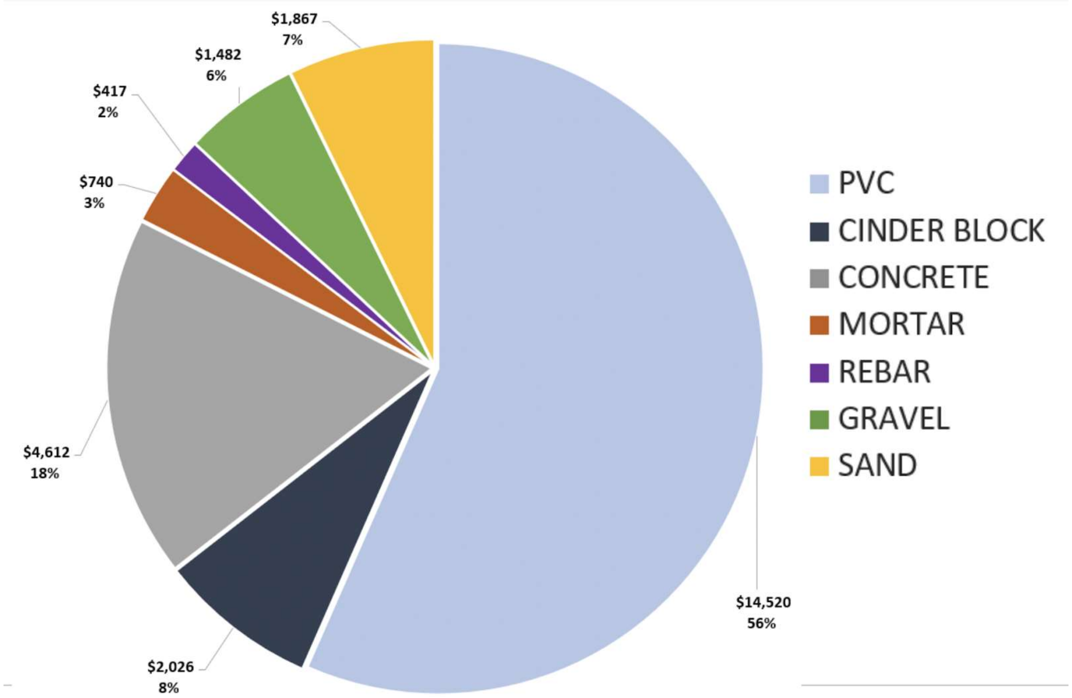
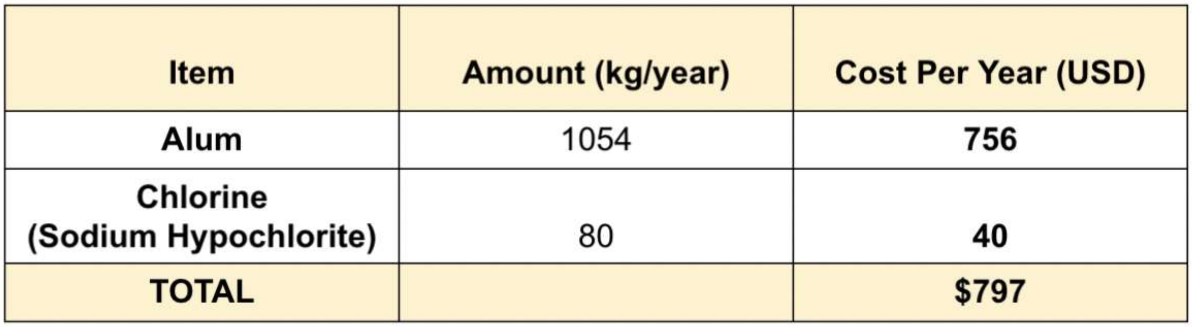


Figure 18: Fixed construction cost of water treatment and distribution system.

Due to the limited community resources and funding, the ideal scenario would be for a Guatemalan or an American non-profit organization, such as Rotary International, to provide financial support for the construction of the project. This similar model, where an organization purchases materials and the community provides the labor, was executed in 2020 by Rotary International and Los Buenos Vecinos with the Tippy Tap Project. To minimize costs, the team recommends sourcing materials from neighboring cities to avoid importing and the associated shipping costs from a different country.

Table 3 below contains the annual cost of procuring the necessary chemicals for use in the water treatment system. It should be noted that the cost of calcium hypochlorite was substituted by sodium hypochlorite as pricing for calcium hypochlorite in Guatemala was unavailable to the design team at the time of this report's submission. Sodium hypochlorite will not be utilized in this design.

Table 3: Water Treatment System Operating Costs



Item	Amount (kg/year)	Cost Per Year (USD)
Alum	1054	**756**
Chlorine (Sodium Hypochlorite)	80	**40**
TOTAL		**$797**

Purchasing local materials to be used for the construction of the water treatment and distribution system will also help to support the local economy.

10. Non-Technical Considerations

10.1 *Ethical Considerations*

Ethical considerations for this project included providing Panimache II with safe and clean water they can trust, an adequate supply of daily water such that basic needs can be met, and an affordable but effective water treatment and distribution system, as well as ensuring that the water they receive is consistent and dependable, and ensuring that anyone who maintains the treatment system is well qualified to do so because of chemicals additions to the water included in the team's design.

As previously stated, many members of the community expressed concerns over the quality and safety of the contaminated water. The team felt that, in response to these concerns, it was ethically responsible for the water treatment system to supply the community with water that they can trust and will not contain unhealthy levels of contaminants from the nearby volcano and other sources. As such, the design of the treatment system considered the different methods of removal for different types of contaminants. The hydraulic flocculator, sedimentation basin, and slow-sand filter work in conjunction to remove solid particles from the water, whereas the chlorination chamber was designed to remove pathogenic organisms. With this design, the community can be assured that their drinking water will be safe to consume.

10.2 *Health and Safety Considerations*

Panimache II's location factors into the largest health and safety consideration; their proximity to Volcan de Fuego, an active volcano, means that they are always in danger of a potential eruption. Eruptions trigger multiple safety concerns, including pyroclastic flow that will burn through and destroy anything it touches. The hardened lava and ash could potentially clog up the waterways in the area, changing the direction of the flow, and damaging/burning anything in its path. Eruptions also cause ash to accumulate in the surrounding area, and in the case of Panimache II, it would be normal to see approximately 30 cm of ash accumulated following an eruption. The ash in the water causes a drop in pH, and an increase in calcium, sodium, sulfate, and other ions.

11. Conclusion

11.1 *Fulfilling Project Needs*

To better illustrate how the design of the water treatment and distribution system meet the project needs, a review of the project's problem statement is necessary. Panimache II community leaders indicated to the team's partner organization, INCYT, that activity from the nearby Volcano, Vulcan de Fuego, introduced high levels of ash in Panimache II's water supply.

Panimache II's proximity and exposure to Volcan de Fuego make it vulnerable to receive ash falls after a volcanic eruption. According to Stewart et al. (2006), volcanic ashfall on natural waters can negatively affect turbidity, pH levels and concentrations of metals, leaving water non-potable. Many community members have expressed concerns to the community leaders regarding the ash and other contaminants emitted from the volcano in their drinking water supply. This information was relayed from the community leaders to the INCYT partners, which led to the partnership of this community. Data and anecdotal evidence suggest that there are high levels of suspended solids, and contamination from the ash and the algae growth that is prevalent in the river that is their drinking source. Although the community currently chlorinates the water, it does not completely remove the heavy metals and suspended solids from the water and runs the risk of creating disinfection byproducts that can be hazardous to the community members. The team's goal was to meet the international potable water standards to produce and deliver reliable and clean water that also meets the aesthetic factors of taste, color, and odor.

11.2 *Future Considerations*

For any future groups that will continue efforts to provide Panimache II with potable water, this team's theoretical design will provide them with a baseline to actually implement a treatment system. When the travel restrictions due to COVID-19 are lifted, future groups will have the opportunity to complete a thorough water quality analysis of Panimache II's water source for a better understanding of the contaminants and the appropriate water treatment processes. Additionally, future groups must identify a funding source that can cover the cost of constructing the treatment system, which may include non-profits or international grants. Lastly, avenues will open in which future groups will have a direct line of communication with the community, and they can clarify their needs as well as which method the community prefers.

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Appendix A: Cost Analysis

Item	Amount	Cost (USD)
65 mm diameter PVC Pipe (Water Pond A to water treatment system)	498.9 meters	**2,220.75**
PVC Pipe for Slow Sand Filter (65 mm diameter)	60 meters	**267.53**
90 degree elbows (65 mm diam.)	4 pieces	**37.02**
PVC Tee Socket (65 mm diam.)	8 pieces	**68.68**
PVC Pipe for between water treatment system components (65 mm diameter)	10 meters	**44.59**
PVC Pipe for the Distribution System	0.5in - 23 0.75in - 7 1in - 10 1.25in - 10 1.5in - 8 2in - 19 2.5in - 13 3in - 7 4in - 7	**11,413.56**
Gate Valve	1 valve	**468.34**
Cinder blocks for hydraulic flocculator	184 cinder blocks	**127.92**
Cinder blocks for Slow Sand Filter Exterior	1690 cinder blocks	**1,160.99**
Cinder blocks for sedimentation basin exterior	390 cinder blocks	**267**
Cinder blocks for storage tank	680 cinder blocks	**470.18**
Concrete	Total kg=	**HF=292.23** **SB=611.85** **SSF= 2643.76** **ST=1,063.90**
Mortar (HF, SB, SSF, ST)	Mortar Calculator	**HF=52.44** **SB= 95.57** **SSF= 408.33**

		ST= 183.56
Rebar (#3, 0.375 in diameter)	28.50 quetzales	**HF=26.30** **SB= 96.67** **SSF= 204.49** **ST= 89.23**
Gravel (30 mm sized gravel)	48.14 cubic meters	**1,481.96**
Sand	160.5 cubic meters	**1,866.50**
TOTAL		**$25,663.35**

Table 1: Fixed Construction Costs - Estimated Cost Analysis

Item	**Amount (kg/year)**	**Cost Per Year (USD)**
Alum	1054	**756**
Chlorine (Sodium Hypochlorite)	80	**40.08**
TOAL		**$797**

Table 2: Annual Chemical Costs - Estimated Cost Analysis

Appendix B: Report from Guatemala

Samples taken from two different water sources from the same river.

Test number one

Walking upstream over the Quixiya river, the first water source is located at 14° 26.808' N, 90° 56.492' W; Altitude 1160 mts. This water spring is exposed on the ground, the rising water is mixed with the water flowing downstream. At this point a reservoir is made and the water is piped.

Data:
PH: 6.53-6.59
Temperature: 20.3°C

Test number two

Keep walking upstream the river the second and main water source is located at 14° 26.842'N, 90° 56.493'W, Altitude: 1177 mts. A concrete structure was built over the water source that reservoirs it and collects it in pipes.

Data:
PH: 6.28
Temperature: 20.1°C

*The following tests were taken from a piped water supply in a school, and two houses,

Test number three

Coming back from the water source, in the community of Panimaché II the School is one of the first rural constructions that appears. The test was taken from a tap water that is located at 14° 26.565'N, 90° 56.982'W, Altitude 1079 mts

Data:
PH: 6.39-6.40
Temperature: 20.7°C

Test number four.

The lower point in Panimaché II where a PH test was taken is the house of the community leader: Jaime Loch, an elementary school teacher. The test was taken from a tap water located at: 14° 26.329’N, 90° 57.031’W, Altitude 1056 mts.

Data:
PH: 6.78
Temperature: 24.2°C

Test number five:

Panimaché 1 is the other community that receives water from the locations where the test 1 and 2 were taken. This sample was taken from a tap water in the house located at: 14° 25.703’ N, 90° 56.401’ W, Altitude: 1052 mts.

Data
PH = 6.87
Temperature = 21°C

Pictures from PH test number 1

Picture 1

Picture of the pipe water entry of the water source where the PH Test number one was taken.

Picture 2

A view from the reservoir constructed in the same PH test.

Picture 3

A view of the pipe that comes from an upper water source.

Pictures from PH test number 2

Picture 4

A view of the upper water source and the structure built over it.

Picture 5

A view of the structure above the upper water source.

In this picture appears at left the community leader Jaime Loch and the Volcanologist from SE-CONRED, William Chigna he manages the risk related to the Fuego Volcano in the communities in its skirts.

Picture 6

A close up to the pipes and the reservoir built on the water source.

Picture 7

The water source under the structure that covers it.

Other pictures

Picture 8

An image of the tank that stores the water piped from two water sources.
The water is chlorinated before being stored.
This tank is located at 14° 26.685’ N
90° 56.728’ W
Altitude 1128mts
The water is not pumped, is distributed by gravity

Picture 9

A pipe at some point between the water tank and the village

Picture 10

The PH Meter utilized.

Picture 11

The GPS utilized is a Garmin Forerunner 410

Picture 12

An image from the water samples collected. The sample that corresponds to the PH test 2 was lost when it fell during the ascent of a ravine.

Water Pond A, Water Collector and Water Level Overflow TAP

Description	Water Pond A (the lower one)
Longitude	-90.941367
Latitude	14.44685

Description	Water Collector (Collects water from ponds A and B)	
Longitude	-90.941397	
Latitude	14.44683	
Flowing Water Riverbed Dimensions (in meters)	Wide:0.58	Depth: 0.06
Whole, Dry Riverbed dimensions (in meters)	Wide 1.89	Depth 0.5 (estimation from the high of the border)
Description	Riverbed wide near Water Pond A	
Longitude	-90.941417	
Latitude	14.44695	
Flowing Water Riverbed Dimensions (in meters)	Wide:0.58	Depth: 0.06
Whole, Dry Riverbed dimensions (in meters)	Wide 1.89	Depth 0.5 (estimation from the high of the border)
Flow rate (m/s)	0.4-0.6	

Water Pond A

Water Collector

Water Pond A, Water Collector and Flow Regulation Tap

Water level overflow pipe

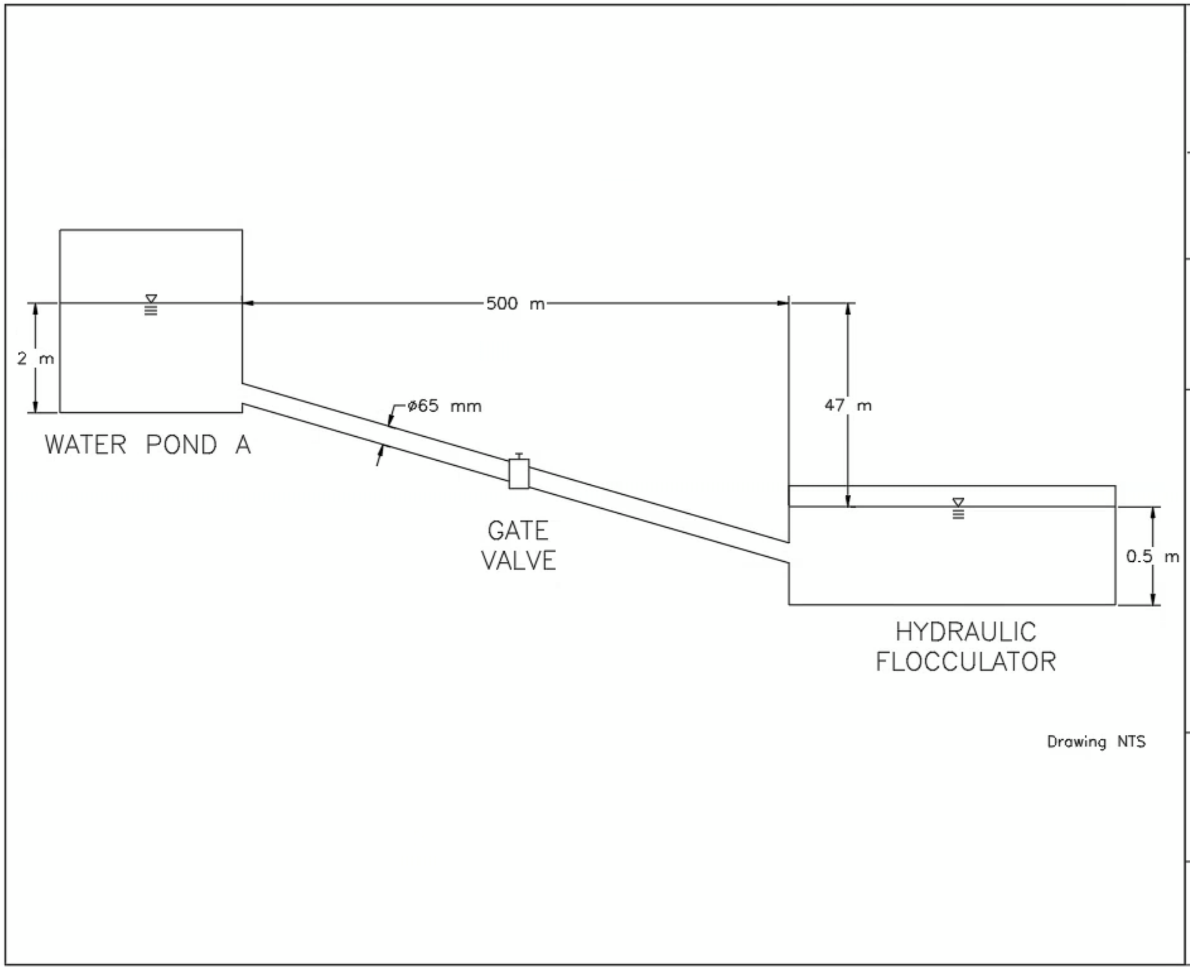
Pipe diameter	3 inches
Flow Rate (m/s)	1.1-1.3
Flowing riverbed dimension	0.3 meters wide .07 meters depth
Flow Rate (m/s)	0.3-0.4
Dry riverbed dimension	1.5 meters wide .25 meters depth (estimated)

Water Pond B (upper one)

Description	Water Pond B (the lower one)
Longitude	-90.941383
Latitude	14.447233

Description	Riverbed wide near Water Pond B	
Longitude	-90.941317	
Latitude	14.447217	
Flowing Water Riverbed Dimensions (in meters)	Wide:0.5	Depth: 0.07
Whole Dry Riverbed dimensions (in meters)	Wide 3.1	Depth 0.5 (estimation from the high of the border)
Flow rate (m/s)	0.4-0.6	

Appendix C: Water Treatment System Details



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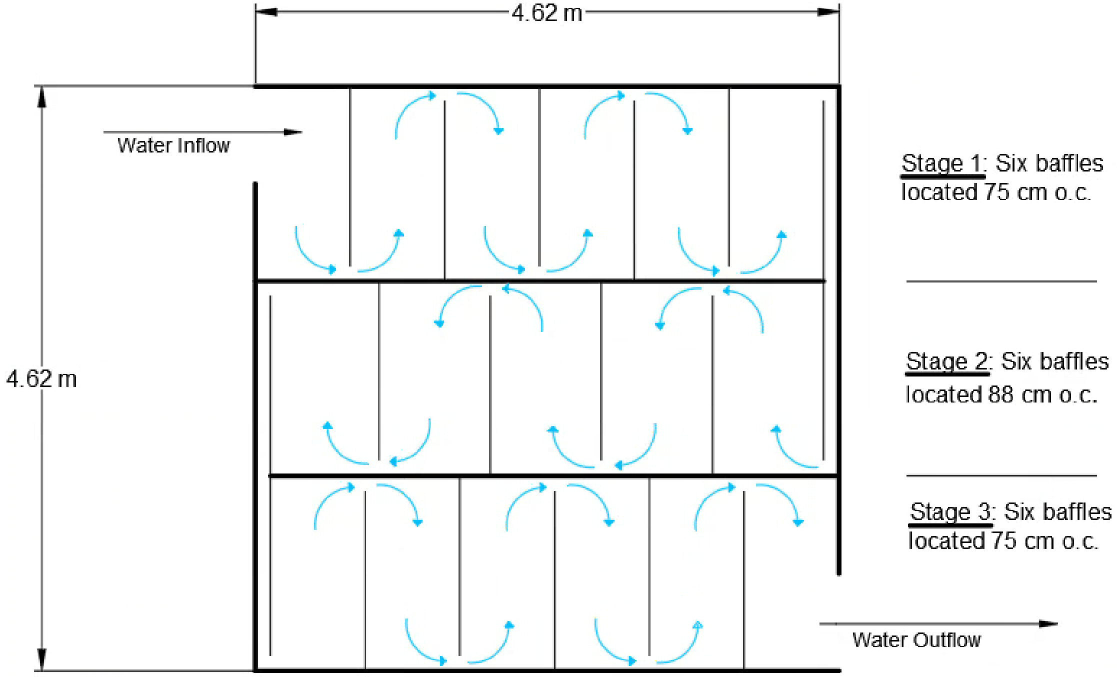
WATER DIVERSION

SHEET
AO.1

Water Diversion Side View Detail



Stage 1: Six baffles located 75 cm o.c.

Stage 2: Six baffles located 88 cm o.c.

Stage 3: Six baffles located 75 cm o.c.

Notes:

- Distance between baffle and stage wall: 12 cm
- Water velocity at turns: 1.5 m/s
- Water Depth: 0.5 m

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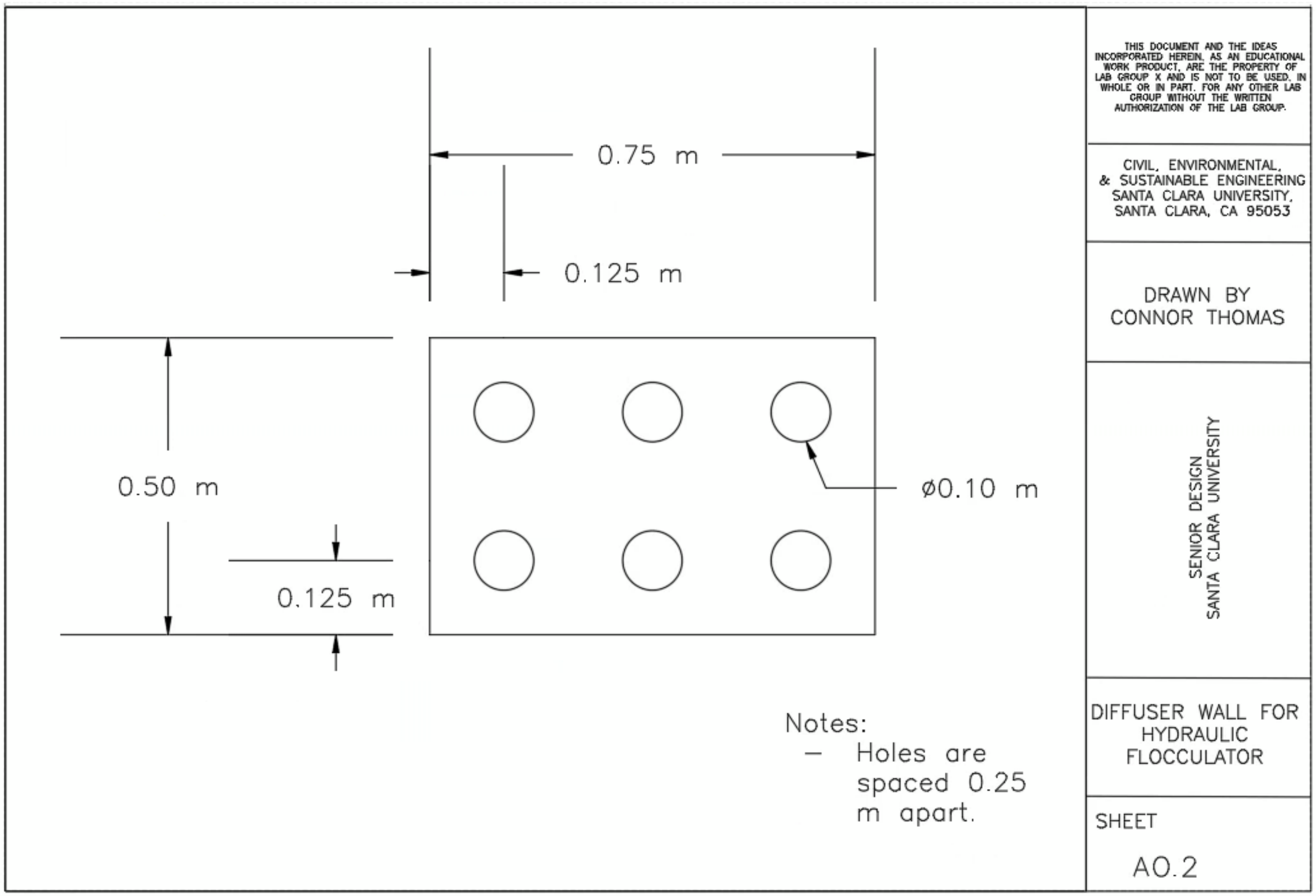
HYDRAULIC
FLOCCULATOR FOR
PANIMACHE II

SHEET
A0.2

Hydraulic Flocculator Top View Detail and Notes



Notes:
- Holes are spaced 0.25 m apart.

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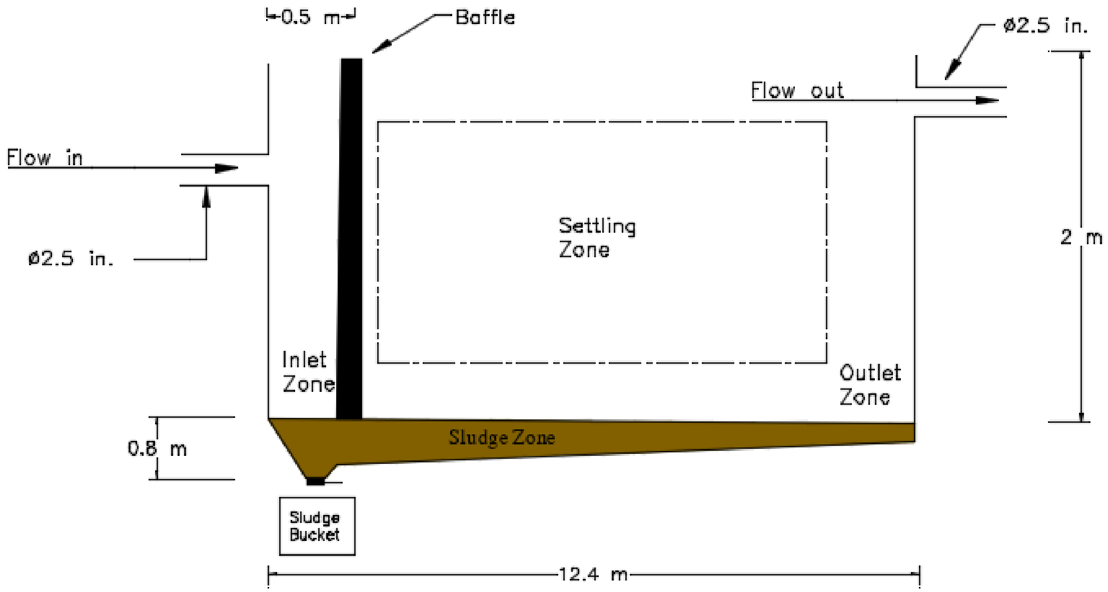
DIFFUSER WALL FOR
HYDRAULIC
FLOCCULATOR

SHEET
AO.2

Hydraulic Flocculator: Diffuser Wall Detail and Notes



Notes:

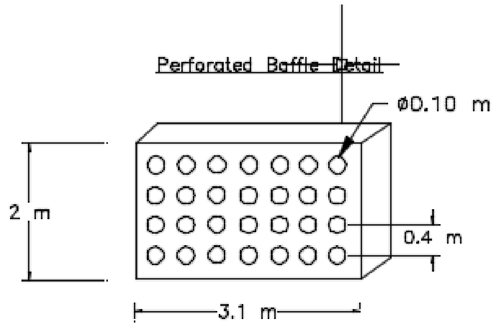
-Detention Time: 2.4 hours

-Flow in: 770 cubic meters per day

-Tank width: 3.10 m

-Sludge Zone slope: 1:600

Drawings NTS



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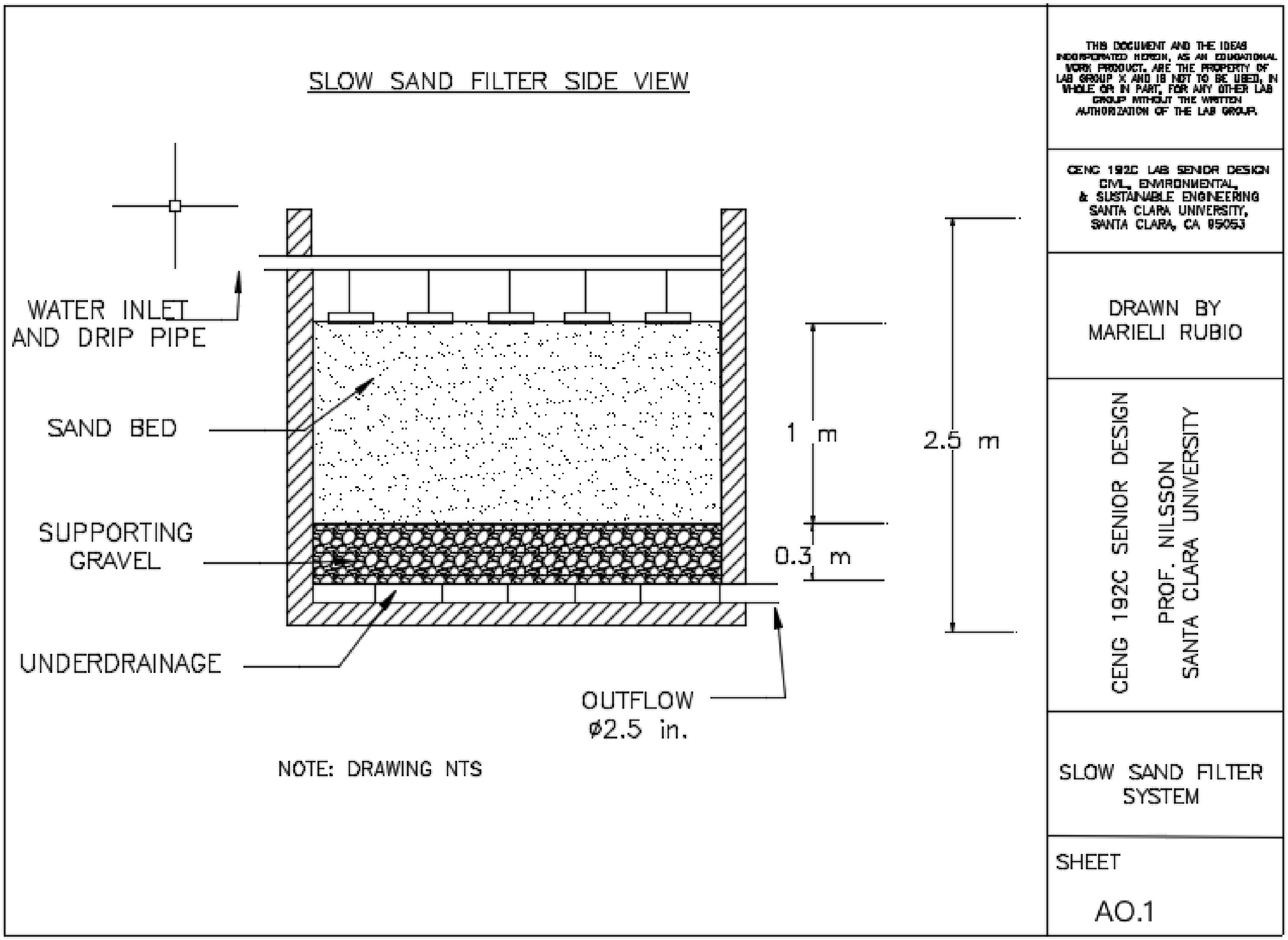
SEDIMENTATION
TANK FOR
PANIMACHE II

SHEET

AO.1

Sedimentation Tank and Perforated Baffle Details and Notes



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PROF. NILSSON
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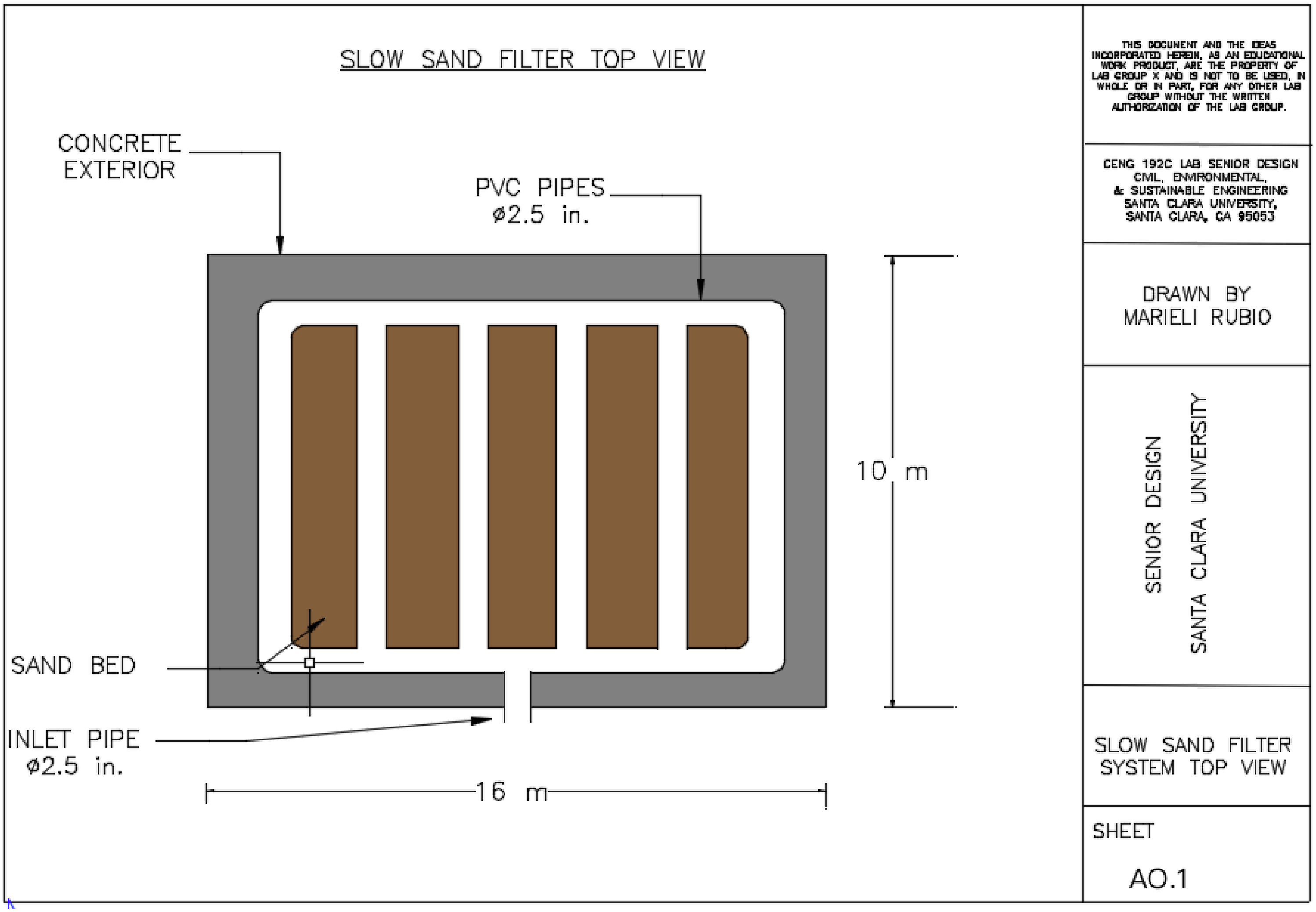
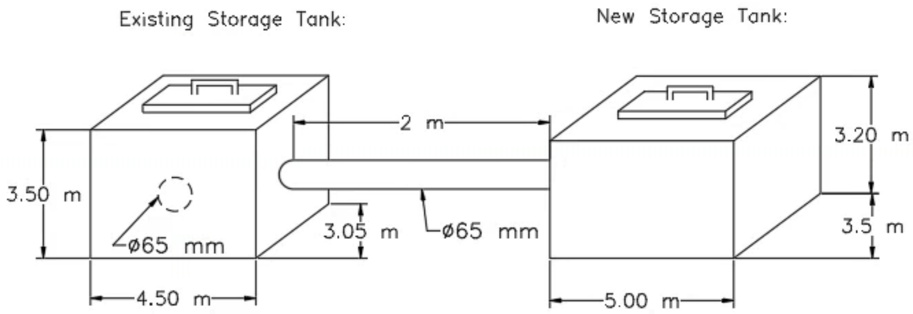
SLOW SAND FILTER SYSTEM

SHEET
AO.1

Slow Sand Filter Side View Detail



Slow Sand Filter Top View Detail



- Volume: 48.04 m^3
- Required Sodium Hypochlorite Dosage: 100.87 g/day
- Disinfection Time: 25 min.

- Volume: 56.00 m^3
- Required Sodium Hypochlorite Dosage: 117.59 g/day
- Disinfection Time: 25 min.

Drawing NTS

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STORAGE
TANK/CHLORINATION
CHAMBER

SHEET

AO.2

Storage Tank/Chlorination Chamber Details and Notes

Appendix D: Water Treatment System Calculations

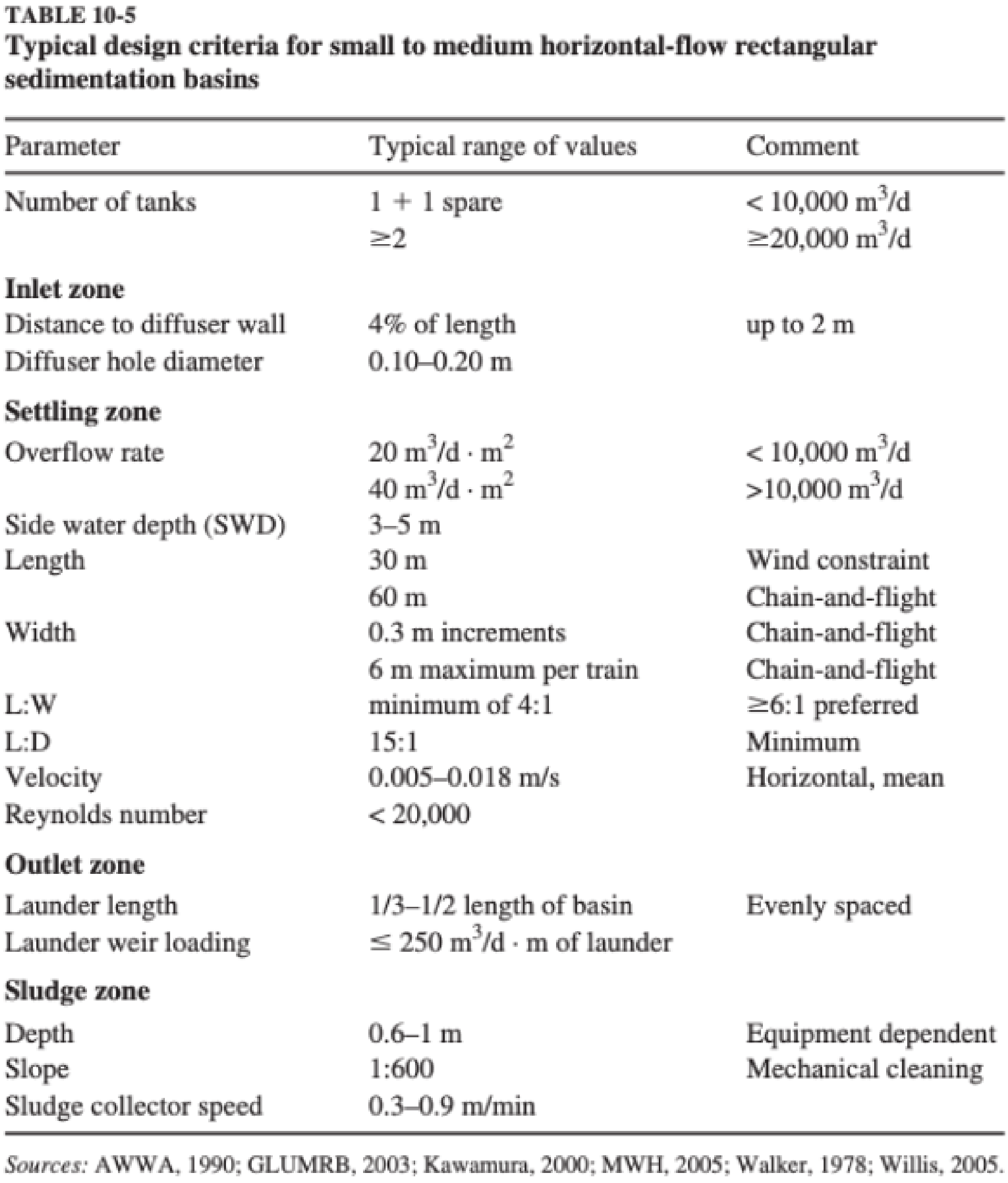


TABLE 10-5

Typical design criteria for small to medium horizontal-flow rectangular sedimentation basins

Parameter	Typical range of values	Comment
Number of tanks	1 + 1 spare	< 10,000 m^3/d
	≥2	≥20,000 m^3/d
Inlet zone		
Distance to diffuser wall	4% of length	up to 2 m
Diffuser hole diameter	0.10–0.20 m	
Settling zone		
Overflow rate	20 $m^3/d \cdot m^2$	< 10,000 m^3/d
	40 $m^3/d \cdot m^2$	>10,000 m^3/d
Side water depth (SWD)	3–5 m	
Length	30 m	Wind constraint
	60 m	Chain-and-flight
Width	0.3 m increments	Chain-and-flight
	6 m maximum per train	Chain-and-flight
L:W	minimum of 4:1	≥6:1 preferred
L:D	15:1	Minimum
Velocity	0.005–0.018 m/s	Horizontal, mean
Reynolds number	< 20,000	
Outlet zone		
Launder length	1/3–1/2 length of basin	Evenly spaced
Launder weir loading	≤ 250 $m^3/d \cdot m$ of launder	
Sludge zone		
Depth	0.6–1 m	Equipment dependent
Slope	1:600	Mechanical cleaning
Sludge collector speed	0.3–0.9 m/min	

Sources: AWWA, 1990; GLUMRB, 2003; Kawamura, 2000; MWH, 2005; Walker, 1978; Willis, 2005.

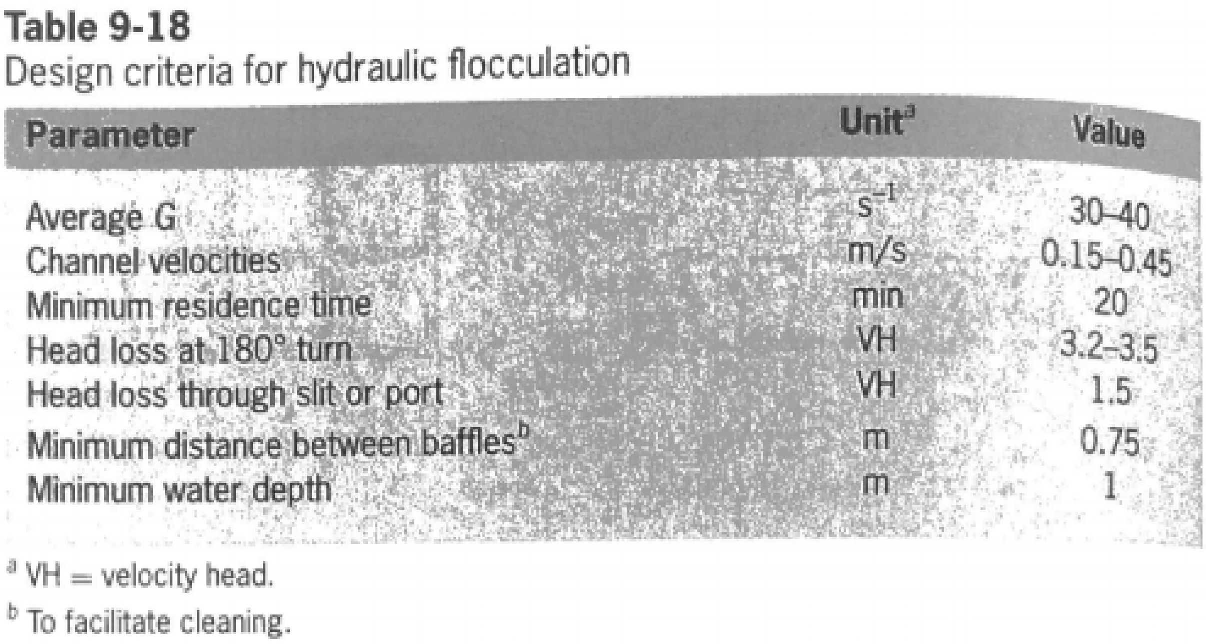


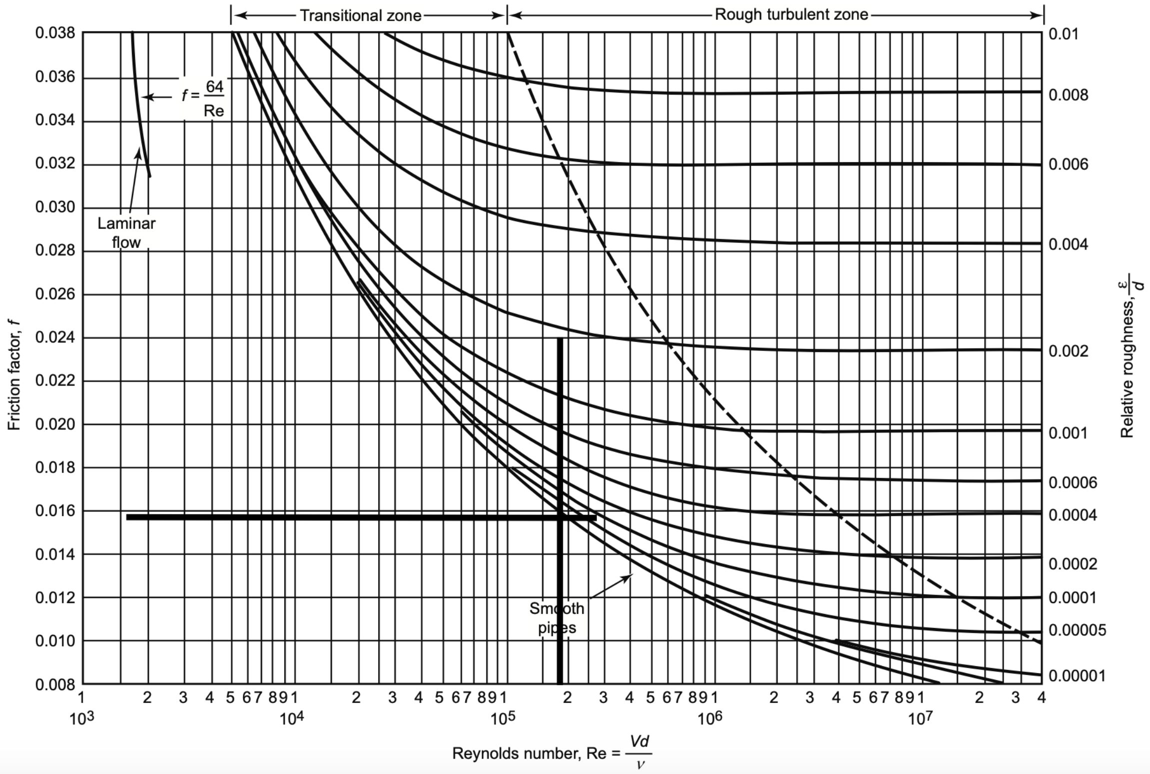
Table 9-18
Design criteria for hydraulic flocculation

Parameter	Unit[a]	Value
Average G	s^{-1}	30–40
Channel velocities	m/s	0.15–0.45
Minimum residence time	min	20
Head loss at 180° turn	VH	3.2–3.5
Head loss through slit or port	VH	1.5
Minimum distance between baffles[b]	m	0.75
Minimum water depth	m	1

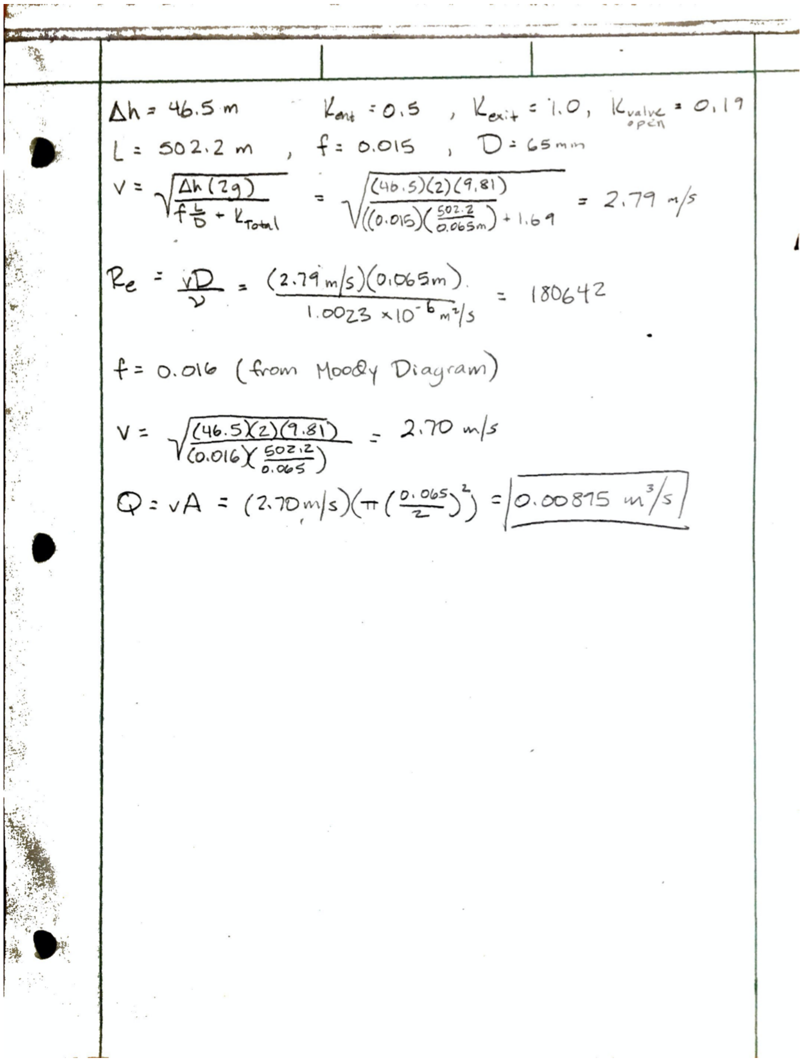
[a] VH = velocity head.

[b] To facilitate cleaning.

Figure 15.4 Moody diagram for friction factor for pipes.



Moody Diagam



$\Delta h = 46.5\ m$ $K_{ent} = 0.5$, $K_{exit} = 1.0$, $K_{\substack{valve \\ open}} = 0.19$

$L = 502.2\ m$, $f = 0.015$, $D = 65\ mm$

$$v = \sqrt{\frac{\Delta h\,(2g)}{f\frac{L}{D} + K_{Total}}} = \sqrt{\frac{(46.5)(2)(9.81)}{((0.015)(\frac{502.2}{0.065m}) + 1.69}} = 2.79\ m/s$$

$$R_e = \frac{vD}{\nu} = \frac{(2.79\ m/s)(0.065m)}{1.0023 \times 10^{-6}\ m^2/s} = 180642$$

$f = 0.016$ (from Moody Diagram)

$$v = \sqrt{\frac{(46.5)(2)(9.81)}{(0.016)(\frac{502.2}{0.065})}} = 2.70\ m/s$$

$$Q = vA = (2.70\ m/s)(\pi(\frac{0.065}{2})^2) = \boxed{0.00875\ m^3/s}$$

Head loss/Flow Rate Calculations

Ergun Equation to determine head loss

$$h_L = K_V \frac{(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu L v_F}{\rho_w g d^2} + K_I \frac{1-\varepsilon}{\varepsilon^3} \frac{L v_F^2}{g d} \quad \text{— Eq. 7-20}$$

VISCOUS LOSS INITIAL LOSS

K_V, K_I = Ergun coefficients for viscous and inertial losses, unitless

ε = filter bed porosity, dimensionless

μ = viscosity of water, kg/m·s

ρ_w = density of water, kg/m³

g = gravitational constant, m/s²

d = diameter of media, m

L = depth of grav

Givens

filtration rate = 0.2 m/hr

temp = 20 °C

coefficients of Porosity, - Table 7-3

SAND $K_V = 113$

$K_I = 2.3$

d_{10} = ES = 2 mm

$\varepsilon = 0.41$

L = 1 m

Table C-1 in App C.

ρ_w = 999 kg/m³

$\mu = 1.14 \times 10^{-3}$ kg/m·s

Plug into Eq. 7-20

$\frac{.0089}{9.72}$

$$= \frac{(113)(1-0.41)^2(1.14\cdot10^{-3}\ \text{kg/m·s})(1\ \text{m})(0.2\ \text{m/h})}{(0.41)^3(999\ \text{kg/m}^3)(9.81\ \text{m/s}^2)(2\ \text{mm})^2(10^{-3}\ \text{m/mm})^2(3600\ \text{s/h})}$$

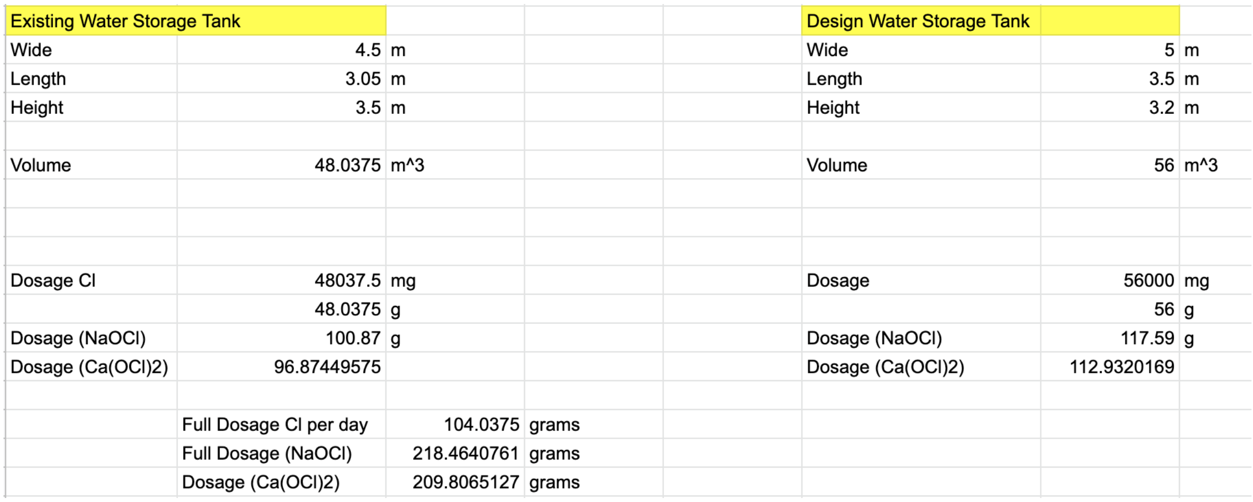
$$= 9.22\cdot10^{-4}\ \text{m}$$

$$= \frac{(2.3)(1-0.41)(1\ \text{m})(0.2\ \text{m/h})^2}{(0.41)^3(9.81\ \text{m/s}^2)(2\ \text{mm})(10^{-3}\ \text{m/mm})(3600\ \text{s/h})^2}$$

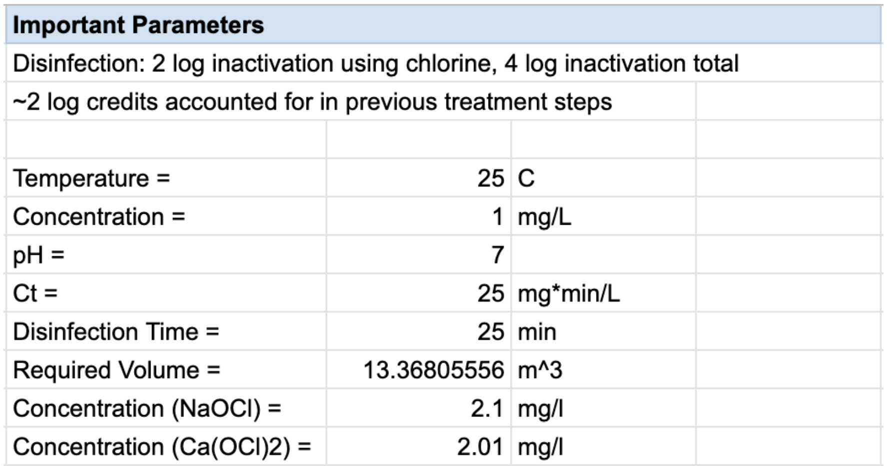
$$= 3.097\cdot10^{-6}$$

$$h_L = 9.22\cdot10^{-4}\ \text{m} + 3.097\cdot10^{-6}\ \text{m} = \boxed{9.25\cdot10^{-4}\ \text{m}}$$

Storage Tank Calculations



Existing Water Storage Tank					Design Water Storage Tank		
Wide	4.5	m			Wide	5	m
Length	3.05	m			Length	3.5	m
Height	3.5	m			Height	3.2	m
Volume	48.0375	m^3			Volume	56	m^3
Dosage Cl	48037.5	mg			Dosage	56000	mg
	48.0375	g				56	g
Dosage (NaOCl)	100.87	g			Dosage (NaOCl)	117.59	g
Dosage (Ca(OCl)2)	96.87449575				Dosage (Ca(OCl)2)	112.9320169	
	Full Dosage Cl per day	104.0375	grams				
	Full Dosage (NaOCl)	218.4640761	grams				
	Dosage (Ca(OCl)2)	209.8065127	grams				



Important Parameters			
Disinfection: 2 log inactivation using chlorine, 4 log inactivation total			
~2 log credits accounted for in previous treatment steps			
Temperature =	25	C	
Concentration =	1	mg/L	
pH =	7		
Ct =	25	mg*min/L	
Disinfection Time =	25	min	
Required Volume =	13.36805556	m^3	
Concentration (NaOCl) =	2.1	mg/l	
Concentration (Ca(OCl)2) =	2.01	mg/l	

Steps to design SSF

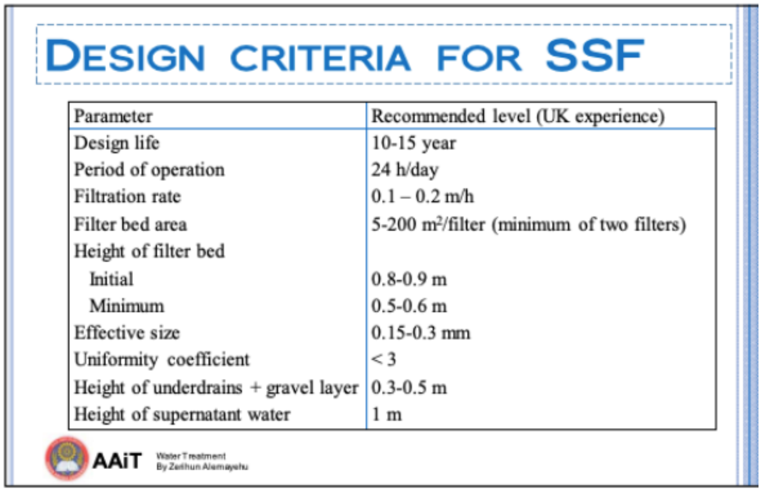
Sand measurements include:

- **Effective Size (ES):** The effective size of filter media is the diameter of the filter grain for which 10% percent of the total grains are smaller and 90% of the total grains are larger (calculated on a weight basis). In other words, the effective size is the size where only 10% of the sample is a smaller size. This is referred to as D10. Effective size is determined by passing a known amount of filter media through a series of progressively smaller sieve sizes and weighing the amount of media retained on each sieve.

  For a slow sand filter an ES of 0.15 to 0.35 millimeters is generally recommended.

- **Uniformity Coefficient (UC):** The uniformity coefficient is defined as the ratio of the sieve size where 60% of the filter media is smaller (referred to as D60) to the sieve size where 10% of the filter media is smaller (D10). So UC is D60 divided by D10.

  For a slow sand filter an UC of 1.5 to 3 is generally recommended.



DESIGN CRITERIA FOR SSF

Parameter	Recommended level (UK experience)
Design life	10-15 year
Period of operation	24 h/day
Filtration rate	0.1 – 0.2 m/h
Filter bed area	5-200 m^2/filter (minimum of two filters)
Height of filter bed	
Initial	0.8-0.9 m
Minimum	0.5-0.6 m
Effective size	0.15-0.3 mm
Uniformity coefficient	< 3
Height of underdrains + gravel layer	0.3-0.5 m
Height of supernatant water	1 m

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Steps to Design Sedimentation Basin

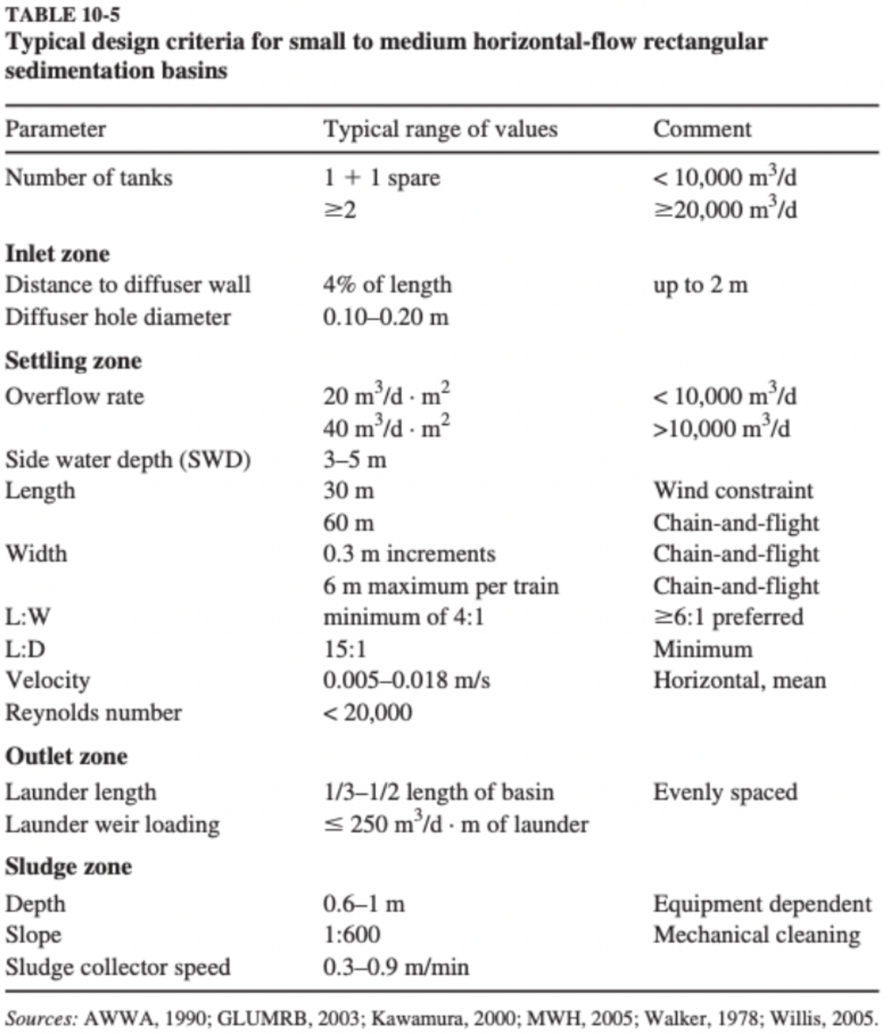
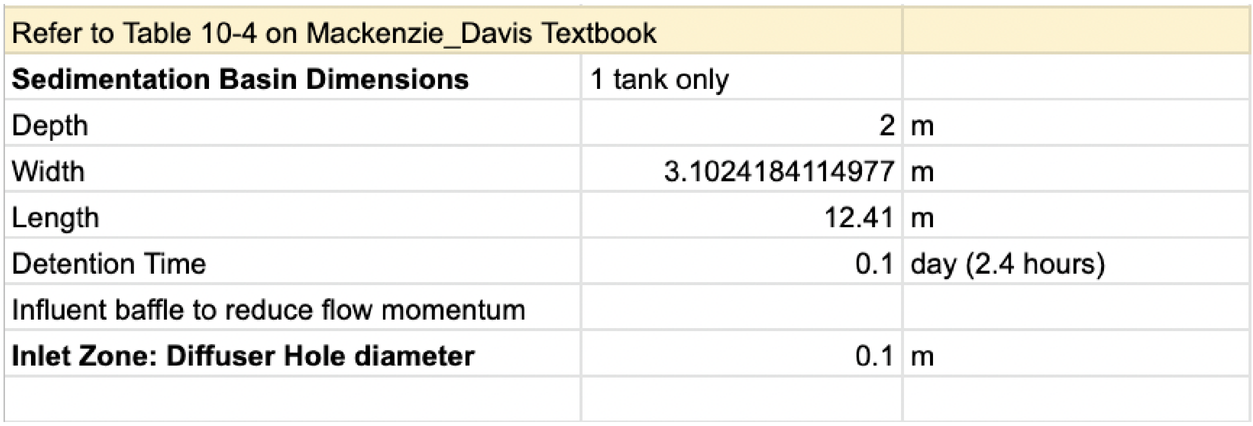


TABLE 10-5
Typical design criteria for small to medium horizontal-flow rectangular sedimentation basins

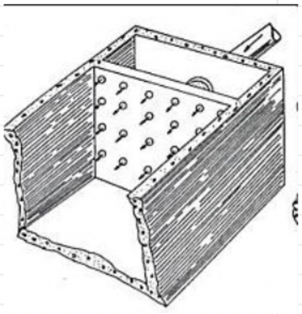
Parameter	Typical range of values	Comment
Number of tanks	1 + 1 spare	< 10,000 m^3/d
	≥2	≥20,000 m^3/d
Inlet zone		
Distance to diffuser wall	4% of length	up to 2 m
Diffuser hole diameter	0.10–0.20 m	
Settling zone		
Overflow rate	20 $m^3/d \cdot m^2$	< 10,000 m^3/d
	40 $m^3/d \cdot m^2$	>10,000 m^3/d
Side water depth (SWD)	3–5 m	
Length	30 m	Wind constraint
	60 m	Chain-and-flight
Width	0.3 m increments	Chain-and-flight
	6 m maximum per train	Chain-and-flight
L:W	minimum of 4:1	≥6:1 preferred
L:D	15:1	Minimum
Velocity	0.005–0.018 m/s	Horizontal, mean
Reynolds number	< 20,000	
Outlet zone		
Launder length	1/3–1/2 length of basin	Evenly spaced
Launder weir loading	≤ 250 $m^3/d \cdot m$ of launder	
Sludge zone		
Depth	0.6–1 m	Equipment dependent
Slope	1:600	Mechanical cleaning
Sludge collector speed	0.3–0.9 m/min	

Sources: AWWA, 1990; GLUMRB, 2003; Kawamura, 2000; MWH, 2005; Walker, 1978; Willis, 2005.

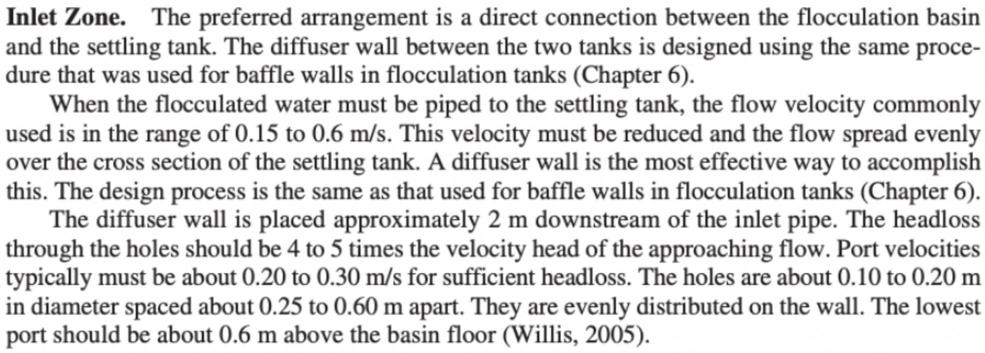


Refer to Table 10-4 on Mackenzie_Davis Textbook		
Sedimentation Basin Dimensions	1 tank only	
Depth	2	m
Width	3.1024184114977	m
Length	12.41	m
Detention Time	0.1	day (2.4 hours)
Influent baffle to reduce flow momentum		
Inlet Zone: Diffuser Hole diameter	0.1	m

Perforated Baffle		
Purpose: Spreads the flow across the total inlet of the tank to prevent short circuiting in the tank		
Distance to perforated baffle (4% its length)	0.50	m
Width of perforated baffle	3.10	m
Height of perforated baffle	2	m
Thickness of perforated baffle	0.15	m
Number of holes	28	holes
Disntace between holes	0.4	m
Hole diameter	0.1	m
Sludge zone Depth	0.8	m
Slope	1::600	



Perforated Baffle Design Criteria: CENG 144 Textbook

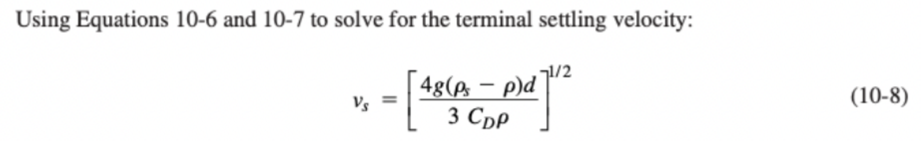


Inlet Zone. The preferred arrangement is a direct connection between the flocculation basin and the settling tank. The diffuser wall between the two tanks is designed using the same procedure that was used for baffle walls in flocculation tanks (Chapter 6).

When the flocculated water must be piped to the settling tank, the flow velocity commonly used is in the range of 0.15 to 0.6 m/s. This velocity must be reduced and the flow spread evenly over the cross section of the settling tank. A diffuser wall is the most effective way to accomplish this. The design process is the same as that used for baffle walls in flocculation tanks (Chapter 6).

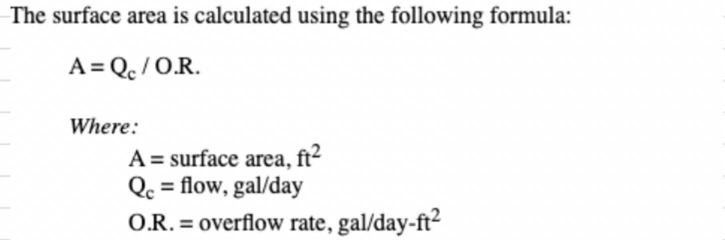
The diffuser wall is placed approximately 2 m downstream of the inlet pipe. The headloss through the holes should be 4 to 5 times the velocity head of the approaching flow. Port velocities typically must be about 0.20 to 0.30 m/s for sufficient headloss. The holes are about 0.10 to 0.20 m in diameter spaced about 0.25 to 0.60 m apart. They are evenly distributed on the wall. The lowest port should be about 0.6 m above the basin floor (Willis, 2005).

STEP I: Determine overflow rate for the sedimentation tank			
Overflow rate= equal to the settling velocity of the smallest particle which the basin will remove			
Due to the high measurement of suspended solids, turbidity is the main objective.			
According to Table 10-5: (<10,000 m^3/d)		**20**	**m^3/d*m^2**
Calculate Terminal Settling Velocity			


Using Equations 10-6 and 10-7 to solve for the terminal settling velocity:

$$v_s = \left[\frac{4g(\rho_s - \rho)d}{3\,C_D\rho}\right]^{1/2} \qquad (10\text{-}8)$$

STEP II: Calulate Surface Area		Source: https://water.mecc.edu/courses/ENV115/sedimentationb.htm


The surface area is calculated using the following formula:

$A = Q_c$ / O.R.

Where:

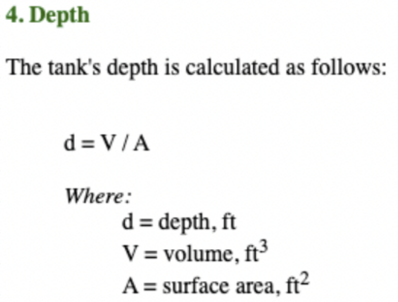
A = surface area, ft^2

Q_c = flow, gal/day

O.R. = overflow rate, gal/day-ft^2

Q	770	m^3/day	(770,000 liters/day)
O.R	**20**	**m^3/d*m^2**	
Surface area	38.5	m^2	

STEP III: Calulate Volume and Detention Time		
Minimum Side Water Depth (height)	2	m
Settling velocity (v=Q/A)	20.00	m/day
V=Qt	77	
V=(hQ/v)	77	m^3
Detention Time (t=V/Q)	0.1	day = (2.4 hours)
STEP V: Calulate Width and Length		
V= L*W*d		


4. Depth

The tank's depth is calculated as follows:

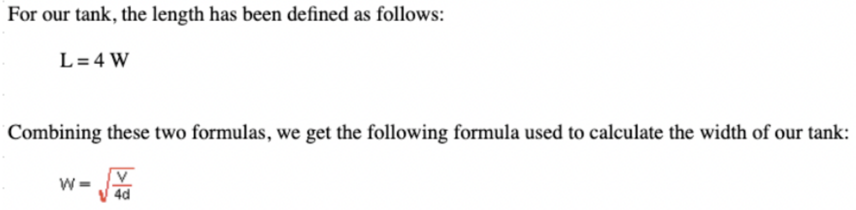
d = V / A

Where:

d = depth, ft

V = volume, ft^3

A = surface area, ft^2


For our tank, the length has been defined as follows:

L = 4 W

Combining these two formulas, we get the following formula used to calculate the width of our tank:

$W = \sqrt{\frac{V}{4d}}$

width	3.1024184114977	meters
length	12.41	meters

SLOW SAND FILTER DESIGN

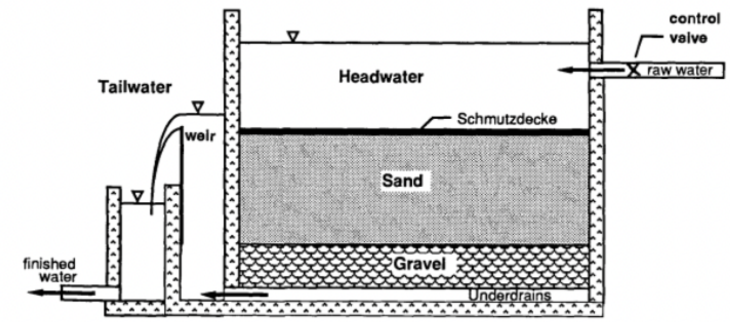


Figure 1.1 Schematic Cross Section of a Slow Sand Filter

Design Approach: Gathered Design Parameter Tables from 5 different sources and avera

Design Parameters		
Daily Demand for treated water (Q)	770	m^3/day
	0.008912037037	m^3/s
	32.08333333	m^3/hr
Hydraulic Loading Rate/Filtration Rate (v)	0.2	m/hr (avera
The flow rate is divided by the filter area to determine the loading rate.		
Filter Bed Area		
(A=Q/HLR)	160.4166667	m^2
Slow Sand Tank Dimensions		
Width	10	m
Length	16	m
Depth	2.515	m
Sand Specification		
Effective Size (d10)	0.2	mm
d60	0.4	mm
Uniformity Coefficient	2	

Depth of sand bed	1	m	
Depth of gravel support	0.3	m	
Gravel Size (Table 12)	30	mm	
Schmutzdecke depth	0.015	cm	(1.5 cm)
Supernatant Depth (headwater above sand)	1.2	m	
Head Loss Calculation	0.000925	m	see eq. 11-9 in textbook

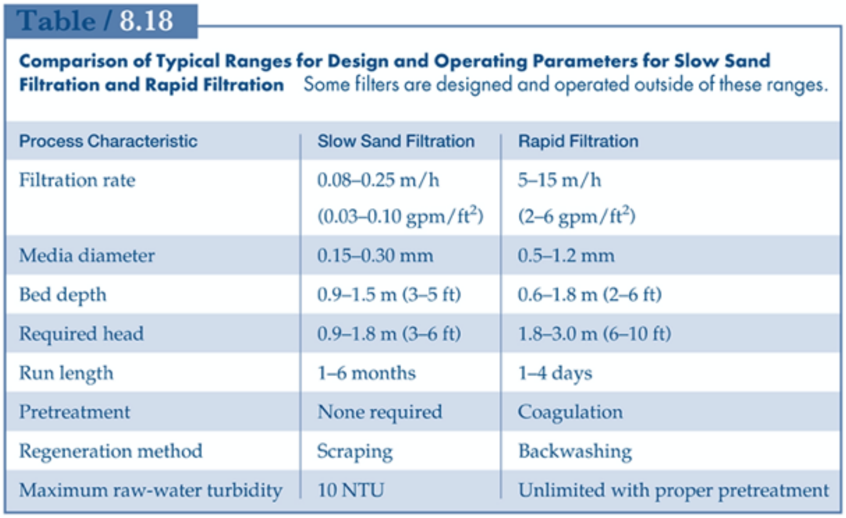


Table / 8.18

Comparison of Typical Ranges for Design and Operating Parameters for Slow Sand Filtration and Rapid Filtration Some filters are designed and operated outside of these ranges.

Process Characteristic	Slow Sand Filtration	Rapid Filtration
Filtration rate	0.08–0.25 m/h (0.03–0.10 gpm/ft^2)	5–15 m/h (2–6 gpm/ft^2)
Media diameter	0.15–0.30 mm	0.5–1.2 mm
Bed depth	0.9–1.5 m (3–5 ft)	0.6–1.8 m (2–6 ft)
Required head	0.9–1.8 m (3–6 ft)	1.8–3.0 m (6–10 ft)
Run length	1–6 months	1–4 days
Pretreatment	None required	Coagulation
Regeneration method	Scraping	Backwashing
Maximum raw-water turbidity	10 NTU	Unlimited with proper pretreatment

SOURCE: Crittenden et al., 2012. Reprinted with permission of John Wiley & Sons, Inc.

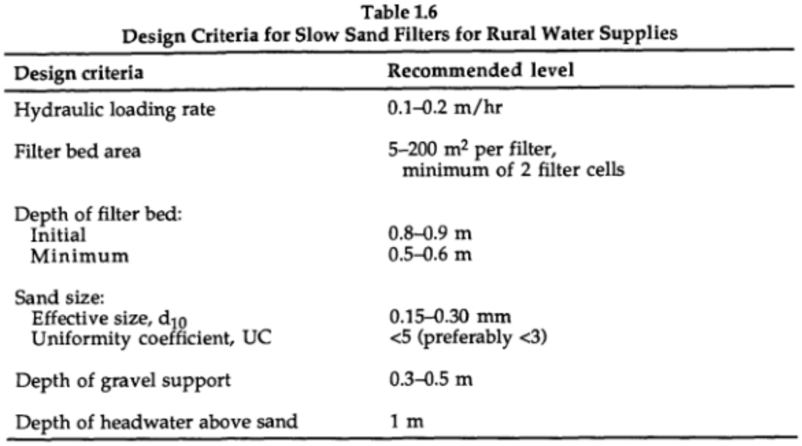


Table 1.6
Design Criteria for Slow Sand Filters for Rural Water Supplies

Design criteria	Recommended level
Hydraulic loading rate	0.1–0.2 m/hr
Filter bed area	5–200 m^2 per filter, minimum of 2 filter cells
Depth of filter bed:	
Initial	0.8–0.9 m
Minimum	0.5–0.6 m
Sand size:	
Effective size, d_{10}	0.15–0.30 mm
Uniformity coefficient, UC	<5 (preferably <3)
Depth of gravel support	0.3–0.5 m
Depth of headwater above sand	1 m

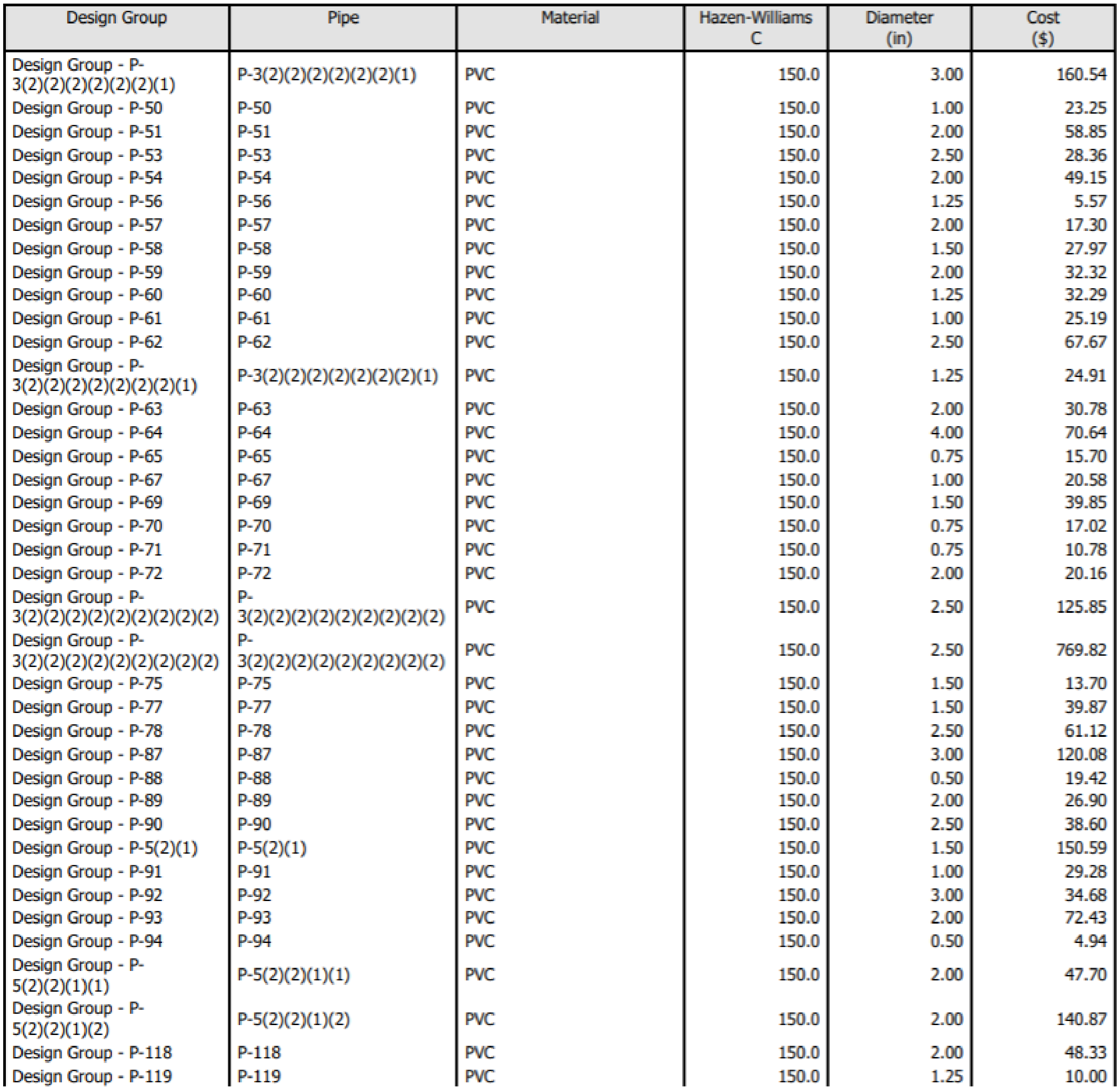
Source: Adapted from Visscher (1988).

Appendix E: Water Distribution System Details

PVC Piping (⅓)

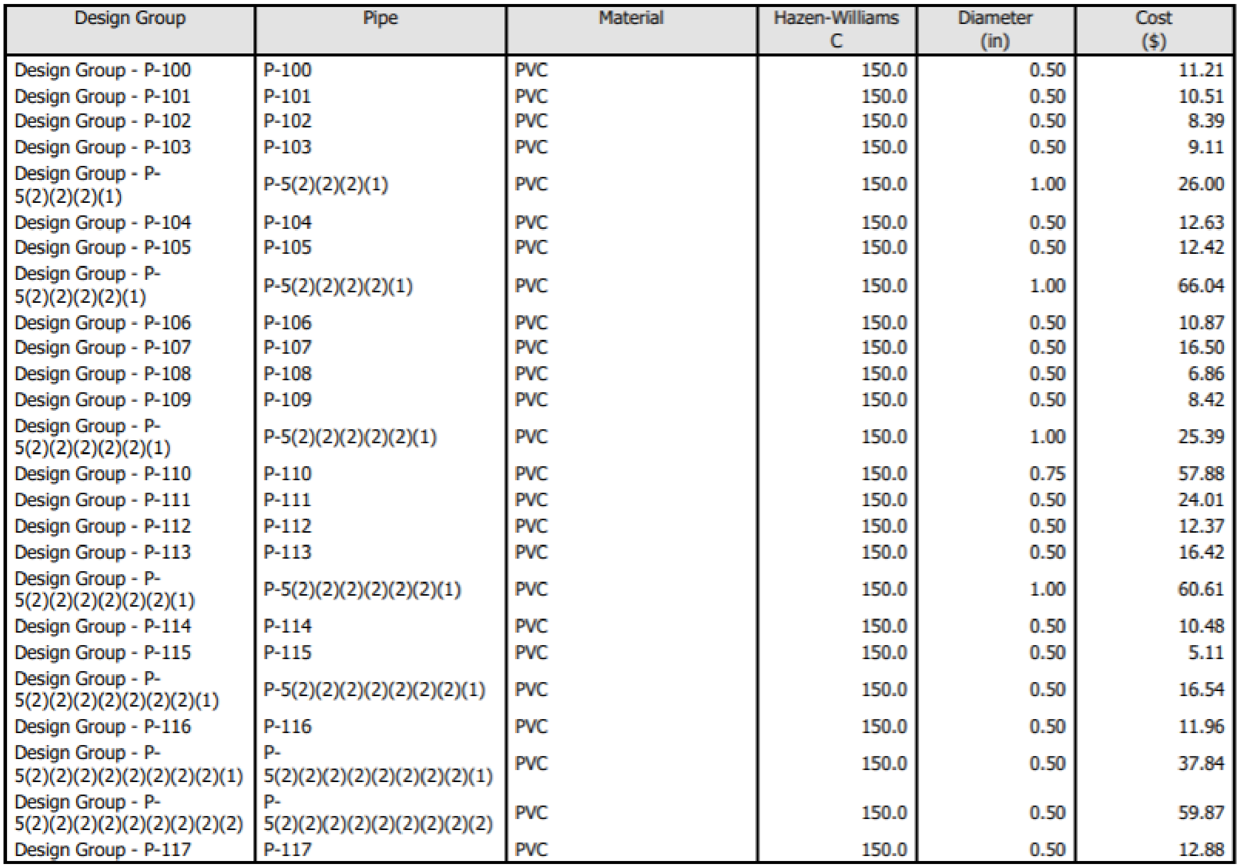
Design Group	Pipe	Material	Hazen-Williams C	Diameter (in)	Cost ($)
Design Group - P-11	P-11	PVC	150.0	1.25	32.06
Design Group - P-12	P-12	PVC	150.0	3.00	97.65
Design Group - P-13	P-13	PVC	150.0	2.00	82.01
Design Group - P-14	P-14	PVC	150.0	0.75	13.36
Design Group - P-15	P-15	PVC	150.0	2.50	88.01
Design Group - P-16	P-16	PVC	150.0	2.00	37.47
Design Group - P-17	P-17	PVC	150.0	2.00	83.70
Design Group - P-18	P-18	PVC	150.0	1.50	23.27
Design Group - P-19	P-19	PVC	150.0	2.00	219.06
Design Group - P-20	P-20	PVC	150.0	1.00	22.62
Design Group - P-21	P-21	PVC	150.0	2.50	32.13
Design Group - P-22	P-22	PVC	150.0	3.00	150.81
Design Group - P-23	P-23	PVC	150.0	2.50	68.52
Design Group - P-30	P-30	PVC	150.0	0.75	11.84
Design Group - P-31	P-31	PVC	150.0	4.00	163.75
Design Group - P-36	P-36	PVC	150.0	0.50	12.40
Design Group - P-38	P-38	PVC	150.0	1.25	22.40
Design Group - P-39	P-39	PVC	150.0	1.50	29.74
Design Group - P-41	P-41	PVC	150.0	1.25	60.01
Design Group - P-42	P-42	PVC	150.0	1.25	32.90
Design Group - P-3(2)(2)(2)(1)	P-3(2)(2)(2)(1)	PVC	150.0	4.00	178.89
Design Group - P-43	P-43	PVC	150.0	2.50	51.56
Design Group - P-3(2)(2)(2)(2)(1)	P-3(2)(2)(2)(2)(1)	PVC	150.0	2.50	153.87
Design Group - P-44	P-44	PVC	150.0	1.50	27.16
Design Group - P-3(2)(2)(2)(2)(2)(1)	P-3(2)(2)(2)(2)(2)(1)	PVC	150.0	4.00	98.72
Design Group - P-45	P-45	PVC	150.0	1.00	9.69
Design Group - P-46(1)	P-46(1)	PVC	150.0	3.00	144.74
Design Group - P-46(2)	P-46(2)	PVC	150.0	0.75	5.58
Design Group - P-47	P-47	PVC	150.0	4.00	99.65
Design Group - P-48	P-48	PVC	150.0	2.50	82.39
Design Group - P-80	P-80	PVC	150.0	4.00	218.66
Design Group - P-81	P-81	PVC	150.0	1.25	38.03
Design Group - P-82	P-82	PVC	150.0	2.00	68.76
Design Group - P-83	P-83	PVC	150.0	2.50	136.74
Design Group - P-84	P-84	PVC	150.0	2.00	60.87
Design Group - P-85	P-85	PVC	150.0	1.25	31.02
Design Group - P-86	P-86	PVC	150.0	3.00	69.88
Design Group - P-122	P-122	PVC	150.0	2.00	553.33
Design Group - P-130	P-130	PVC	150.0	4.00	4,655.58

PVC Piping (⅔)



Design Group	Pipe	Material	Hazen-Williams C	Diameter (in)	Cost ($)
Design Group - P-3(2)(2)(2)(2)(2)(2)(1)	P-3(2)(2)(2)(2)(2)(2)(1)	PVC	150.0	3.00	160.54
Design Group - P-50	P-50	PVC	150.0	1.00	23.25
Design Group - P-51	P-51	PVC	150.0	2.00	58.85
Design Group - P-53	P-53	PVC	150.0	2.50	28.36
Design Group - P-54	P-54	PVC	150.0	2.00	49.15
Design Group - P-56	P-56	PVC	150.0	1.25	5.57
Design Group - P-57	P-57	PVC	150.0	2.00	17.30
Design Group - P-58	P-58	PVC	150.0	1.50	27.97
Design Group - P-59	P-59	PVC	150.0	2.00	32.32
Design Group - P-60	P-60	PVC	150.0	1.25	32.29
Design Group - P-61	P-61	PVC	150.0	1.00	25.19
Design Group - P-62	P-62	PVC	150.0	2.50	67.67
Design Group - P-3(2)(2)(2)(2)(2)(2)(2)(1)	P-3(2)(2)(2)(2)(2)(2)(2)(1)	PVC	150.0	1.25	24.91
Design Group - P-63	P-63	PVC	150.0	2.00	30.78
Design Group - P-64	P-64	PVC	150.0	4.00	70.64
Design Group - P-65	P-65	PVC	150.0	0.75	15.70
Design Group - P-67	P-67	PVC	150.0	1.00	20.58
Design Group - P-69	P-69	PVC	150.0	1.50	39.85
Design Group - P-70	P-70	PVC	150.0	0.75	17.02
Design Group - P-71	P-71	PVC	150.0	0.75	10.78
Design Group - P-72	P-72	PVC	150.0	2.00	20.16
Design Group - P-3(2)(2)(2)(2)(2)(2)(2)(2)(2)	P-3(2)(2)(2)(2)(2)(2)(2)(2)(2)	PVC	150.0	2.50	125.85
Design Group - P-3(2)(2)(2)(2)(2)(2)(2)(2)(2)	P-3(2)(2)(2)(2)(2)(2)(2)(2)(2)	PVC	150.0	2.50	769.82
Design Group - P-75	P-75	PVC	150.0	1.50	13.70
Design Group - P-77	P-77	PVC	150.0	1.50	39.87
Design Group - P-78	P-78	PVC	150.0	2.50	61.12
Design Group - P-87	P-87	PVC	150.0	3.00	120.08
Design Group - P-88	P-88	PVC	150.0	0.50	19.42
Design Group - P-89	P-89	PVC	150.0	2.00	26.90
Design Group - P-90	P-90	PVC	150.0	2.50	38.60
Design Group - P-5(2)(1)	P-5(2)(1)	PVC	150.0	1.50	150.59
Design Group - P-91	P-91	PVC	150.0	1.00	29.28
Design Group - P-92	P-92	PVC	150.0	3.00	34.68
Design Group - P-93	P-93	PVC	150.0	2.00	72.43
Design Group - P-94	P-94	PVC	150.0	0.50	4.94
Design Group - P-5(2)(2)(1)(1)	P-5(2)(2)(1)(1)	PVC	150.0	2.00	47.70
Design Group - P-5(2)(2)(1)(2)	P-5(2)(2)(1)(2)	PVC	150.0	2.00	140.87
Design Group - P-118	P-118	PVC	150.0	2.00	48.33
Design Group - P-119	P-119	PVC	150.0	1.25	10.00

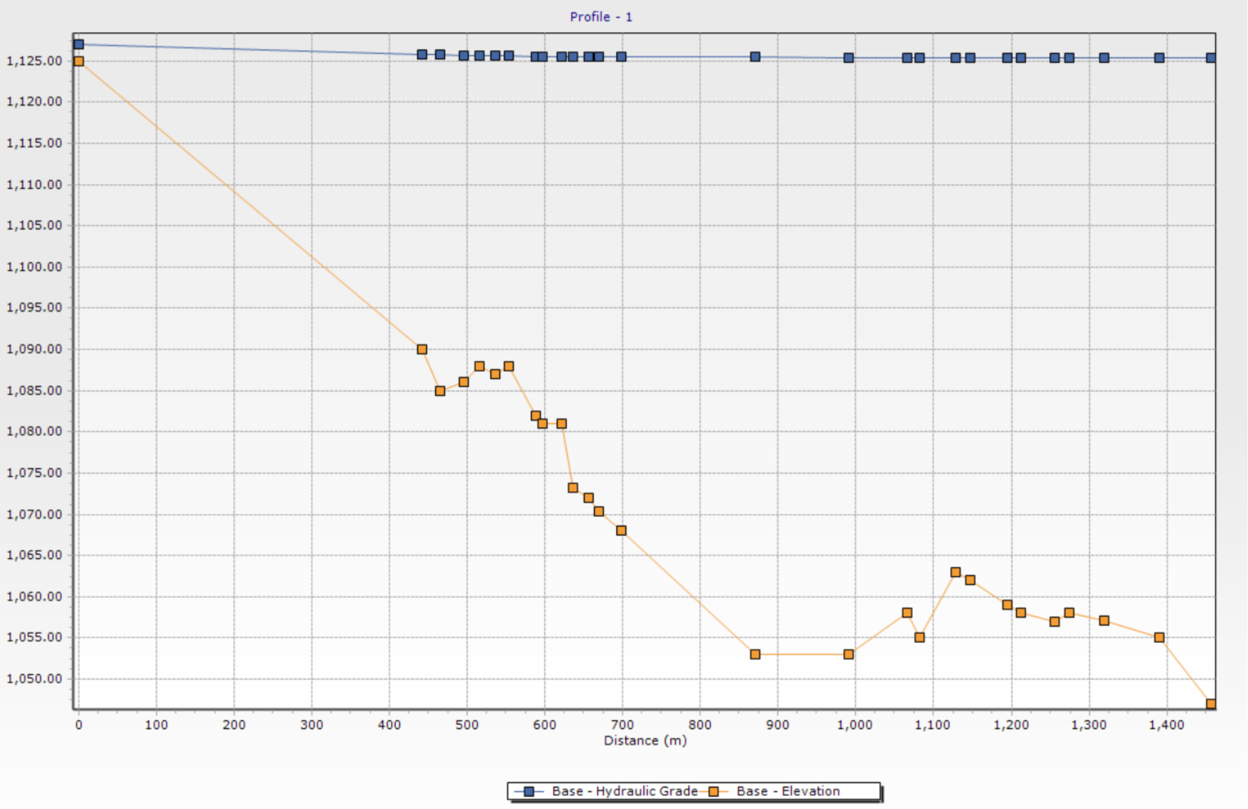
PVC Piping (3/3)



Design Group	Pipe	Material	Hazen-Williams C	Diameter (in)	Cost ($)
Design Group - P-100	P-100	PVC	150.0	0.50	11.21
Design Group - P-101	P-101	PVC	150.0	0.50	10.51
Design Group - P-102	P-102	PVC	150.0	0.50	8.39
Design Group - P-103	P-103	PVC	150.0	0.50	9.11
Design Group - P-5(2)(2)(2)(1)	P-5(2)(2)(2)(1)	PVC	150.0	1.00	26.00
Design Group - P-104	P-104	PVC	150.0	0.50	12.63
Design Group - P-105	P-105	PVC	150.0	0.50	12.42
Design Group - P-5(2)(2)(2)(2)(1)	P-5(2)(2)(2)(2)(1)	PVC	150.0	1.00	66.04
Design Group - P-106	P-106	PVC	150.0	0.50	10.87
Design Group - P-107	P-107	PVC	150.0	0.50	16.50
Design Group - P-108	P-108	PVC	150.0	0.50	6.86
Design Group - P-109	P-109	PVC	150.0	0.50	8.42
Design Group - P-5(2)(2)(2)(2)(2)(1)	P-5(2)(2)(2)(2)(2)(1)	PVC	150.0	1.00	25.39
Design Group - P-110	P-110	PVC	150.0	0.75	57.88
Design Group - P-111	P-111	PVC	150.0	0.50	24.01
Design Group - P-112	P-112	PVC	150.0	0.50	12.37
Design Group - P-113	P-113	PVC	150.0	0.50	16.42
Design Group - P-5(2)(2)(2)(2)(2)(2)(1)	P-5(2)(2)(2)(2)(2)(2)(1)	PVC	150.0	1.00	60.61
Design Group - P-114	P-114	PVC	150.0	0.50	10.48
Design Group - P-115	P-115	PVC	150.0	0.50	5.11
Design Group - P-5(2)(2)(2)(2)(2)(2)(2)(1)	P-5(2)(2)(2)(2)(2)(2)(2)(1)	PVC	150.0	0.50	16.54
Design Group - P-116	P-116	PVC	150.0	0.50	11.96
Design Group - P-5(2)(2)(2)(2)(2)(2)(2)(2)(1)	P-5(2)(2)(2)(2)(2)(2)(2)(2)(1)	PVC	150.0	0.50	37.84
Design Group - P-5(2)(2)(2)(2)(2)(2)(2)(2)(2)	P-5(2)(2)(2)(2)(2)(2)(2)(2)(2)	PVC	150.0	0.50	59.87
Design Group - P-117	P-117	PVC	150.0	0.50	12.88

Design Event	Element	Required Minimum Pressure (kPa)	Required Maximum Pressure (kPa)	Simulated Pressure (kPa)	Violation (kPa)
req pressure	J-1	140	500	295	0
req pressure	J-2	140	500	461	0
req pressure	J-4	140	500	441	0
req pressure	J-5	160	500	519	19
req pressure	J-14	140	500	314	0
req pressure	J-15	140	500	314	0
req pressure	J-16	140	500	303	0
req pressure	J-17	140	500	299	0
req pressure	J-18	140	500	303	0
req pressure	J-19	140	500	303	0
req pressure	J-20	140	500	263	0
req pressure	J-21	140	500	283	0
req pressure	J-22	140	500	283	0
req pressure	J-23	140	500	290	0
req pressure	J-24	140	500	290	0
req pressure	J-25	140	500	270	0
req pressure	J-26	140	500	290	0
req pressure	J-33	140	500	268	0
req pressure	J-34	140	500	264	0
req pressure	J-35	140	500	268	0
req pressure	J-37	140	500	227	0
req pressure	J-38	140	500	246	0
req pressure	J-39	140	500	227	0
req pressure	J-41	140	500	150	0
req pressure	J-42	140	500	126	14
req pressure	J-43	140	500	140	0
req pressure	J-44	140	500	270	0
req pressure	J-45	140	500	241	0
req pressure	J-46	140	500	206	0
req pressure	J-47	140	500	215	0
req pressure	J-48	140	500	158	0
req pressure	J-49	140	500	158	0
req pressure	J-50	140	500	147	0
req pressure	J-51	140	500	157	0
req pressure	J-52	140	500	179	0
req pressure	J-53	140	500	179	0
req pressure	J-54	140	500	188	0
req pressure	J-55	140	500	187	0
req pressure	J-56	140	500	137	3
req pressure	J-57	140	500	129	11
req pressure	J-58	140	500	119	21
req pressure	J-59	140	500	149	0
req pressure	J-60	140	500	188	0
req pressure	J-62	140	500	188	0
req pressure	J-63	140	500	178	0
req pressure	J-66	140	500	178	0
req pressure	J-67	140	500	188	0
req pressure	J-69	140	500	188	0
req pressure	J-70	140	500	197	0

Design Event	Element	Required Minimum Pressure (kPa)	Required Maximum Pressure (kPa)	Simulated Pressure (kPa)	Violation (kPa)
req pressure	J-71	140	500	227	0
req pressure	J-72	140	500	246	0
req pressure	J-73	140	500	276	0
req pressure	J-74	140	500	285	0
req pressure	J-75	140	500	276	0
req pressure	J-76	140	500	263	0
req pressure	J-77	140	500	276	0
req pressure	J-78	140	500	246	0
req pressure	J-79	140	500	217	0
req pressure	J-81	140	500	276	0
req pressure	J-82	140	500	280	0
req pressure	J-83	140	500	292	0
req pressure	J-85	140	500	295	0
req pressure	J-86	140	500	285	0
req pressure	J-87	140	500	295	0
req pressure	J-88	140	500	305	0
req pressure	J-91	140	500	315	0
req pressure	J-93	140	500	320	0
req pressure	J-98	140	500	461	0
req pressure	J-99	140	500	441	0
req pressure	J-100	140	500	431	0
req pressure	J-101	140	500	431	0
req pressure	J-102	140	500	441	0
req pressure	J-103	140	500	412	0
req pressure	J-104	140	500	402	0
req pressure	J-105	140	500	402	0
req pressure	J-106	140	500	392	0
req pressure	J-107	140	500	392	0
req pressure	J-116	140	500	363	0
req pressure	J-117	140	500	353	0
req pressure	J-118	140	500	333	0
req pressure	J-119	140	500	353	0
req pressure	J-120	140	500	353	0
req pressure	J-121	140	500	372	0
req pressure	J-122	140	500	363	0
req pressure	J-123	140	500	363	0
req pressure	J-124	140	500	402	0
req pressure	J-125	140	500	402	0
req pressure	J-126	140	500	421	0
req pressure	J-127	140	500	421	0
req pressure	J-128	140	500	402	0
req pressure	J-129	140	500	412	0
req pressure	J-130	140	500	402	0
req pressure	J-131	140	500	382	0
req pressure	J-132	140	500	382	0
req pressure	J-133	140	500	392	0
req pressure	J-134	140	500	421	0
req pressure	J-135	140	500	412	0
req pressure	J-136	140	500	412	0
req pressure	J-137	140	500	412	0
req pressure	J-138	140	500	412	0
req pressure	J-139	140	500	420	0
req pressure	J-140	140	500	421	0
req pressure	J-142	140	500	441	0
req pressure	J-143	140	500	441	0
req pressure	J-144	140	500	188	0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200
300
400
500
600
700
800
900
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1,100
1,200
1,300
1,400
Distance (m)
Base - Hydraulic Grade
Base - Elevation

Diameter	Class	Pressure Rating
1/2	DR 13.5	315
3/4	DR 17	250
1	DR 26	160
1 1/4	DR 32.5	125
1 1/2	DR 32.5	125
2	DR 32.5	125
2 1/2	DR 32.5	125
3	DR 32.5	125
4	DR 32.5	125