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Supetai Well Water Purification

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ENTITLED

SUPETAI WELL WATER PURIFICATION

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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SUPETAI WELL WATER PURIFICATION

By
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SENIOR DESIGN PROJECT REPORT

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SUPETAI WELL WATER PURIFICATION

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Santa Clara University, Spring 2022

Abstract

The rural Kenyan community of Oldonya Rasha had depended on water from a distant spring of unknown quality from which there have been reports of typhoid. A non-governmental organization, Sabore's Well, built the centrally-located Supetai Well with the intention of solving the lack of accessible potable water, but due to high fluoride levels in the groundwater, this water source is unsafe. The team designed a water treatment system to be integrated into the existing well infrastructure that removes fluoride and pathogens to meet Kenyan and World Health Organization (WHO) water quality standards. The design includes dosage of alum and soda ash; a parshall flume for chemical mixing and coagulation; a vertical impeller flocculator; a sedimentation basin; a slow sand filter; and a final holding tank with inline chlorinators for disinfection. The system supports a conservative load estimate to be a consistent and dependable potable water source, and was designed to empower the community with self-sufficiency after the initial development. The team will deliver the design to the client along with a cost estimate, sludge management and disposal procedure, a non-technical operation and maintenance manual, and a community education plan.

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INTRODUCTION

Problem Statement

The rural community of Oldonya Rasha in Narok County, Kenya is in need of a safe and reliable potable water source. Currently, residents consume untreated water from a spring of unknown quality approximately five kilometers away, and cases of typhoid fever have been reported within the community. Supetai Well (Figure 1) was built by the non-governmental organization, Sabore's Well, to supply potable water, but water quality tests have shown high levels of fluoride, making it unsafe to consume. Currently, Supetai well water is only used for consumption by livestock and for cleaning at a nearby school, Naretu Academy. Representatives from the community and Sabore's Well are requesting aid in solving this lack of safe, accessible water.

Figure 1. Supetai Well and solar power pump system.

Scope of Work

This technical report outlines the design of a conventional water treatment system integrated with the existing Supetai Well infrastructure to purify the groundwater to Kenyan and World

Health Organization (WHO) safe consumption standards. It presents a comparative analysis of alternative solutions based on identified criteria, constraints, and regulations; the design itself; a preliminary cost estimate; and additional resources to be given to the community explaining the system, operation, and maintenance in non-technical language. Key physical design components include the determination of chemical dosage, coagulation and flocculation systems, a sedimentation basin, a slow sand filter, and disinfection. It also includes a plan for sludge management and disposal.

Description of Client

Oldonya Rasha is a community of approximately 3,500 Maasai people who are primarily shepherds of goats, cows, and sheep. The community is structured in household units, each of which may contain 10-40 people, as they are a polygamist and multi-generational people. Water is generally inaccessible: according to the UNICEF Situation Analysis of Women and Children in Kenya, 2017, Narok County has some of the highest rates of water deprivation in children at 74 - 80% (UNICEF, 2018). The burden of collecting water falls on women and girls, which, in addition to other family and home maintenance tasks, limits their ability to get an education or learn trades. In Oldonya Rasha, women and girls must walk five kilometers each way to a spring to collect water. Supetai Well was constructed near Naretu Academy to address both water deprivation in children by providing consistent clean water to the students, and to empower girls by allowing them to collect water for their families and attend school.

Description of Site

The climate of Narok County is temperate, with average temperatures ranging from 16.1ºC - 19.5ºC through the year. It experiences a dry season from June through October, receiving 19 millimeters (mm) of rain on average during the driest month, July. During the remainder of the year, it receives 126 mm of rain monthly on average (Climate Data).

The land near the well is flat and undeveloped with some shrubbery. Existing infrastructure includes the well itself, a 10,000 L holding tank, and pump, and a solar panel. There is also piping to deliver water to Naretu Academy and troughs for livestock to drink the well water.

ANALYSIS of ALTERNATIVES

Constraints

The design should provide safe water to the community year round, including during dry season or drought, as judged against Kenyan and World Health Organization (WHO) standardized water quality regulations (see Codes and Regulations). The constraints are potability of water provided to the community, consistent availability of source water, and the building, disinfection and maintenance resources available in Kenya.

Criteria

A total of nine criteria were made to evaluate the effectiveness of each alternative. Each was given a weight between 1 and 5 based on importance (see Established Alternative Ranking System). Table 1 details the criteria by which the group judged the efficacy of each alternative considered.

Table 1. List of criteria, weights, and weight justification.

Criteria	**Weight (1-5)**	**Justification**
Durability	3	The design should be able to withstand everyday use as well as Kenyan weather, both now and as the climate grows more extreme. The climate currently is relatively mild, with consistent temperatures throughout the year and rainy and dry seasons. Durability was given a weight of 3/5 because the design should be relatively durable on its own, but the team prioritized the community's ability to repair the design over the design's ability to withstand extreme events. (See "ease of operation and maintenance" criteria.) Access to potable water during Kenya's most common natural disaster, drought, is covered in the "consistent supply" criteria.
Ease of operation and maintenance	4	The community's ability to operate and maintain the solution is instrumental to the function and adoption of the solution, as opposed

		to continuation of the status quo, and is an important factor in contributing to community self-sufficiency. Ease of operation and maintenance was given a weight of 4/5 because of its importance to the long-term success of the design.
Cost of construction	2	The design should be frugal, but the partner NGO, Sabore's Well, will financially support the initial implementation of new infrastructure. Cost of construction was given a weight of 2/5 because there will be external financial support.
Cost of operation and maintenance	4	High costs of operation and maintenance of the solution may result in additional costs to community members, which could cause financial stress or returning to the status quo, or support from Sabore's Well to offset the costs, which would decrease community self-sufficiency. Cost of operation and maintenance was given a weight of 4/5 because of its importance to the long-term success of the design.
Ease of access to water	3	The solution should be accessible to all households in the community, ideally more accessible than the status quo. The solution should decrease time and/or risk associated with collecting water. Ease of access to water was given a weight of 3/5 because the solution should improve accessibility, but given the inaccessibility of the status quo, it is clear that distance is not an integral factor.
Variation in source water	5	Less variation in source water will improve sustainability of the solution because consistent source water quality will reduce the need for future adjustments to the solution. Variation in source water was given a weight of 5/5 because less variation would simplify the solution and make the design more trustworthy long-term, but can be planned for with redundancy. Additionally, any variation in the source water significantly increases the cost and ease of operation/maintenance.

Ease of access to construction materials	3	If the design requires construction of new infrastructure, the materials should be retrievable by truck within a timely manner. Ease of access to construction materials was given a weight of 3/5 because it will impact the schedule and budget of the project, but will not be an ongoing issue.
Ease of access to maintenance materials	4	Any additional materials for the operation and maintenance of the design should be easily accessible to increase likelihood of long-term adoption. Access to maintenance materials should not decrease community self-sufficiency. Ease of access to maintenance materials was given a weight of 4/5 because of its importance to the long-term success of the design.
Community self-sufficiency	4	An accessible, safe water source should empower the community by minimizing coping costs, saving time, and decreasing risk. The design should improve or maintain the community's current self-sufficiency, and should not force the community to be dependent on outside organizations.

Alternative Solutions

Four solutions were identified and compared against each other and the baseline. The solutions are as follows:

- Well water purification system: construct a water purification system to purify the groundwater pumped by Supetai Well.
- Personal home water purification system: provide each household with a personal water filtration system, such as Lifestraw Family™.
- Spring water purification system: construct a water purification system to purify the water of the spring where community members currently collect their water.
- Frequent water truck delivery: hire a truck to deliver clean water to the community on a regular basis.

Alternatives Analysis

To determine the solution that best fits the need, each alternative was assigned a value from 1-5 that quantifies how closely it meets each criteria. Table 2 outlines the definitions of each numerical value.

Table 2. Alternatives Ranking System.

Numerical Value	Meaning
1	Does not meet criteria.
2	Barely or partially meets criteria.
3	Adequately meets criteria.
4	Meets criteria well.
5	Exceeds criteria.

The results of the alternative analysis are summarized in Table 3. The complete alternatives analysis matrix can be found in Table A-1.

Table 3. Alternatives Analysis Summary.

Solution	Score
Baseline	115
Well Purification System	106
Supply Purification Tools by Household	70
Spring Purification System	80
Water Truck	100

The highest scoring solution is the baseline, at 115, due largely to the lack of financial spending. Though it best meets criteria, it is disqualified as a solution because it does not meet the constraint of providing potable water adhering to the Kenyan and WHO drinking water standards.

Designing a well water purification system received a score of 106. The design would be a conventional purification system, including coagulation and flocculation, sedimentation, filtration, and disinfection. It would require the addition of chemicals to coagulate and stabilize pH in addition to the constructed infrastructure. This solution scored positively in the criteria of ease of access to potable water, low variability in source water, and facilitation of community-self sufficiency. It scored poorly in cost of construction, cost of operation and maintenance, and ease of operation and maintenance.

Providing each household in the community with a personal water filtration system received a score of 70. The filtration system assessed was the Lifestraw Family^{TM}, due it being the most cost effective option with the longest filter lifespan of the personal filters researched. Water collected from the spring would be passed through the membrane filter to remove harmful pathogens at a rate of up to 12 liters per hour (L/hr) (Lifestraw). This solution scored positively in cost and ease of operation and maintenance. It scored poorly in ease of access to materials, variation in source water, and community self-sufficiency

Designing a spring water purification system received a score of 72. Like the well purification system, it would consist of physical infrastructure for coagulation and flocculation, sedimentation, filtration, and disinfection, as well as chemical addition. This solution scored positively in ease of access to construction materials and community self-sufficiency. It scored poorly in ease of access to water and variability in source water.

A scheduled 4,000 gallon water truck delivering potable water to the community every two days received a score of 100. This solution scored positively in ease of operation and maintenance, variation in source water, cost of construction, and ease of access to construction materials, as no additional construction would be required. It scored poorly in cost of operation and maintenance and community self-sufficiency.

Proposed Solution

According to the alternatives analysis detailed above, the well purification system was the solution that both satisfied the constraints and best fit the solution criteria. It is the most likely to succeed in being widely and sustainably adopted by the community, and provide a long-term clean and accessible water source.

DESIGN CRITERIA and STANDARDS

Codes and Regulations

The group evaluated and compared Kenyan, American, and international water quality regulations to determine water constituent ranges. For any instances where water quality regulations were inconsistent across agencies, the most conservative value was taken. Relevant codes and standards as they relate to specific water attributes are listed below.

- The Kenyan Water Quality Regulations and WHO stipulate that maximum fluoride levels should not exceed 1.5 milligrams per liter (mg/L) for domestic use (Kivuthia 2006) (WHO 2017). The Environmental Protection Agency (EPA) stipulates that the maximum fluoride levels should not exceed four (4) mg/L (EPA). In this case, the treated water will be designed to contain 1.5 mg/L of fluoride or less.
- The WHO maintains that no health-based guideline value has been derived for sodium, as the contribution from drinking water to daily intake is minute. The EPA supports this guideline by stating that dietary intakes of sodium range from 1800 milligrams per day (mg/day) to 5000 mg/day (EPA). The 448 mg/L level of sodium in the groundwater tested therefore is not of health concern. The WHO notes that at room temperature, however, the average taste threshold for sodium is 200 mg/L (WHO 2017). The Water Services Regulatory Board in Kenya upholds that this is merely an aesthetic aspect. Therefore, high sodium concentrations were not addressed in the design.
- The WHO states that for effective disinfection with chlorine, the pH of water should be within the range of 6.5-8.5 (WHO 2017). This range is upheld by the Water Services Regulatory Board, the Kenyan Water Quality Regulations, and the EPA. This pH range will be upheld in the final design.
- Nationwide Private Client suggests that the minimum water pressure for a home pipe system is 30 pounds per square inch (psi), with a maximum pressure of 80 psi (NWPC). This is to prevent leakages and appliance failure. This is the range of water pressure that was used in the final design.

DESCRIPTION of DESIGNED FACILITY

Design Approach

The solution was designed to be a conventional water treatment system. It was based on U.S. standards and guidelines for water treatment design, then adapted and scaled to fit the needs and constraints of the community. The design process included capacity analysis to determine flow rate, lab work to determine chemical concentrations, and theoretical design of physical infrastructure.

Site Considerations

There is ample space for additional infrastructure to be constructed near the well and school with minimal need for vegetation clearing or site grading. The design should utilize the existing infrastructure - the well, pump, and primary storage tank - and be integrated seamlessly. The solar panel supports the pump with minimal extra power. The design should rely primarily on head drop for energy, and any electrical components in addition to the pump cannot exceed the capacity of the solar panel. Platforms may be required to achieve head drop due to the land's minimal natural elevation change.

Some water is currently being diverted to troughs for herd animals, and the design should continue to meet this need. Purified water should be easily stored and collected at the termination of the treatment train, such that it is accessible to all community members and the school.

Capacity

Community water usage, frugality and design footprint were key factors in determining the capacity of the system. Based on communication with community contact, Sabore, a conservative estimate for individual water needs is 25 L/day, and about 3500 people would be served by the well. The demand was calculated to be 87,500 L/day (Figure A-2). The flow rate of the design was constrained by the decision to make it a gravity-fed system, as well as to follow U.S. standards regarding water treatment design principles and checks. Due to the large scale of the system compared to community need, the system is designed to only operate for 1 hour at a time at a flow rate of 87,500 L/hr. Though the flow rate was based on daily water needs, the actual water use of individuals in the community is very low. Sabore estimates that this quantity of water will meet community demand for two to three weeks.

Overview

The treatment plan schematic is illustrated in Figure 2. Water pumped from the well will be stored in the existing holding tank. Some untreated water will be diverted to existing troughs to which shepherds bring their goats, sheep, and cows so they can continue to utilize the well without spending treatment resources on livestock. The remaining water will have alum and sodium carbonate added and be sent through a parshall flume and vertical impeller flocculator for coagulation and flocculation, then a sedimentation basin to remove the majority of the sludge, followed by a slow sand filter to remove remaining particulates. Finally, the final holding tank will have in-line chlorinators in the pipes entering and exiting to ensure no organic growth in the tank and adequately disinfected water consumed by the community.

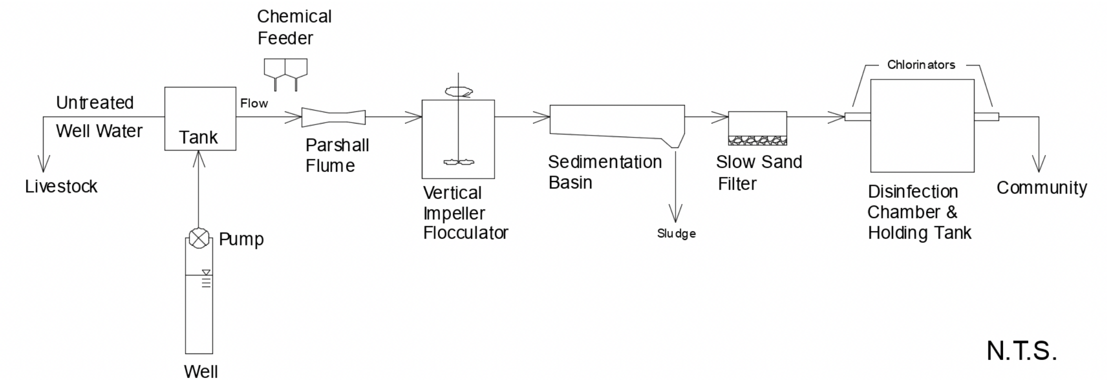

Figure 2. Treatment plant schematic.

Chemical Addition

To remove fluoride from water, the surface charge of the fluoride atoms must be altered (coagulation), such that the particles will group together as flocs (flocculation) that can be removed through sedimentation and filtration. The selected coagulant is aluminum sulfate ($Al_2(SO_4)_3$), or alum, because aluminum hydroxides are effective absorbents of fluoride, and alum is a common, accessible chemical.

When alum dissociates in water and aluminum bonds with hydroxide, the pH drops (Equation 2). Low pH does not meet WHO safe water standards, and is outside of the aluminum hydroxide solubility range (Figure A-5), preventing the formation of flocs. Thus, in addition to alum, sodium carbonate (Na_2CO_3), or soda ash, is added to rebalance the pH to acceptable levels.

$$Al_2(SO_4)_3 \rightarrow 2\,Al^{3+} + 3\,SO_4^{\,2-}$$

Equation 1: Dissociation of alum.

$$2\,Al^{3+} + 6\,OH^{-} \rightarrow 2\,Al_2(OH)_{3\,(S)}$$

Equation 2: Formation of aluminum hydroxide.

Both alum and soda ash are accessible; they were found by the community contact to be available for purchase in a nearby town.

To determine the concentrations of alum and soda ash required to remove fluoride and balance pH, a batch solution of synthesized well water was mixed using the lab data provided by Sabore's Well (Figure A-4a). Calculations supporting the recipe can be found in Figure A-5a, A-5b and A-5c. The pH and fluoride levels were tested to confirm similarity to the lab data.

Varying quantities of alum were added to the synthesized water to determine the optimal quantity to absorb fluoride and reduce the fluoride concentration below the WHO standard of 1.5 mg/L. Figure 3 shows data from two tests fitted with a logistic regression.

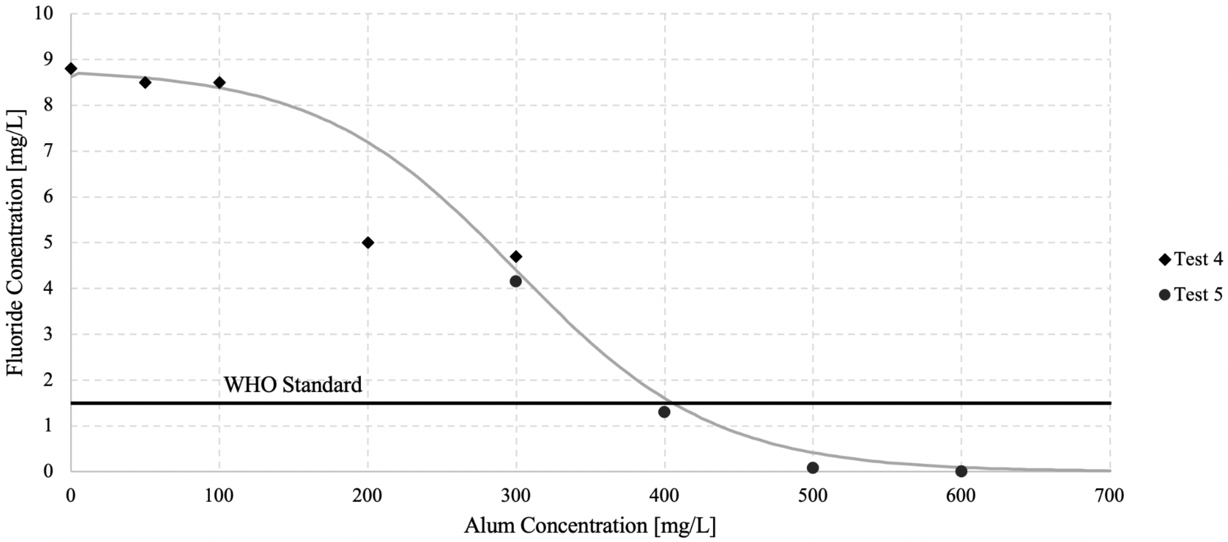

Figure 3. Lab data of dissolved fluoride concentrations after alum addition with WHO water quality standard and fitted logistic regression.

The concentration of alum found to reduce fluoride sufficiently was 400 mg/L. The target pH after alum addition was 6-7 to be well within WHO water quality standards and the pH range for aluminum hydroxide ($Al(OH)_{3(S)}$) to precipitate (Figure A-5). 160 mg/L of soda ash balanced the pH to a safe range. These values are summarized in Table 4. Additional data and lab work details can be found in the Appendix in Tables A-2 through A-6.

Table 4. Chemical addition summary.

Chemical	**Concentration**
Alum	400 mg/L
Soda Ash	160 mg/L

Chemical Feeder

The chemicals will be added using a chemical feeder containing two compartments. The feeder will be made of concrete/masonry and placed above an open channel between the primary storage tank and parshall flume.

The chemical feeder is designed to drip two concentrated alum and soda ash slurries at a constant rate. The alum slurry contains 35 kg alum in 350 L of water, and the soda ash slurry contains 14 kg soda ash in 200 L of water.

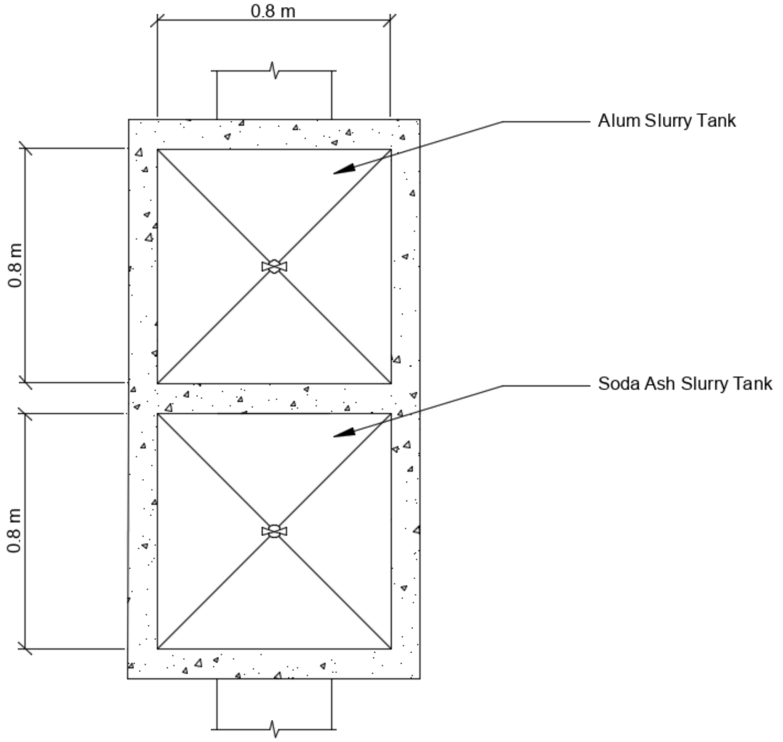

Figure 4a. Chemical Feeder plan view.

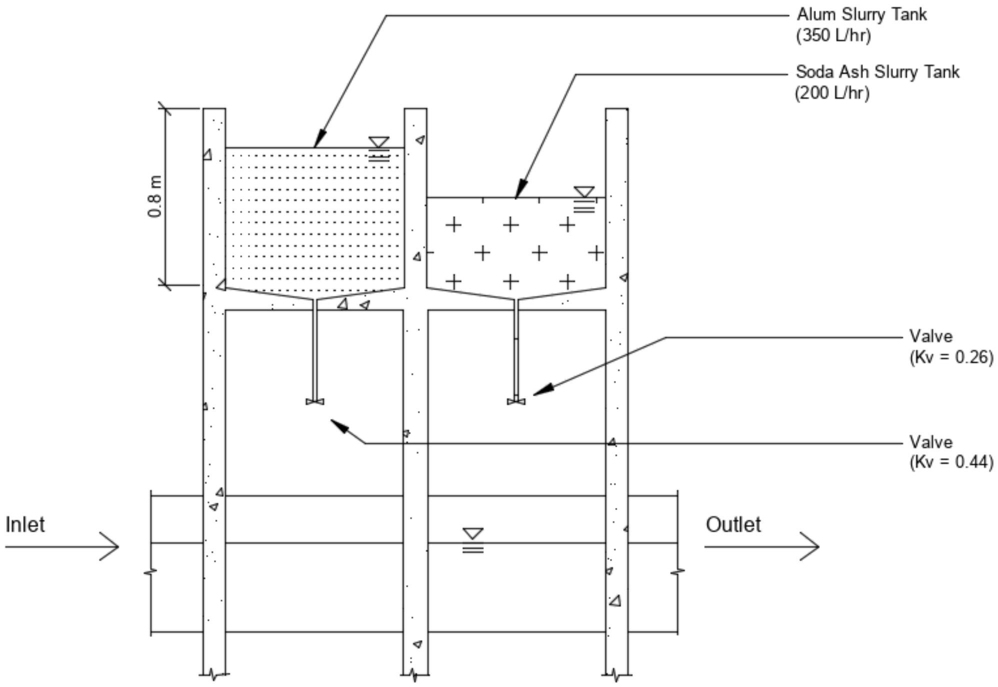

Figure 4b. Chemical feeder elevation view.

Coagulation

The alum and soda ash are to be mixed using a Parshall Flume (Figures 5a and 5b). This method consists of an open flow channel containing a restriction and hydraulic jump which increases turbulence and induces flash mixing without electricity.

The Parshall Flume was designed in order to match the design flow rate requirement of 87,500 L/hr. With this in mind, a parshall flume containing a 0.15 meter throat reduction and 0.27 meter height difference was chosen.

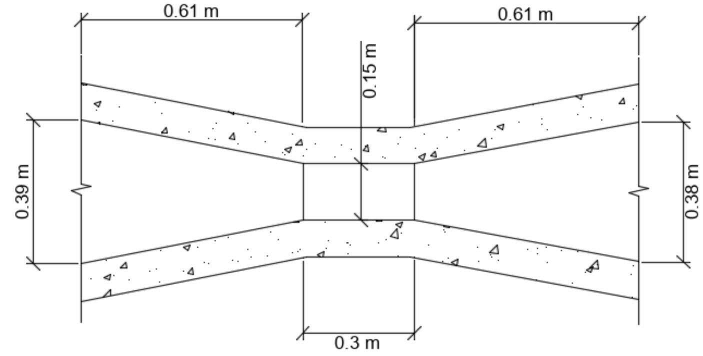

Figure 5a. Parshall flume plan view.

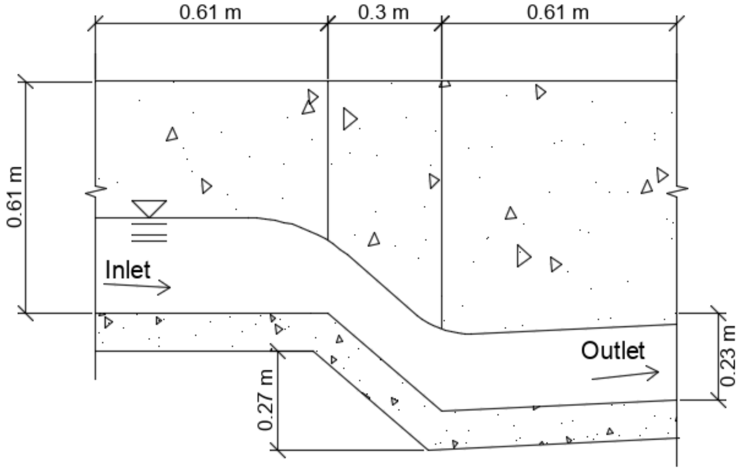

Figure 5b. Parshall flume side view.

Flocculation

The flocculation method chosen for this preliminary design was a vertical impeller flocculator (Figures 6a and 6b). This method consists of a cylindrical basin with a submerged impeller to bring across mixing.

A pitched blade turbine with camber of 2.4 meter diameter was designed to be in a 2 meter high and 5.4 meter in diameter basin. The blade turbine was also designed to be 0.9 meter off the ground of the basin. Four baffle walls 0.54 meters long were placed every 90 degrees within the basin to aid in mixing. This design successfully met all requirements to bring about flocculation for the design flow rate.

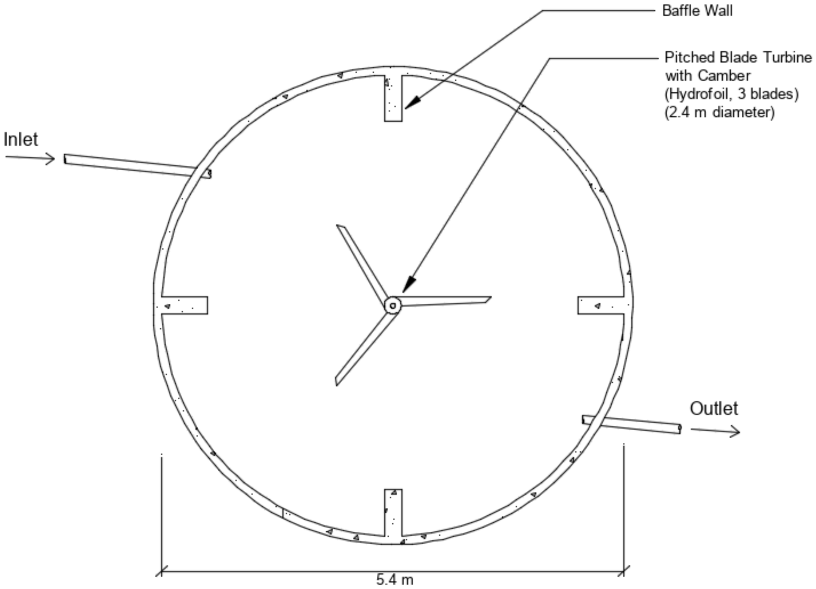

Figure 6a. Vertical impeller flocculator plan view.

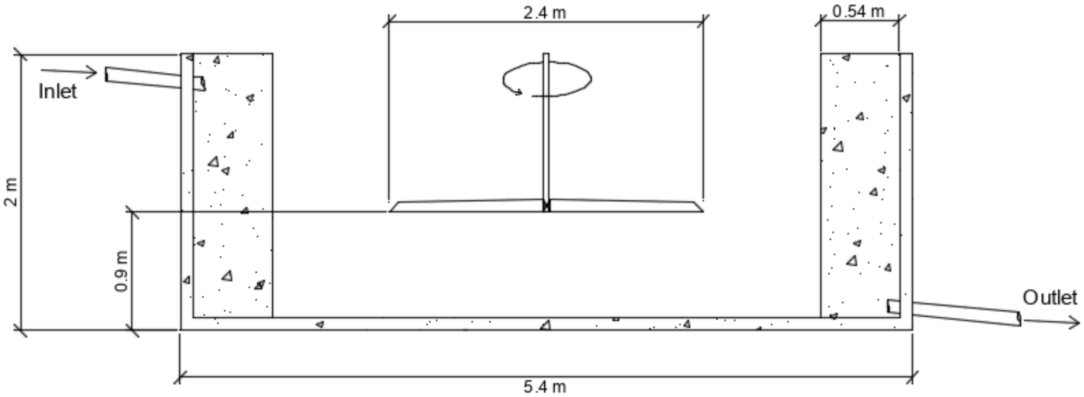

Figure 6b. Vertical impeller flocculator elevation view.

Sedimentation

Per industry standards, the sedimentation basin was designed for 85% particle removal. The width of the sedimentation basin was set to be 1.5 meters. The settling velocity of the alum flocs was assumed to be four (4) meters per hour (m/h) (Crittenden et. al, 2012).

Using the estimated flow rate of 87500 L/day and a system running time of one hour per day, the length of the sedimentation basin was determined to be 15 m, rounded up for safety and security of design. A diffuser wall would be placed 0.5 m (approximately 4% of the length) away from the inlet wall to distribute the flow evenly. The height of the basin was determined to be 1.5 m, not including the sludge zone. The bottom of the tank should have a minimum slope of 1:300 to facilitate sludge removal (Davis and Cornwell, 2008). A slope of 5% was chosen to maximize sludge collection without use of electricity, while keeping the size of the design minimal (Toprak, 2006). The sludge would be collected in a hopper which would need to be periodically cleaned. The hopper was designed to hold 480 kg of sludge, which is the amount that would be generated from running the system one hour every day for one month.

To provide redundancy in case of damage to one basin and for when cleaning of one basin is necessary, an adjacent basin would be attached to the sedimentation basin in use. They will be connected with a pipe (ϕ100 mm) and valve so that a majority of the water could be transferred between basins without being wasted.

The entire sedimentation system would be elevated to ensure that the sludge can be cleaned out easily and efficiently. The system was designed to be elevated a minimum of 0.5 m above the ground level. This was to ensure that the sludge and water will flow to their next respective phases using gravity.

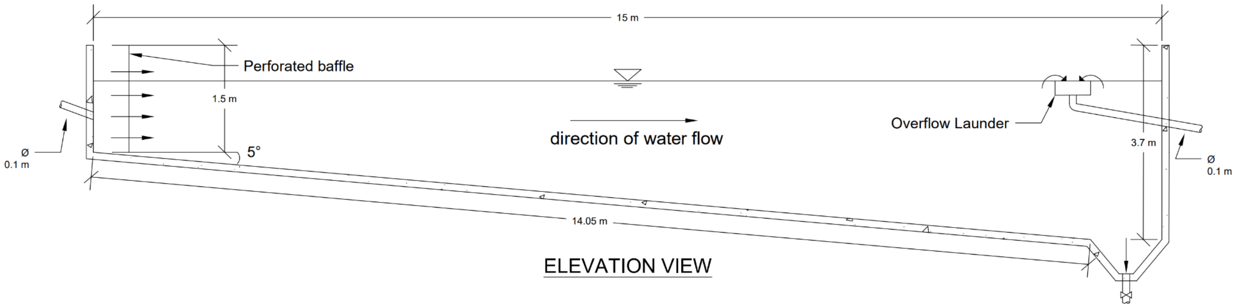

Figure 7a. Sedimentation basin elevation view.

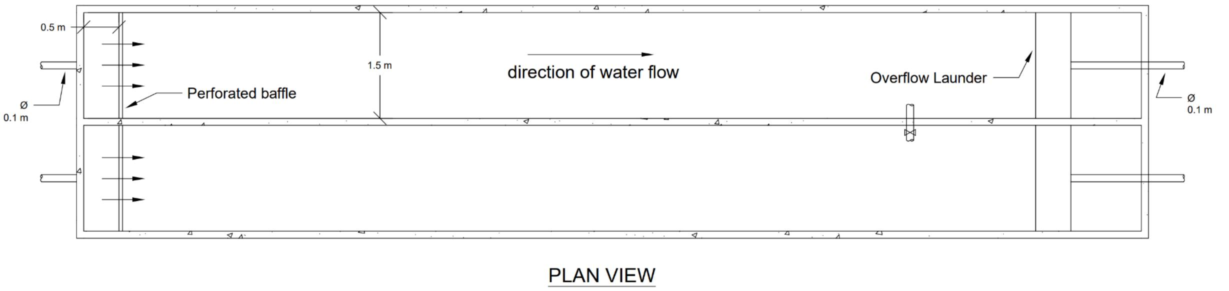

Figure 7b. Sedimentation basin plan view.

The diffuser wall should have baffles that are 50 mm in diameter and offset evenly. This ensures that the water is distributed evenly through the holes. The overflow launder should be placed one meter (1 m) from the end wall to avoid end-wall upflow loss. Additionally, the launder should have v-notched weirs at the top so that water will flow evenly and smoothly into the launder.

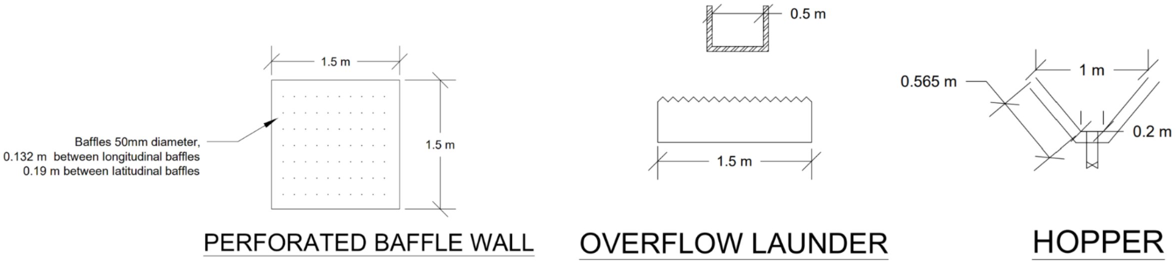

Figure 8. Sedimentation basin details.

Sludge Management

From the sedimentation basin hopper, the sludge will travel through a 100 mm diameter pipe to a percolation pond. The pond is designed to have a bottom layer of gravel with soil on top, onto which the sludge will be deposited. The sludge water will percolate through the layers while evaporating, such that the dry sludge will be integrated into the soil layer above the gravel. Due to the size of the pond and the estimation of how often the plant will need to be run (about two times per month), it is estimated that the sludge and soil layer will need to be disposed of every three years.

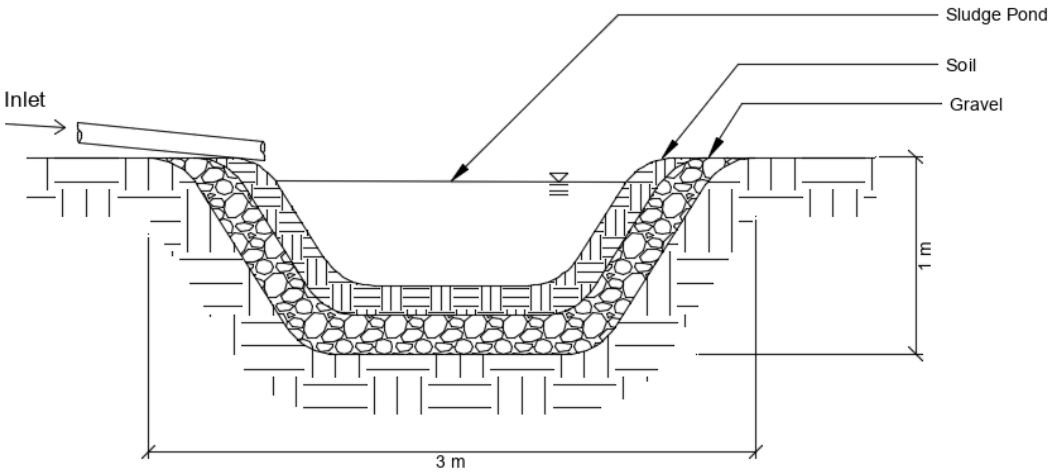

Figure 9a. Sludge Percolation Pond elevation view.

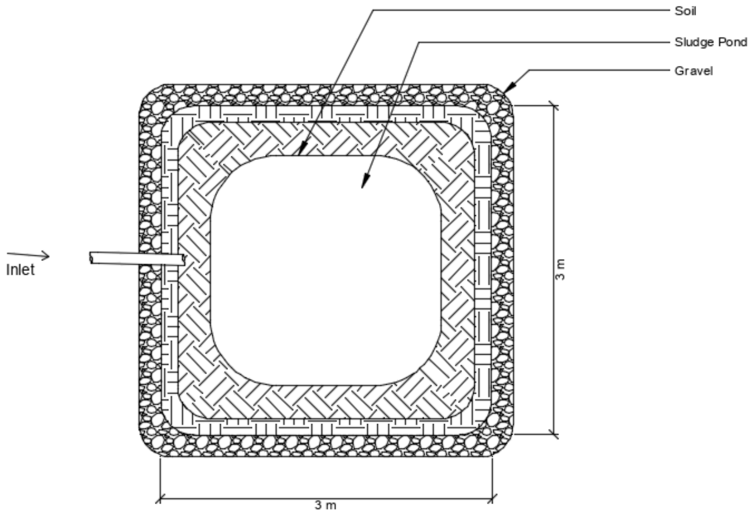

Figure 9b. Sludge percolation pond plan view.

Filtration

After 85% of particulate matter is removed in the sedimentation tank, the water will pass through a slow sand filter to remove the remaining 15%. The filter was sized according to rural sand filter design recommendations (Figure A-). The water will flow into a gutter surrounding the filter, and flow into the main body of the filter through pipes along the perimeter. Plates under each pipe will disperse the water as it falls onto the filter media, preventing erosion where water flows into the filter (Figures _a and _c).

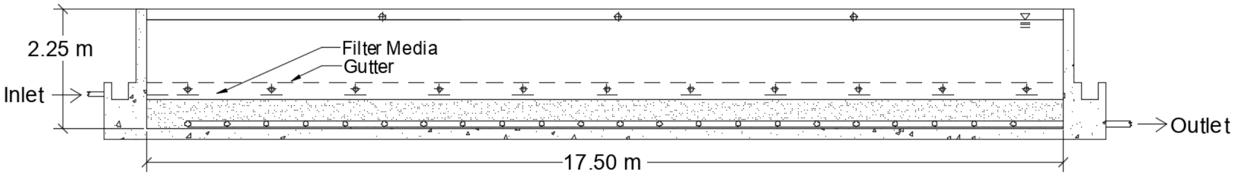

Figure 10a. Slow sand filter elevation view.

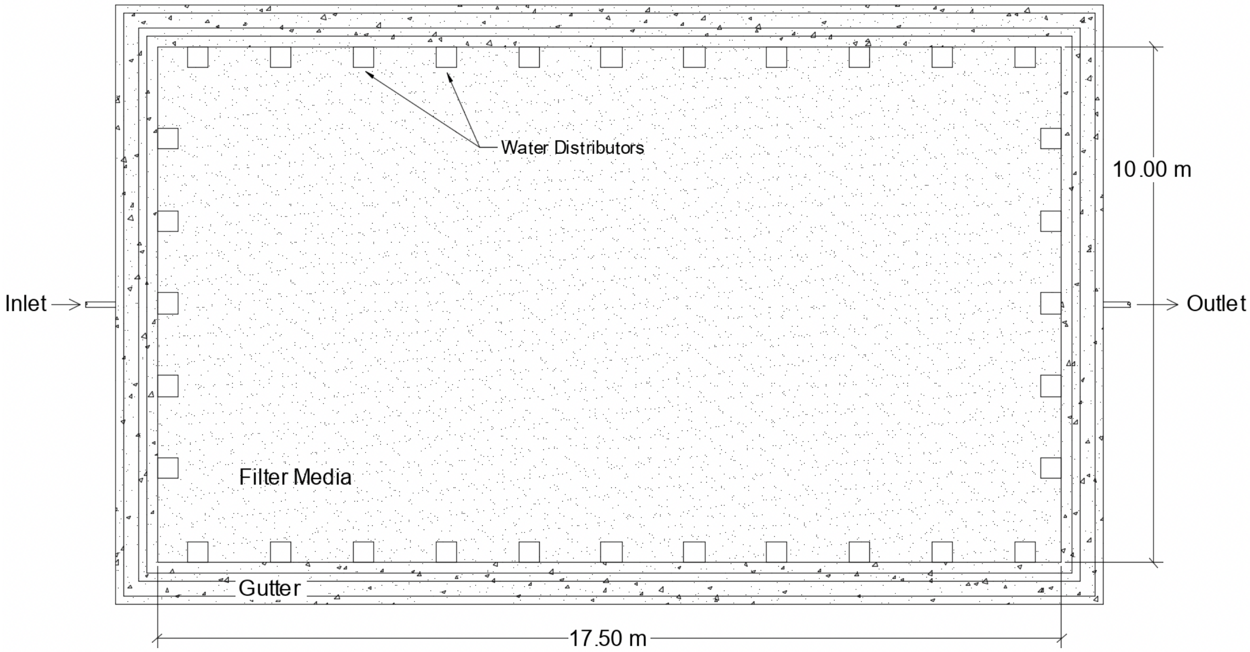

Figure 10b. Slow sand filter plan view.

The water will flood the filter to form a supernatant layer 1.5 meters tall. Suspended particles will settle and be deposited on the filter media as the water is pushed by gravity through layers of sand and gravel, increasing in coarseness. The height of filter media layers is listed in Table 5. At the final layer, a lattice of perforated pipes will collect the purified water to be sent to the final holding tank (Figure _c).

Table 5. Heights of vertical layers of slow sand filter.

Layer		Height (m)
Free Border		0.2
Supernatant Layer		1.5
Sand Bed		0.3
Gravel Bed	Least Coarse (1.5 - 4.0 mm)	0.05
	Med. Coarse (4 - 15 mm)	0.05
	Most Coarse (10 - 40 mm)	0.15
Total Height		2.25

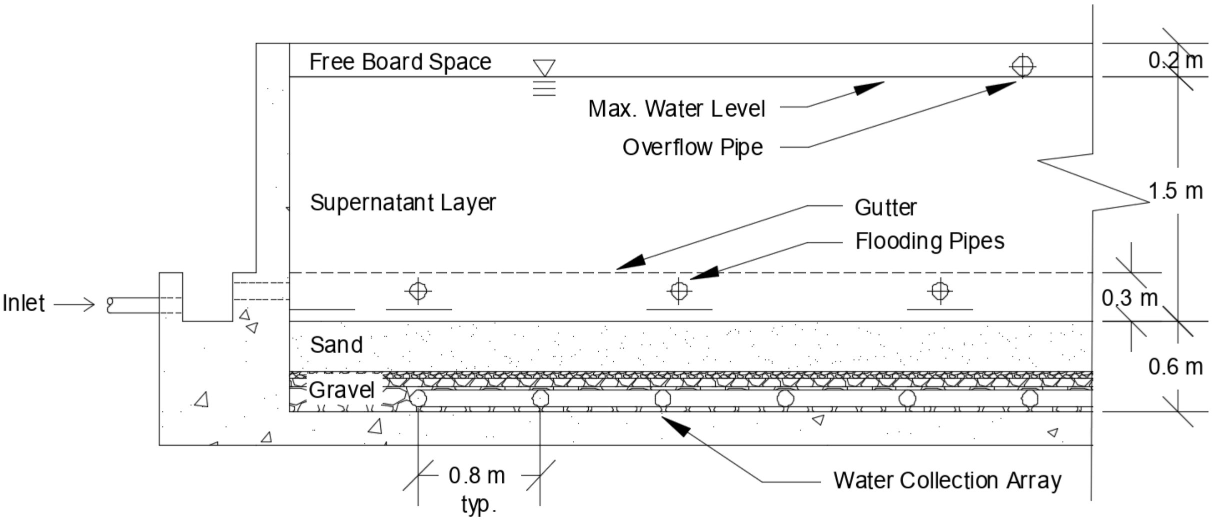

Figure 10c. Slow sand filter: elevation detail.

Typically, a slow sand filter also includes a schmutzdecke, a biological layer that breaks down and collects organic matter. This layer is not expected to form, nor is it necessary for effective purification, due to the low concentration of organic matter in the water.

Disinfection and Final Holding

Disinfection is the final step of the water purification process. Having removed harmful metals and particulates, a disinfectant is added to kill pathogens in the water. The chosen disinfectant is free chlorine in the form of calcium hypochlorite ($Ca(OCl)_2$) because it is accessible to the community and effective against most pathogens.

There is no data for pathogen levels in the water, but because the source of the water is an underground aquifer, it is assumed that the major pathogen of concern is viruses. To ensure thorough disinfection, there should be two (2) mg/L of chlorine and achieve 4-log inactivation of viruses. For the target pH of 6-9 at 15ºC, the Ct value is four (4) min×mg/L (Table A-2). For industry standard superior performance, the short circuiting factor, F_{SC}, was chosen to be 0.7. The required contact time and volume do not necessitate a chlorine contact basin (Figure A-7); the disinfection will occur in the final holding tank (Figure 11).

After the slow sand filter, the water will pass through a pipe with an inline chlorinator, such that the water in the tank will not have any viruses, nor will it be able to support organic growth as it is stored. There will be another inline chlorinator between the tank and the tap to ensure that the water is freshly disinfected before human consumption. Inline chlorinators are commonly used for pools, and are available for purchase in a nearby town. The holding tank will be five (5) cubic meters constructed using cinder blocks. These dimensions will provide ample space for the volume of a cycle of treated water and freeboard space.

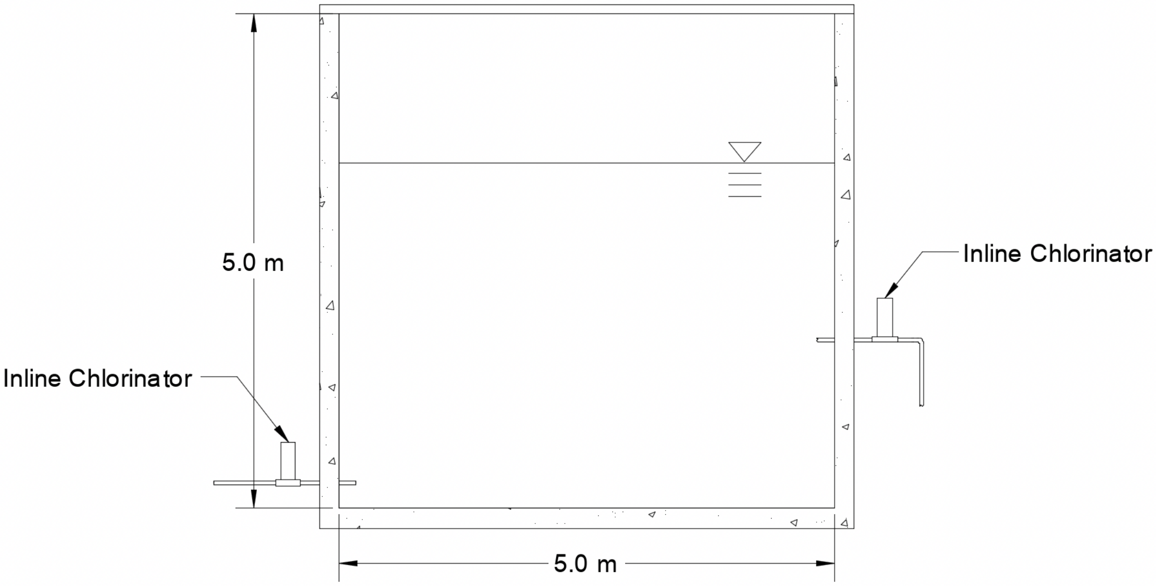

Figure 11. Final holding tank with in-line chlorination elevation view

Non-technical Considerations

The people this project will serve, including their unique historical, social, and cultural backgrounds, were at the heart of the design and all choices made along the way.

The team is aware of the failings of similar projects in the past, and were focused on creating a design that will meet the community's needs for years to come. According to UNICEF's 2017 Situation Analysis of Children and Women in Kenya, "25 to 30 percent of recently-constructed community-managed rural water supply facilities in Kenya will become dysfunctional in the first three years following construction" (UNICEF, 2018). Given this, attention was given to the capabilities and limitations of the community. In later stages, if the design is implemented, community education and involvement will empower them and give them a sense of ownership over the project, which will improve the likelihood of sustained upkeep and use. At this stage in the project, a non-technical educational pamphlet was provided to the client. It provides key information about the risk of fluoride consumption, water treatment design and a timeline of design implementation (Figure A-). The client was also provided with non-technical operation and maintenance information to begin planning for feasibility and implementation (Figure A-).

Additionally, the environmental and political impacts have been considered. Environmental impacts include an increase in the ground-water pumping rate in the region and the natural disposal of sludge produced in water treatment. However, research done regarding the aquifer confirms that there will be little environmental impact (Kariuki 2012). Political impacts will be contained in the community; we are not anticipating involvement of outside political entities. Our client expressed that with the construction of the project will come the establishment of a water system management board to ensure sustained operation of the plant, management of funds and resources, and community access to water. This organization will be facilitated by community leader Sabore.

COST ESTIMATE

Locally available construction materials were taken into consideration when designing the water treatment system. Most components of the design are to be constructed using masonry and reinforced concrete. Connections between water treatment components are to be made using PVC piping. Prices were sourced from local distributors provided to the team by the client. Cement was found to be $9 per 40kg bag, masonry to be $0.23 per foot, and sand to be $14.55 per ton. Electrical components needed include a custom 2.4 meter in diameter impeller and motor. These prices were sourced from an international distributor.

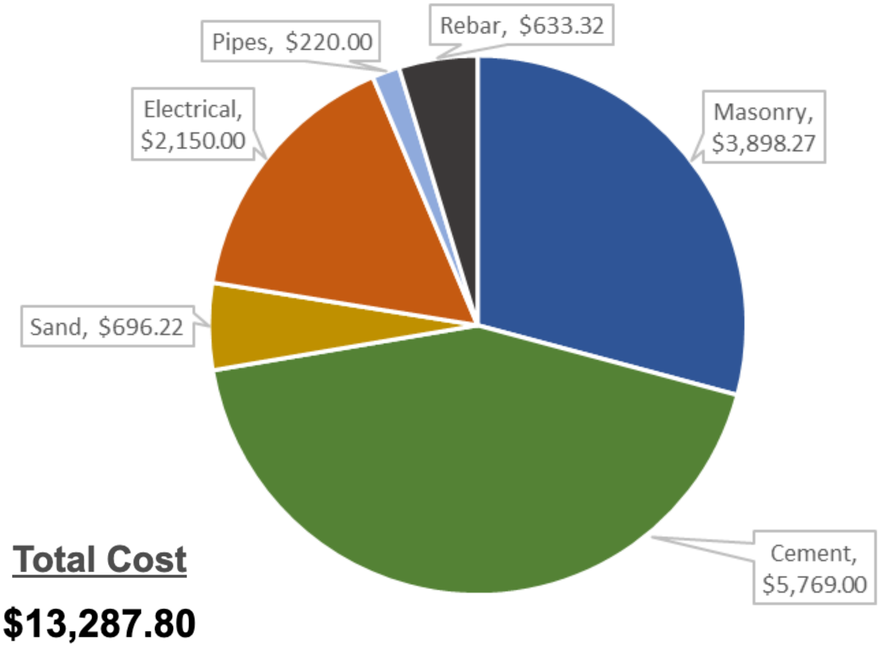

Figure 12. Pie chart showing estimated construction cost.

The design will also require ongoing costs to run, primarily alum and soda ash. Operation costs were estimated using the annual chemical requirements. Prices were sourced from a local distributor provided by the client.

Table 6. Table showing estimated annual operating cost.

Chemical	**Cost**
Alum	$3.159.29
Soda Ash	$193.27
Chlorine	$86.80
Total	**$3,439.36**

CONCLUSION

Clean, potable water is a fundamental human need. The residents of Oldonya Rasha currently do not have this need met. This is due to the unhealthy levels of fluoride that permeate the water within Supetai Well. The team has designed a gravity-fed water filtration system to remove the fluoride to a healthy, consumable concentration. The team hopes that this system will be constructed and implemented, so that it can be used to provide safe, reliable drinking water to the local community. Having this local source of drinking water could change the lives of the community, as it will reduce risk of disease and day-to-day physical labor.

While the team's design has the potential to impact the lives of the community, the full implementation of it is in its preliminary stages. There is still work to be done to ensure that it can be actualized. This includes a geographic survey of the area, as well as a soil test. Once the soil is assessed, construction planning and drawing can begin. The team recommends that Sabore's Well consults with licensed engineers, specifically those local to the area or those specializing in international development, in order to make the design the most efficient and feasible it can be. Additionally, the community should be kept at the center of all planning and processes regarding the implementation and adoption of the design. This includes educating the community on the use and maintenance of the design, as well as being open to community feedback.

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APPENDIX A

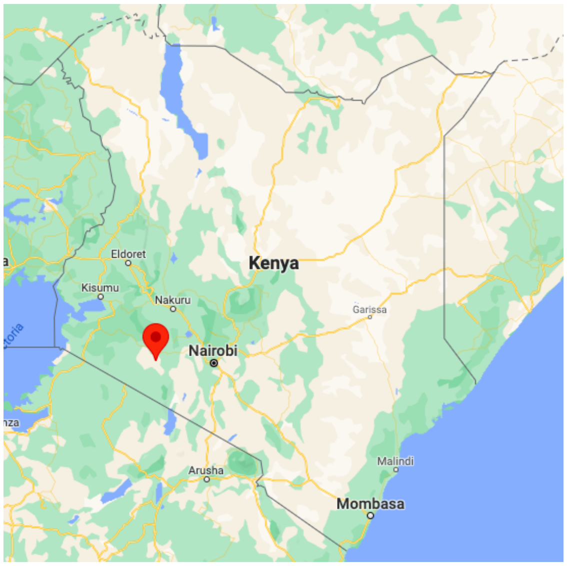
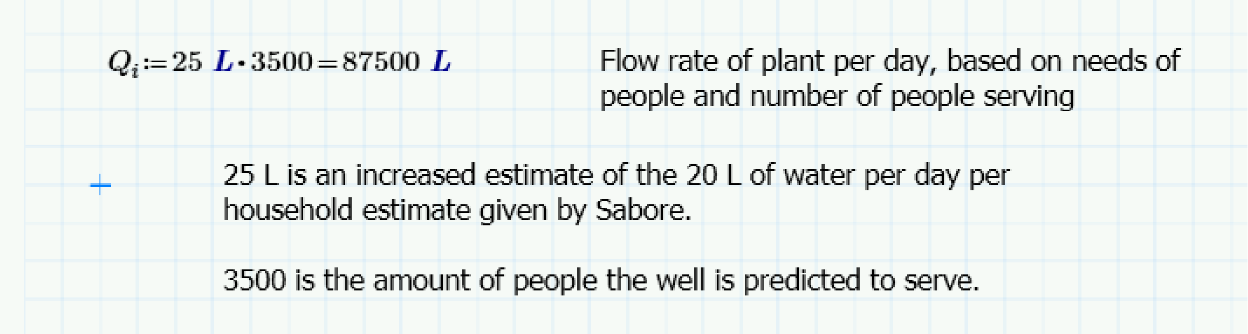


Figure A-1. Location of Oldonya Rasha in Narok County, Kenya.



$Q_i := 25\ L \cdot 3500 = 87500\ L$ Flow rate of plant per day, based on needs of people and number of people serving

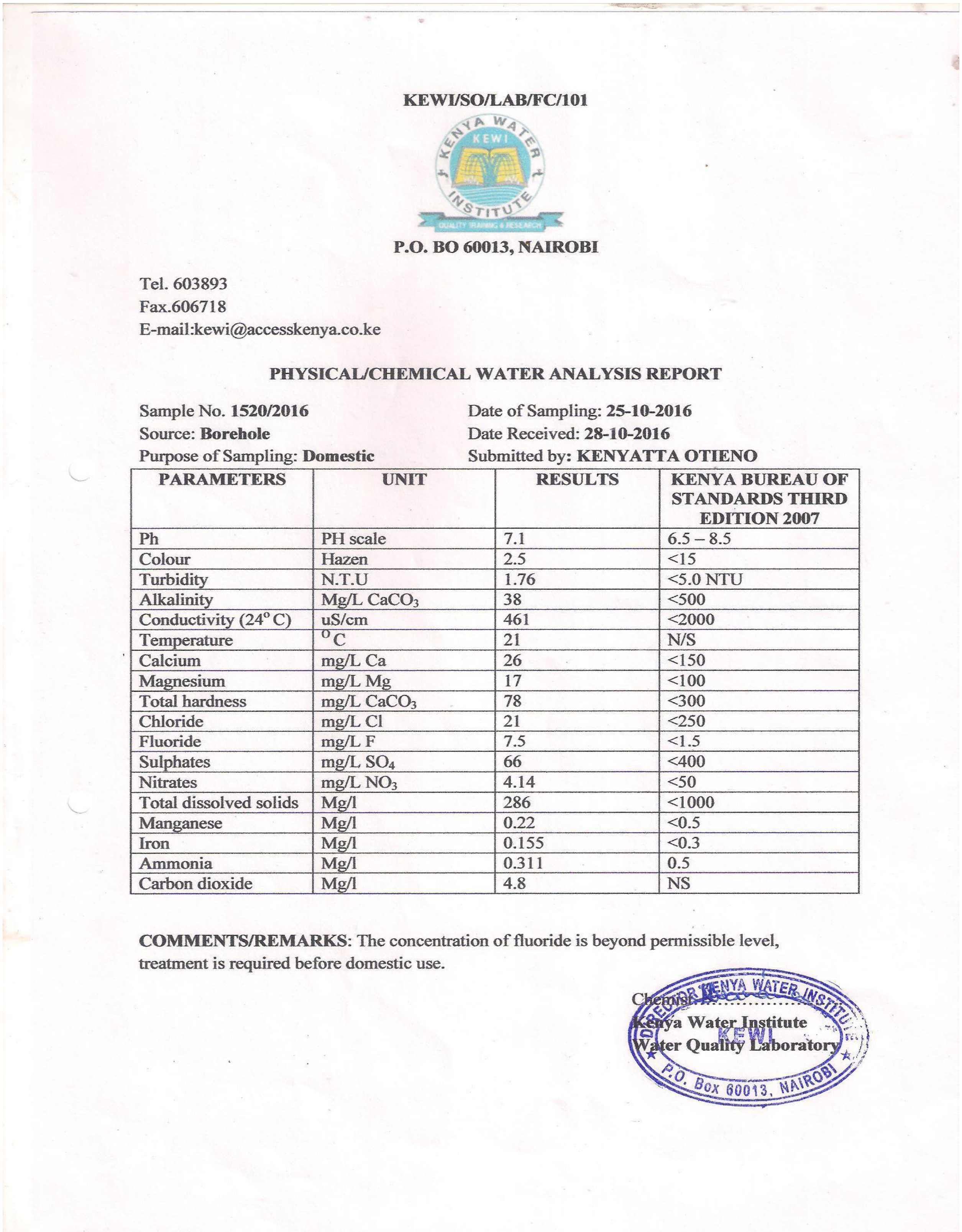
25 L is an increased estimate of the 20 L of water per day per household estimate given by Sabore.

3500 is the amount of people the well is predicted to serve.

Figure A-2. Water needs and flow rate estimate.

Table A-1. Alternative Analysis Matrix.

Criteria	**Weight (1-5)**	**Baseline**	**Well Purification System**	**Supply Purification Tools by Household**	**Spring Purification System**	**Water Truck**
Durability	3	5	3	3	3	3
Ease of operation/maintenance	4	4	2	4	2	4
Cost of construction	2	5	2	5	2	5
Cost of operation/maintenance	4	5	2	4	2	1
Ease of access	3	1	4	1	1	3
Variation in source water	5	0	5	0	0	5
Ease of access to construction materials	3	5	4	0	4	5
Ease of access to maintenance materials	4	5	3	1	3	2
Community self-sufficiency	4	4	4	3	4	1
Total:		115	106	70	72	100



KEWI/SO/LAB/FC/101

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E-mail:kewi@accesskenya.co.ke

PHYSICAL/CHEMICAL WATER ANALYSIS REPORT

Sample No. **1520/2016**
Source: **Borehole**
Purpose of Sampling: **Domestic**

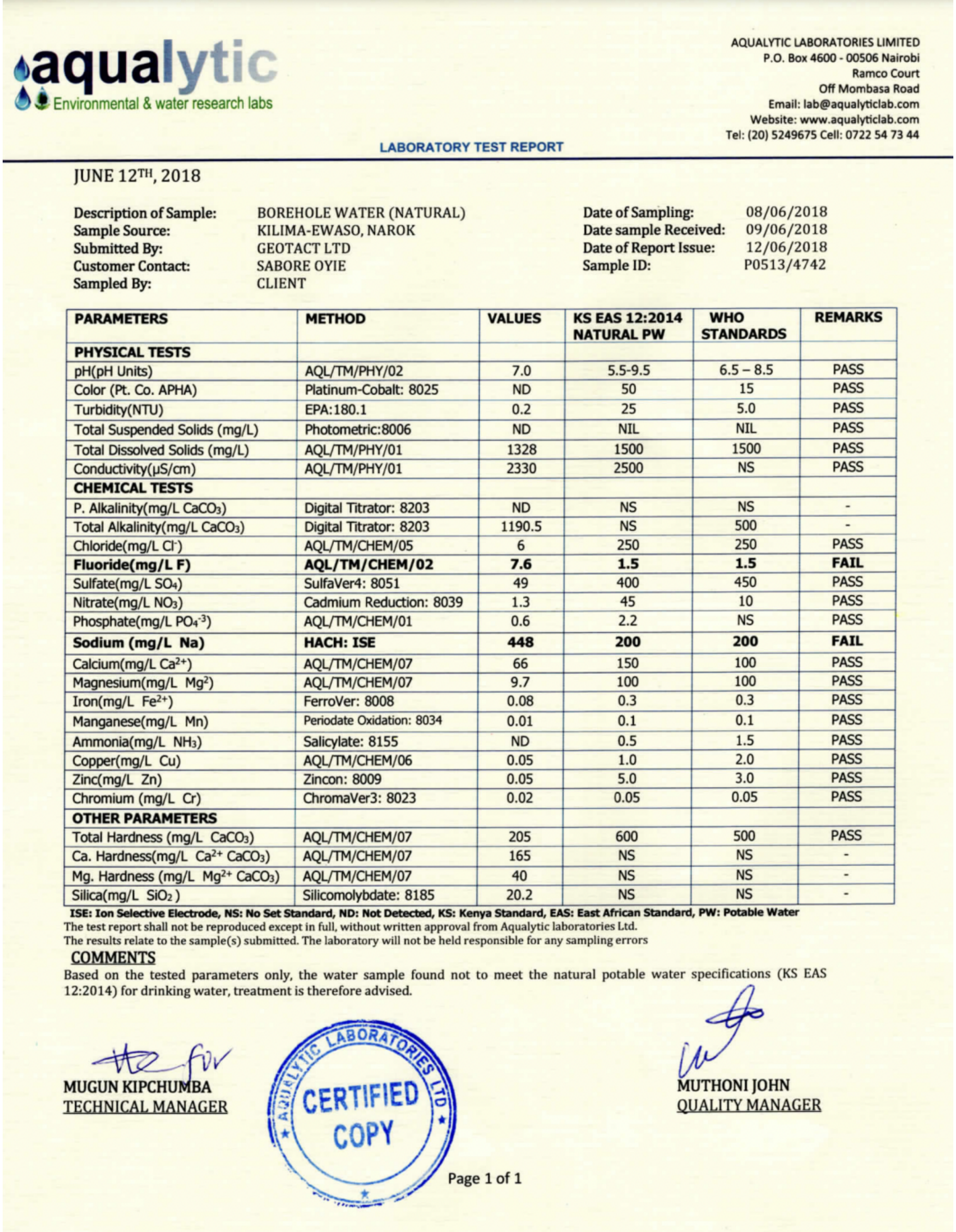
Date of Sampling: **25-10-2016**
Date Received: **28-10-2016**
Submitted by: **KENYATTA OTIENO**

PARAMETERS	UNIT	RESULTS	KENYA BUREAU OF STANDARDS THIRD EDITION 2007
Ph	PH scale	7.1	6.5 – 8.5
Colour	Hazen	2.5	<15
Turbidity	N.T.U	1.76	<5.0 NTU
Alkalinity	Mg/L $CaCO_3$	38	<500
Conductivity (24° C)	uS/cm	461	<2000
Temperature	^oC	21	N/S
Calcium	mg/L Ca	26	<150
Magnesium	mg/L Mg	17	<100
Total hardness	mg/L $CaCO_3$	78	<300
Chloride	mg/L Cl	21	<250
Fluoride	mg/L F	7.5	<1.5
Sulphates	mg/L SO_4	66	<400
Nitrates	mg/L NO_3	4.14	<50
Total dissolved solids	Mg/l	286	<1000
Manganese	Mg/l	0.22	<0.5
Iron	Mg/l	0.155	<0.3
Ammonia	Mg/l	0.311	0.5
Carbon dioxide	Mg/l	4.8	NS

COMMENTS/REMARKS: The concentration of fluoride is beyond permissible level, treatment is required before domestic use.

Chemist: ……………………
Kenya Water Institute
Water Quality Laboratory

Figure A-3a. Supetai Well Water Laboratory Test Report, 2016.



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LABORATORY TEST REPORT

JUNE 12TH, 2018

Description of Sample:	BOREHOLE WATER (NATURAL)	**Date of Sampling:**	08/06/2018
Sample Source:	KILIMA-EWASO, NAROK	**Date sample Received:**	09/06/2018
Submitted By:	GEOTACT LTD	**Date of Report Issue:**	12/06/2018
Customer Contact:	SABORE OYIE	**Sample ID:**	P0513/4742
Sampled By:	CLIENT		

PARAMETERS	METHOD	VALUES	KS EAS 12:2014 NATURAL PW	WHO STANDARDS	REMARKS
PHYSICAL TESTS					
pH(pH Units)	AQL/TM/PHY/02	7.0	5.5-9.5	6.5 – 8.5	PASS
Color (Pt. Co. APHA)	Platinum-Cobalt: 8025	ND	50	15	PASS
Turbidity(NTU)	EPA:180.1	0.2	25	5.0	PASS
Total Suspended Solids (mg/L)	Photometric:8006	ND	NIL	NIL	PASS
Total Dissolved Solids (mg/L)	AQL/TM/PHY/01	1328	1500	1500	PASS
Conductivity(μS/cm)	AQL/TM/PHY/01	2330	2500	NS	PASS
CHEMICAL TESTS					
P. Alkalinity(mg/L $CaCO_3$)	Digital Titrator: 8203	ND	NS	NS	-
Total Alkalinity(mg/L $CaCO_3$)	Digital Titrator: 8203	1190.5	NS	500	-
Chloride(mg/L Cl^-)	AQL/TM/CHEM/05	6	250	250	PASS
Fluoride(mg/L F)	**AQL/TM/CHEM/02**	**7.6**	**1.5**	**1.5**	**FAIL**
Sulfate(mg/L SO_4)	SulfaVer4: 8051	49	400	450	PASS
Nitrate(mg/L NO_3)	Cadmium Reduction: 8039	1.3	45	10	PASS
Phosphate(mg/L PO_4^{-3})	AQL/TM/CHEM/01	0.6	2.2	NS	PASS
Sodium (mg/L Na)	**HACH: ISE**	**448**	**200**	**200**	**FAIL**
Calcium(mg/L Ca^{2+})	AQL/TM/CHEM/07	66	150	100	PASS
Magnesium(mg/L Mg^{2})	AQL/TM/CHEM/07	9.7	100	100	PASS
Iron(mg/L Fe^{2+})	FerroVer: 8008	0.08	0.3	0.3	PASS
Manganese(mg/L Mn)	Periodate Oxidation: 8034	0.01	0.1	0.1	PASS
Ammonia(mg/L NH_3)	Salicylate: 8155	ND	0.5	1.5	PASS
Copper(mg/L Cu)	AQL/TM/CHEM/06	0.05	1.0	2.0	PASS
Zinc(mg/L Zn)	Zincon: 8009	0.05	5.0	3.0	PASS
Chromium (mg/L Cr)	ChromaVer3: 8023	0.02	0.05	0.05	PASS
OTHER PARAMETERS					
Total Hardness (mg/L $CaCO_3$)	AQL/TM/CHEM/07	205	600	500	PASS
Ca. Hardness(mg/L Ca^{2+} $CaCO_3$)	AQL/TM/CHEM/07	165	NS	NS	-
Mg. Hardness (mg/L Mg^{2+} $CaCO_3$)	AQL/TM/CHEM/07	40	NS	NS	-
Silica(mg/L SiO_2)	Silicomolybdate: 8185	20.2	NS	NS	-

ISE: Ion Selective Electrode, NS: No Set Standard, ND: Not Detected, KS: Kenya Standard, EAS: East African Standard, PW: Potable Water

The test report shall not be reproduced except in full, without written approval from Aqualytic laboratories Ltd.
The results relate to the sample(s) submitted. The laboratory will not be held responsible for any sampling errors

COMMENTS

Based on the tested parameters only, the water sample found not to meet the natural potable water specifications (KS EAS 12:2014) for drinking water, treatment is therefore advised.

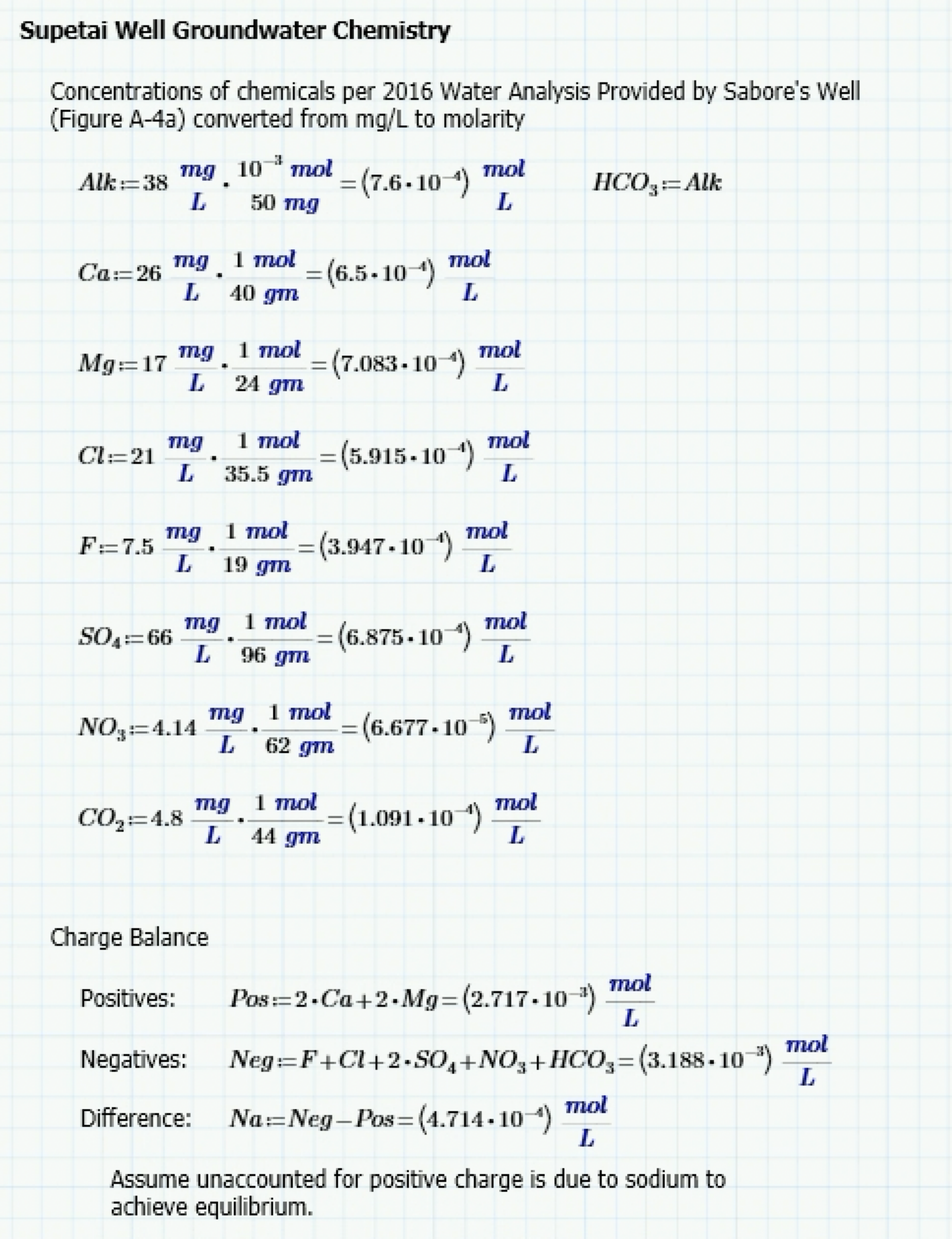
for
MUGUN KIPCHUMBA
TECHNICAL MANAGER

CERTIFIED COPY

MUTHONI JOHN
QUALITY MANAGER

Page 1 of 1

Figure A-3b. Supetai Well Water Laboratory Test Report, 2018.



Supetai Well Groundwater Chemistry

Concentrations of chemicals per 2016 Water Analysis Provided by Sabore's Well (Figure A-4a) converted from mg/L to molarity

$$Alk := 38\ \frac{mg}{L} \cdot \frac{10^{-3}\ mol}{50\ mg} = \left(7.6 \cdot 10^{-4}\right) \frac{mol}{L} \qquad HCO_3 := Alk$$

$$Ca := 26\ \frac{mg}{L} \cdot \frac{1\ mol}{40\ gm} = \left(6.5 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$Mg := 17\ \frac{mg}{L} \cdot \frac{1\ mol}{24\ gm} = \left(7.083 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$Cl := 21\ \frac{mg}{L} \cdot \frac{1\ mol}{35.5\ gm} = \left(5.915 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$F := 7.5\ \frac{mg}{L} \cdot \frac{1\ mol}{19\ gm} = \left(3.947 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$SO_4 := 66\ \frac{mg}{L} \cdot \frac{1\ mol}{96\ gm} = \left(6.875 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$NO_3 := 4.14\ \frac{mg}{L} \cdot \frac{1\ mol}{62\ gm} = \left(6.677 \cdot 10^{-5}\right) \frac{mol}{L}$$

$$CO_2 := 4.8\ \frac{mg}{L} \cdot \frac{1\ mol}{44\ gm} = \left(1.091 \cdot 10^{-4}\right) \frac{mol}{L}$$

Charge Balance

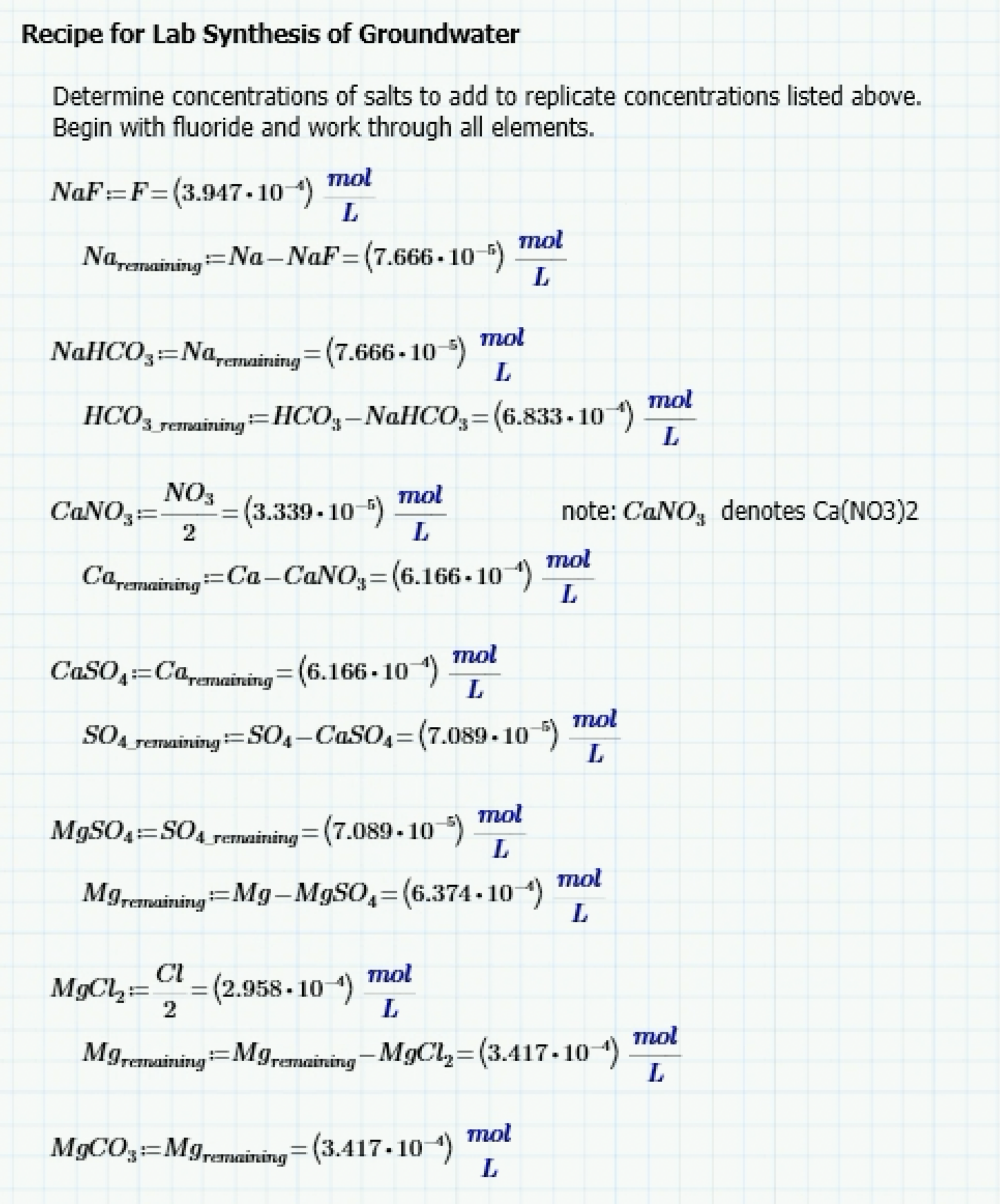
Positives: $Pos := 2 \cdot Ca + 2 \cdot Mg = \left(2.717 \cdot 10^{-3}\right) \frac{mol}{L}$

Negatives: $Neg := F + Cl + 2 \cdot SO_4 + NO_3 + HCO_3 = \left(3.188 \cdot 10^{-3}\right) \frac{mol}{L}$

Difference: $Na := Neg - Pos = \left(4.714 \cdot 10^{-4}\right) \frac{mol}{L}$

Assume unaccounted for positive charge is due to sodium to achieve equilibrium.

Figure A-4a. Groundwater chemistry converted from mg/L to molarity.



Recipe for Lab Synthesis of Groundwater

Determine concentrations of salts to add to replicate concentrations listed above. Begin with fluoride and work through all elements.

$$NaF := F = \left(3.947 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$Na_{remaining} := Na - NaF = \left(7.666 \cdot 10^{-5}\right) \frac{mol}{L}$$

$$NaHCO_3 := Na_{remaining} = \left(7.666 \cdot 10^{-5}\right) \frac{mol}{L}$$

$$HCO_{3\_remaining} := HCO_3 - NaHCO_3 = \left(6.833 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$CaNO_3 := \frac{NO_3}{2} = \left(3.339 \cdot 10^{-5}\right) \frac{mol}{L}$$

note: $CaNO_3$ denotes Ca(NO3)2

$$Ca_{remaining} := Ca - CaNO_3 = \left(6.166 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$CaSO_4 := Ca_{remaining} = \left(6.166 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$SO_{4\_remaining} := SO_4 - CaSO_4 = \left(7.089 \cdot 10^{-5}\right) \frac{mol}{L}$$

$$MgSO_4 := SO_{4\_remaining} = \left(7.089 \cdot 10^{-5}\right) \frac{mol}{L}$$

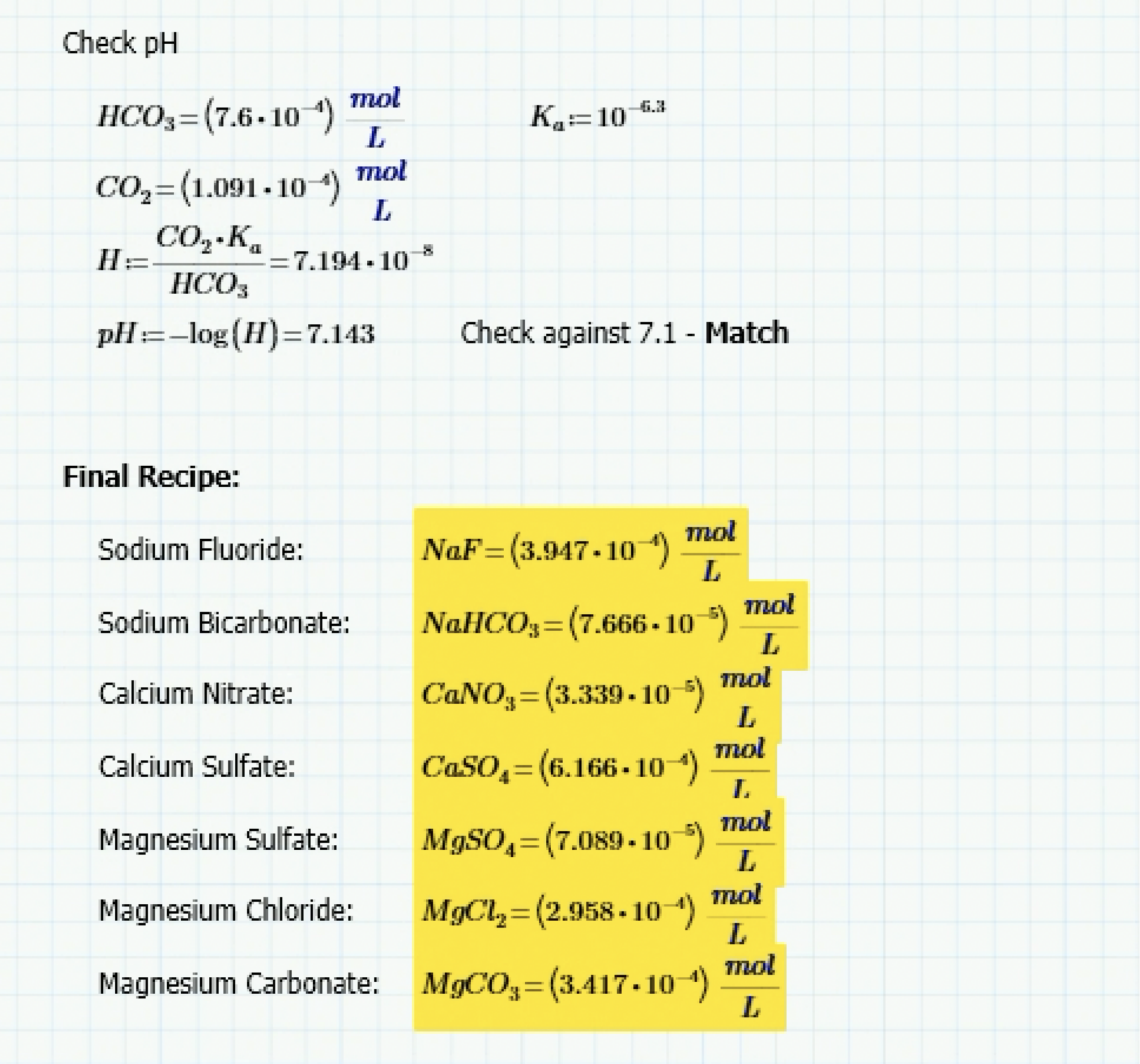
$$Mg_{remaining} := Mg - MgSO_4 = \left(6.374 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$MgCl_2 := \frac{Cl}{2} = \left(2.958 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$Mg_{remaining} := Mg_{remaining} - MgCl_2 = \left(3.417 \cdot 10^{-4}\right) \frac{mol}{L}$$

$$MgCO_3 := Mg_{remaining} = \left(3.417 \cdot 10^{-4}\right) \frac{mol}{L}$$

Figure A-4b. Recipe for lab synthesis: determination of salt concentrations.



Check pH

$HCO_3 = (7.6 \cdot 10^{-4})\ \frac{mol}{L}$ $K_a := 10^{-6.3}$

$CO_2 = (1.091 \cdot 10^{-4})\ \frac{mol}{L}$

$H := \frac{CO_2 \cdot K_a}{HCO_3} = 7.194 \cdot 10^{-8}$

$pH := -\log(H) = 7.143$ Check against 7.1 - **Match**

Final Recipe:

Sodium Fluoride: $NaF = (3.947 \cdot 10^{-4})\ \frac{mol}{L}$

Sodium Bicarbonate: $NaHCO_3 = (7.666 \cdot 10^{-5})\ \frac{mol}{L}$

Calcium Nitrate: $CaNO_3 = (3.339 \cdot 10^{-5})\ \frac{mol}{L}$

Calcium Sulfate: $CaSO_4 = (6.166 \cdot 10^{-4})\ \frac{mol}{L}$

Magnesium Sulfate: $MgSO_4 = (7.089 \cdot 10^{-5})\ \frac{mol}{L}$

Magnesium Chloride: $MgCl_2 = (2.958 \cdot 10^{-4})\ \frac{mol}{L}$

Magnesium Carbonate: $MgCO_3 = (3.417 \cdot 10^{-4})\ \frac{mol}{L}$

Figure A-4c. Recipe for lab synthesis: pH check and final recipe summary.

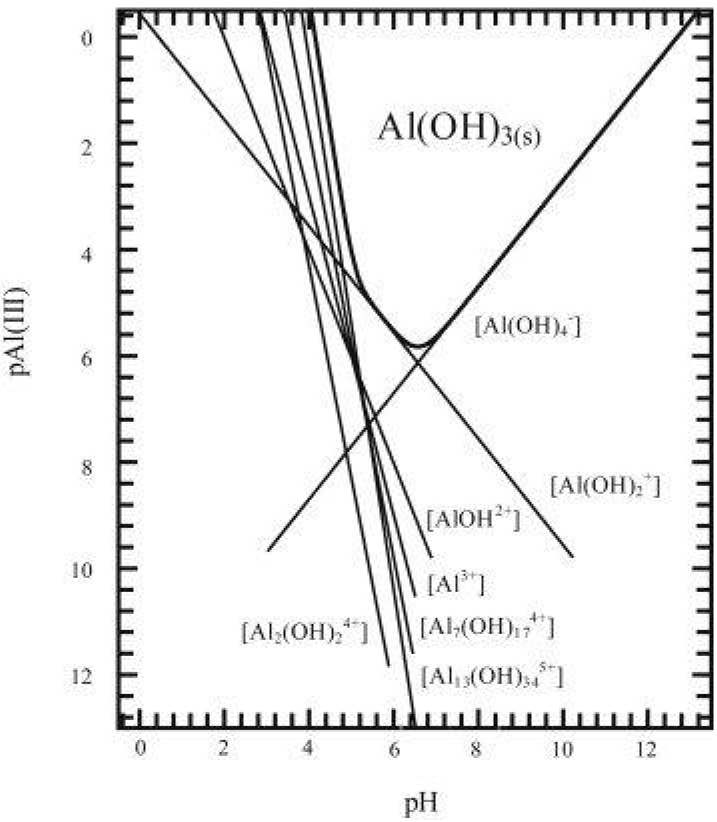


Figure A-5. Solubility diagram of aluminum hydroxide.

Lab Data

For each test, pH was measured before and after adding chemicals to 100 mL of the synthesized well water. Table A-2 contains the data for the first test, for which a somewhat arbitrary concentration of alum, 200 mg/L, was added to see how the pH changed. It dropped dramatically from 9.88 to 4.82.

Table A-2. Lab test one.

pH Before Alum	Conc. Alum [mg/L]	pH After Alum
9.88	200	4.82

Based on test one, 80 mg/L of soda ash was found to rebalance the pH after 200 mg/L of alum was added. A 0.15 molarity solution of soda ash was created to simplify addition, and was scaled linearly from 1 mL added for 200 mg/L alum. Tables A-3 and A-4 show the data from the second test, including more tested alum concentrations, the associated soda ash quantities, and pH measurements before and after chemical additions.

Table A-3. Lab test two.

Conc. Alum [mg/L]	pH After Alum	0.15 M Soda Ash Stock Added [mL]	pH After Soda Ash
0	9.86	-	-
150	4.82	0.75	7.48
200	4.79	1	7.7
250	4.79	1.25	8.45
500	4.66	2	8.33

Table A-4. Lab test three.

Conc. Alum [mg/L]	pH After Alum	0.15 M Soda Ash Stock Added [mL]	pH After Soda Ash
0	8.55	-	-
10	6.94	0.05	8.08
50	5.13	0.25	8.02
100	4.93	0.5	7.69
200	4.71	1	6.67
300	4.66	1.5	6.72

Lab test 3 demonstrated appropriate quantities of soda ash to be added to alum to balance the pH to the target range, allowing flocs to form. In tests four and five, (Tables A-5 and A-6), the fluoride concentration was measured via fluoride electrode. The electrode was calibrated using known fluoride concentrations (Figure A-), allowing translation from millivolt (mV) readings to fluoride concentration in mg/L.

The alum concentration 400 mg/L reduced the fluoride concentration to 1.3 mg/L, below the WHO maximum allowable concentration of 1.5 mg/L.

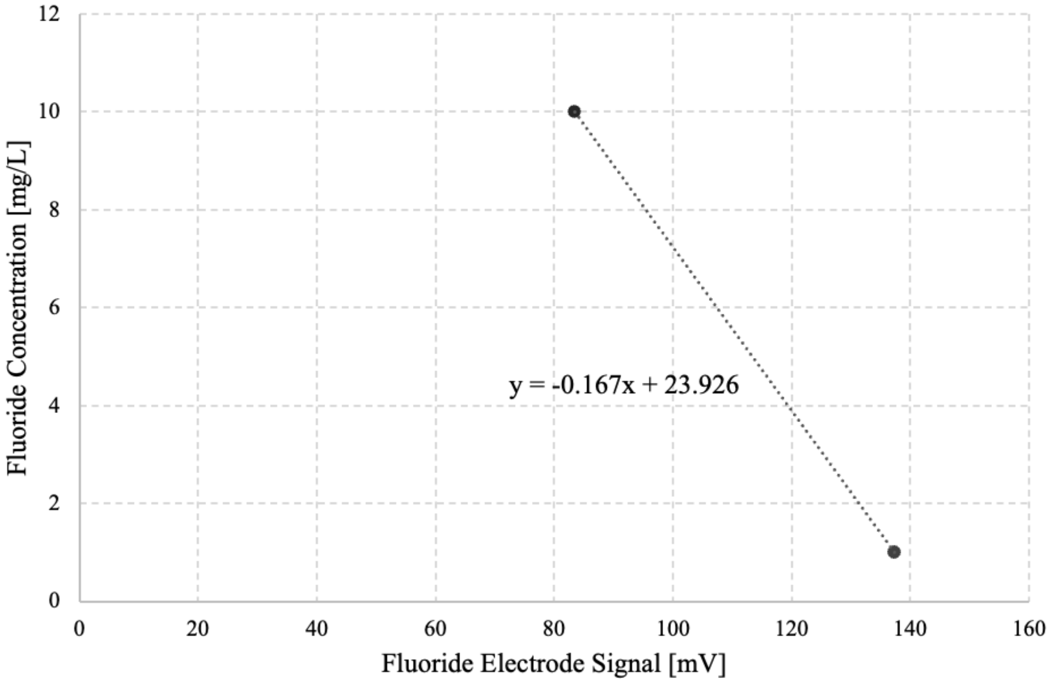


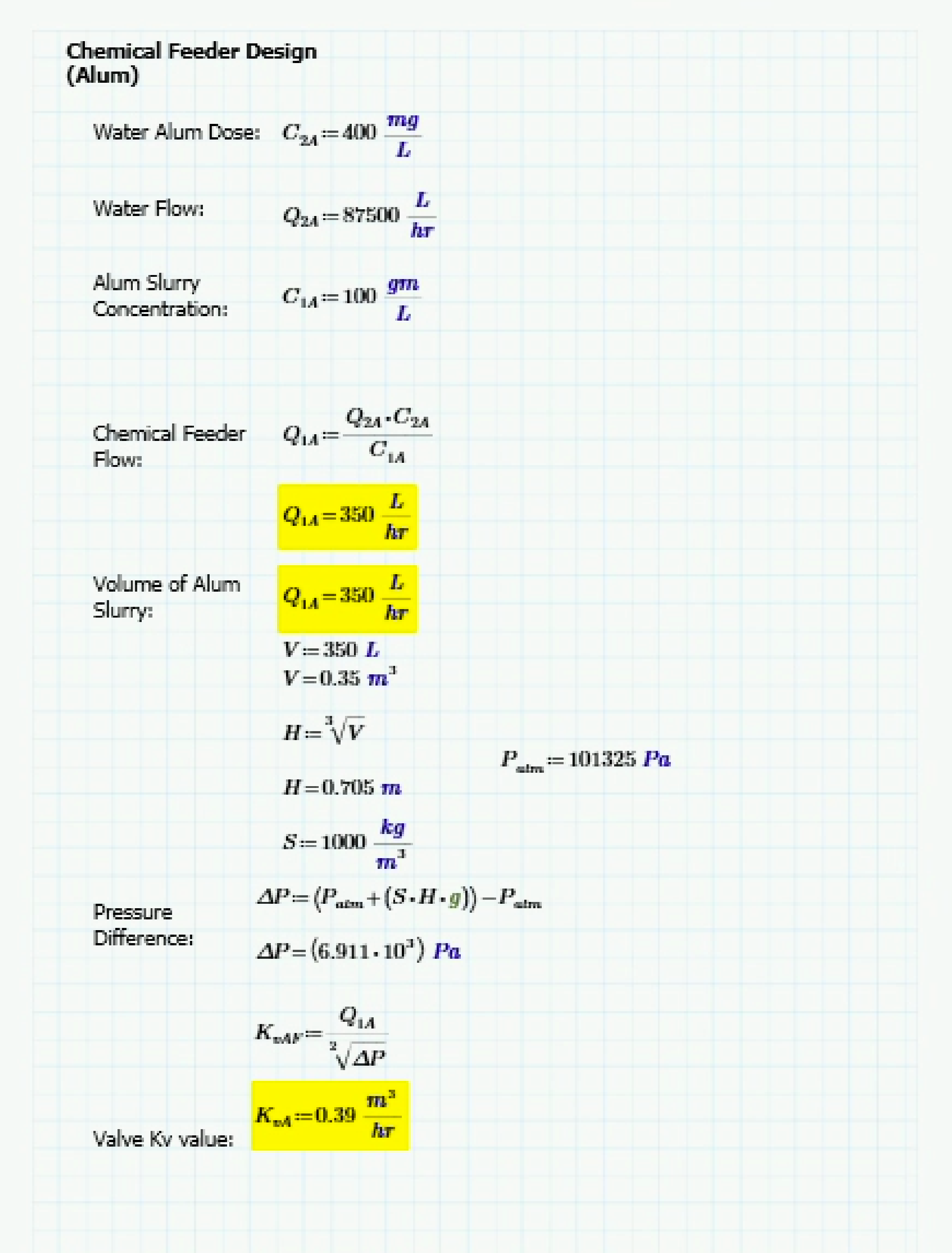
Figure A-6. Fluoride electrode calibration.

Table A-5. Lab test four.

Conc. Alum [mg/L]	F Electrode Signal [mV]	Conc. Fluoride [mg/L]
0	90.4	8.8
50	92.1	8.5
100	92.5	8.5
200	113.3	5
300	114	4.7

Table A-6. Lab test five.

Conc. Alum [mg/L]	pH After Alum and Soda Ash	F Electrode Signal [mV]	Conc. Fluoride [mg/L]
300	7.4	118.4	4.2
400	7.21	135.5	1.3
500	7.06	142.8	0.1
600	6.95	150.5	0.0



Chemical Feeder Design (Alum)

Water Alum Dose: $C_{2A} := 400\ \frac{mg}{L}$

Water Flow: $Q_{2A} := 87500\ \frac{L}{hr}$

Alum Slurry Concentration: $C_{1A} := 100\ \frac{gm}{L}$

Chemical Feeder Flow: $Q_{1A} := \frac{Q_{2A} \cdot C_{2A}}{C_{1A}}$

$Q_{1A} = 350\ \frac{L}{hr}$

Volume of Alum Slurry: $Q_{1A} = 350\ \frac{L}{hr}$

$V := 350\ L$

$V = 0.35\ m^3$

$H := \sqrt[3]{V}$

$P_{atm} := 101325\ Pa$

$H = 0.705\ m$

$S := 1000\ \frac{kg}{m^3}$

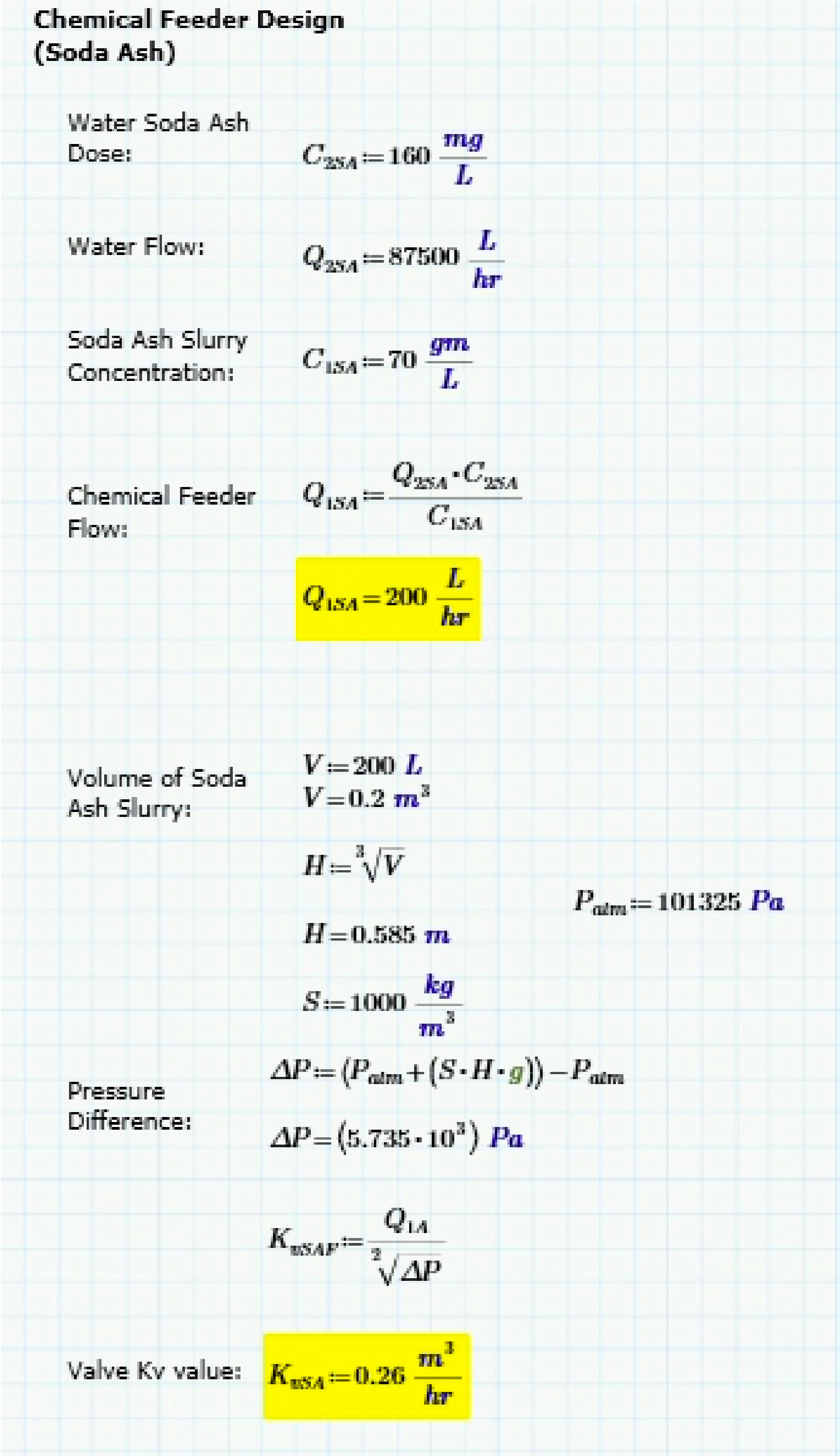
Pressure Difference: $\Delta P := (P_{atm} + (S \cdot H \cdot g)) - P_{atm}$

$\Delta P = (6.911 \cdot 10^3)\ Pa$

$K_{vAF} := \frac{Q_{1A}}{\sqrt[2]{\Delta P}}$

Valve Kv value: $K_{vA} := 0.39\ \frac{m^3}{hr}$

Figure A-7a. Alum Chemical Feeder Design Calculations.



Chemical Feeder Design (Soda Ash)

Water Soda Ash Dose: $C_{2SA} := 160\ \frac{mg}{L}$

Water Flow: $Q_{2SA} := 87500\ \frac{L}{hr}$

Soda Ash Slurry Concentration: $C_{1SA} := 70\ \frac{gm}{L}$

Chemical Feeder Flow: $Q_{1SA} := \frac{Q_{2SA} \cdot C_{2SA}}{C_{1SA}}$

$\boxed{Q_{1SA} = 200\ \frac{L}{hr}}$

Volume of Soda Ash Slurry: $V := 200\ L$

$V = 0.2\ m^3$

$H := \sqrt[3]{V}$

$P_{atm} := 101325\ Pa$

$H = 0.585\ m$

$S := 1000\ \frac{kg}{m^3}$

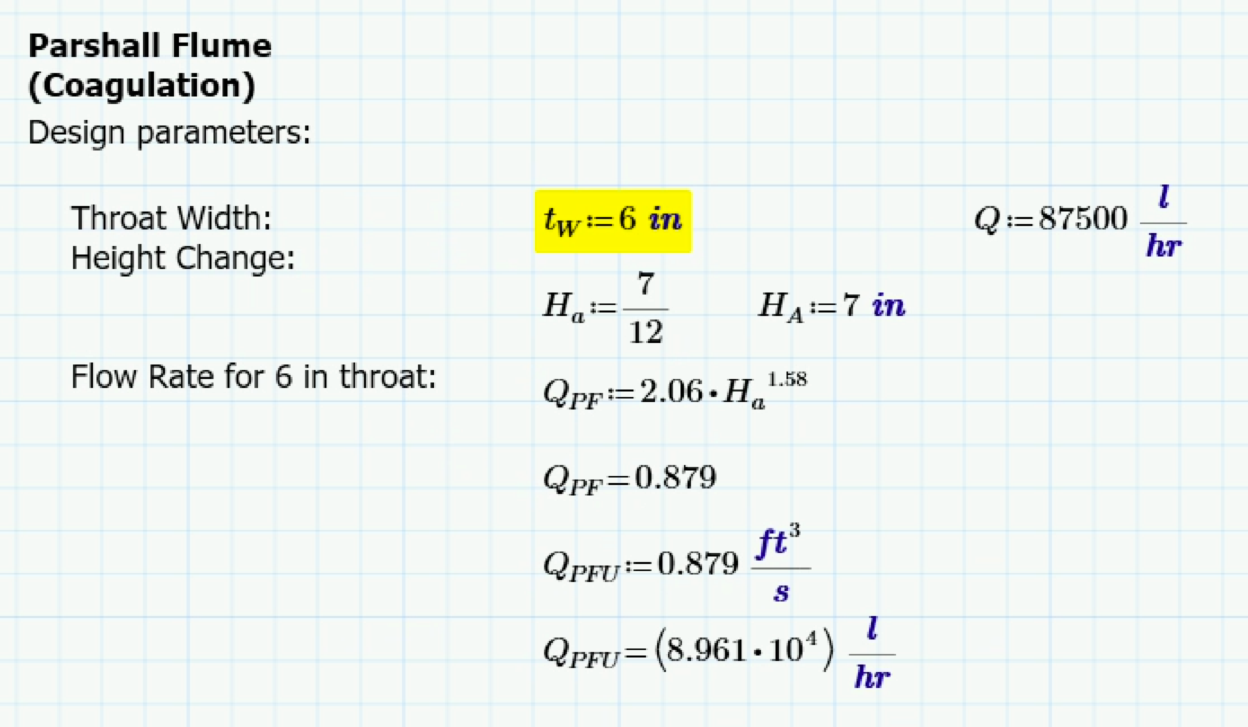
Pressure Difference: $\Delta P := \left(P_{atm} + \left(S \cdot H \cdot g\right)\right) - P_{atm}$

$\Delta P = \left(5.735 \cdot 10^3\right)\ Pa$

$K_{vSAF} := \frac{Q_{1A}}{\sqrt[2]{\Delta P}}$

Valve Kv value: $\boxed{K_{vSA} := 0.26\ \frac{m^3}{hr}}$

Figure A-7b. Soda Ash Chemical Feeder Design Calculations.



Parshall Flume (Coagulation)

Design parameters:

Throat Width: $t_W := 6\ in$

$Q := 87500\ \frac{l}{hr}$

Height Change: $H_a := \frac{7}{12}$ $H_A := 7\ in$

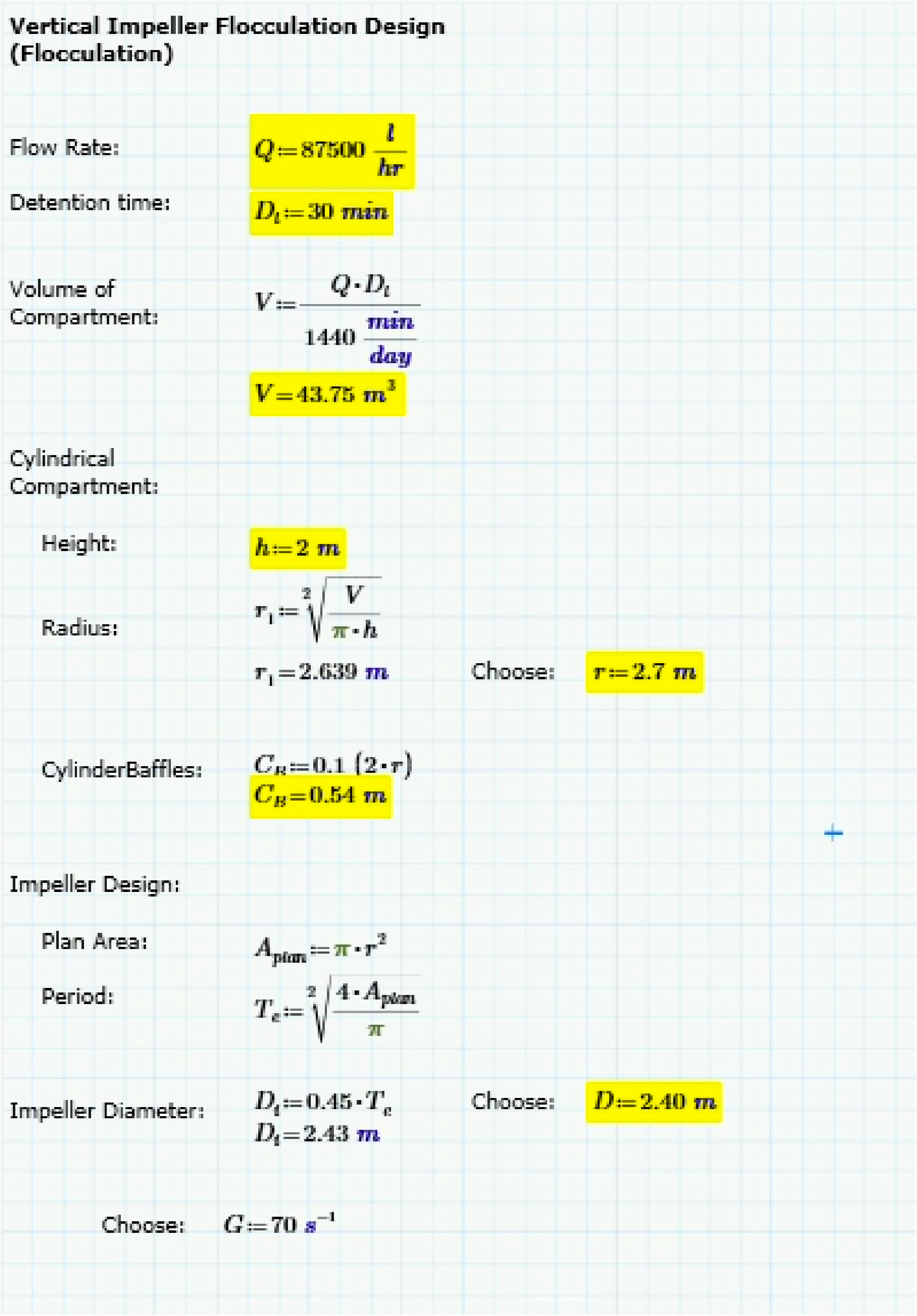
Flow Rate for 6 in throat: $Q_{PF} := 2.06 \cdot {H_a}^{1.58}$

$Q_{PF} = 0.879$

$Q_{PFU} := 0.879\ \frac{ft^3}{s}$

$Q_{PFU} = \left(8.961 \cdot 10^4\right)\ \frac{l}{hr}$

Figure A-8. Coagulation - Parshall Flume Design Calculations.



Vertical Impeller Flocculation Design (Flocculation)

Flow Rate: $Q := 87500\ \frac{l}{hr}$

Detention time: $D_t := 30\ min$

Volume of Compartment: $V := \frac{Q \cdot D_t}{1440\ \frac{min}{day}}$

$V = 43.75\ m^3$

Cylindrical Compartment:

Height: $h := 2\ m$

Radius: $r_1 := \sqrt[2]{\frac{V}{\pi \cdot h}}$

$r_1 = 2.639\ m$ Choose: $r := 2.7\ m$

CylinderBaffles: $C_B := 0.1\ (2 \cdot r)$

$C_B = 0.54\ m$

Impeller Design:

Plan Area: $A_{plan} := \pi \cdot r^2$

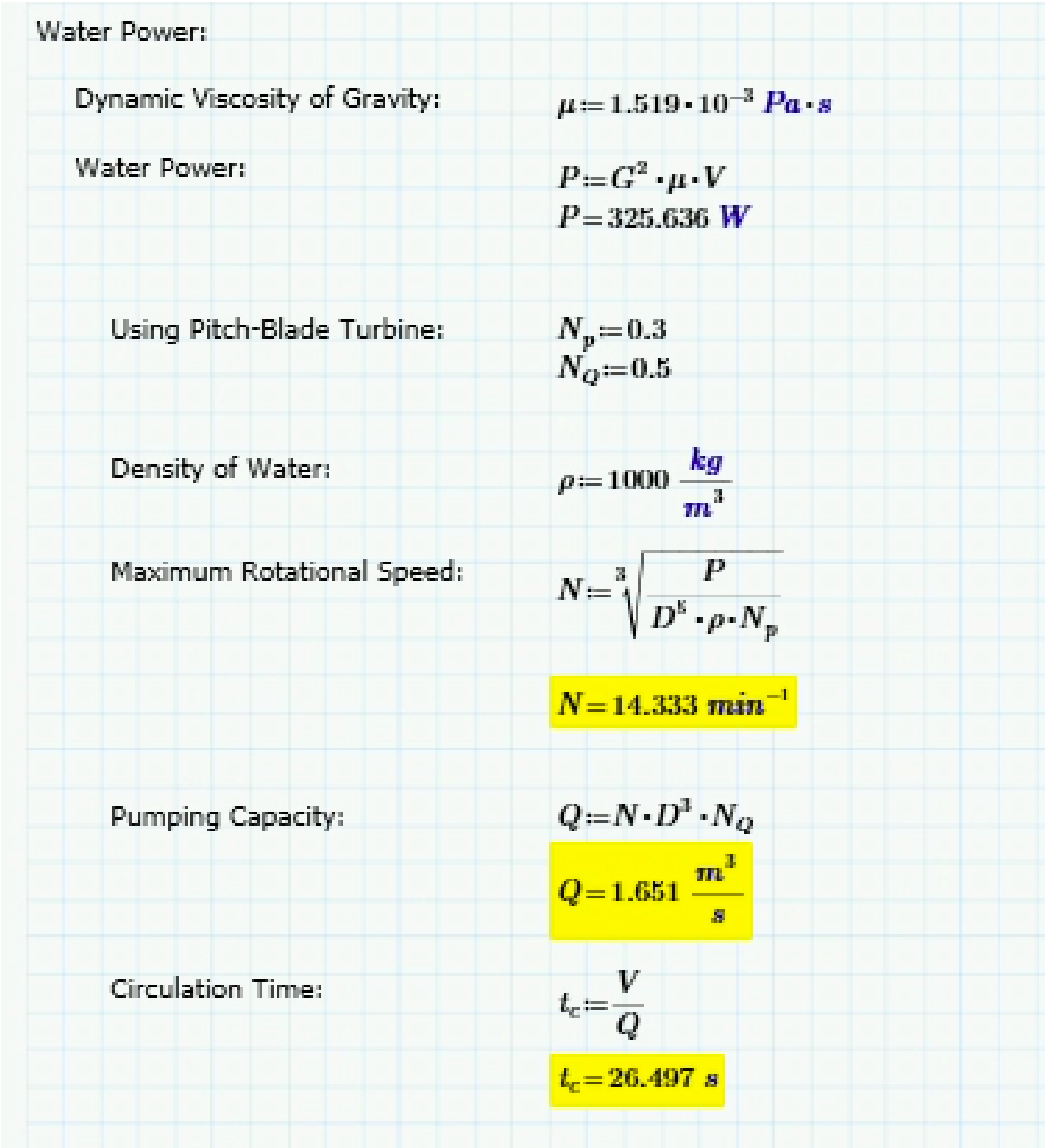
Period: $T_e := \sqrt[2]{\frac{4 \cdot A_{plan}}{\pi}}$

Impeller Diameter: $D_i := 0.45 \cdot T_e$

$D_i = 2.43\ m$ Choose: $D := 2.40\ m$

Choose: $G := 70\ s^{-1}$

Figure A-9a. Flocculation - Vertical Impeller Flocculator Design Calculations.



Water Power:

Dynamic Viscosity of Gravity: $\mu := 1.519 \cdot 10^{-3}\ Pa \cdot s$

Water Power: $P := G^2 \cdot \mu \cdot V$

$P = 325.636\ W$

Using Pitch-Blade Turbine: $N_p := 0.3$

$N_Q := 0.5$

Density of Water: $\rho := 1000\ \frac{kg}{m^3}$

Maximum Rotational Speed: $N := \sqrt[3]{\frac{P}{D^5 \cdot \rho \cdot N_p}}$

$N = 14.333\ min^{-1}$

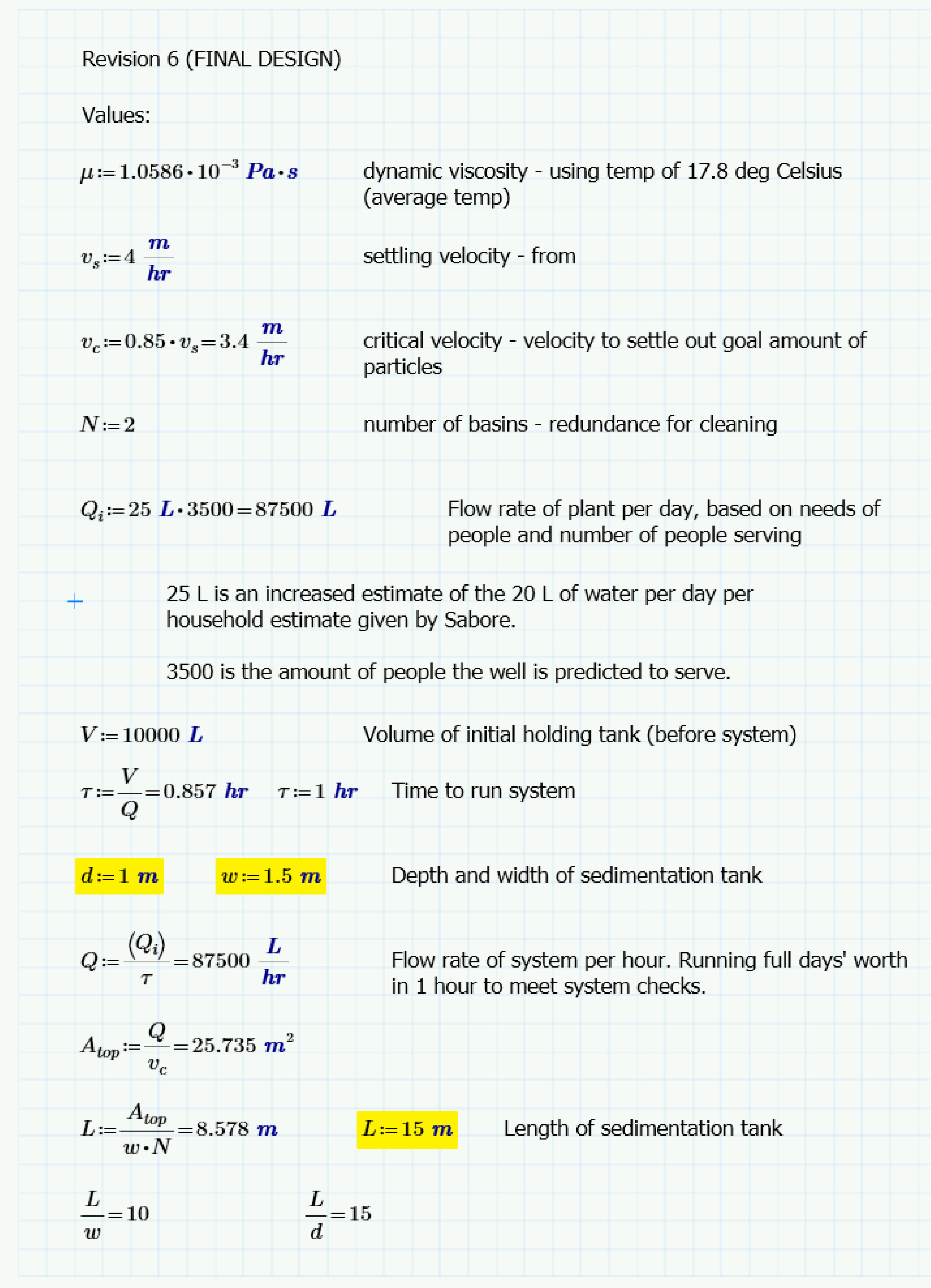
Pumping Capacity: $Q := N \cdot D^3 \cdot N_Q$

$Q = 1.651\ \frac{m^3}{s}$

Circulation Time: $t_c := \frac{V}{Q}$

$t_c = 26.497\ s$

Figure A-9b. Flocculation - Vertical Impeller Flocculator Design Calculations.



Revision 6 (FINAL DESIGN)

Values:

$\mu := 1.0586 \cdot 10^{-3}\ Pa \cdot s$ dynamic viscosity - using temp of 17.8 deg Celsius (average temp)

$v_s := 4\ \frac{m}{hr}$ settling velocity - from

$v_c := 0.85 \cdot v_s = 3.4\ \frac{m}{hr}$ critical velocity - velocity to settle out goal amount of particles

$N := 2$ number of basins - redundance for cleaning

$Q_i := 25\ L \cdot 3500 = 87500\ L$ Flow rate of plant per day, based on needs of people and number of people serving

25 L is an increased estimate of the 20 L of water per day per household estimate given by Sabore.

3500 is the amount of people the well is predicted to serve.

$V := 10000\ L$ Volume of initial holding tank (before system)

$\tau := \frac{V}{Q} = 0.857\ hr$ $\tau := 1\ hr$ Time to run system

$d := 1\ m$ $w := 1.5\ m$ Depth and width of sedimentation tank

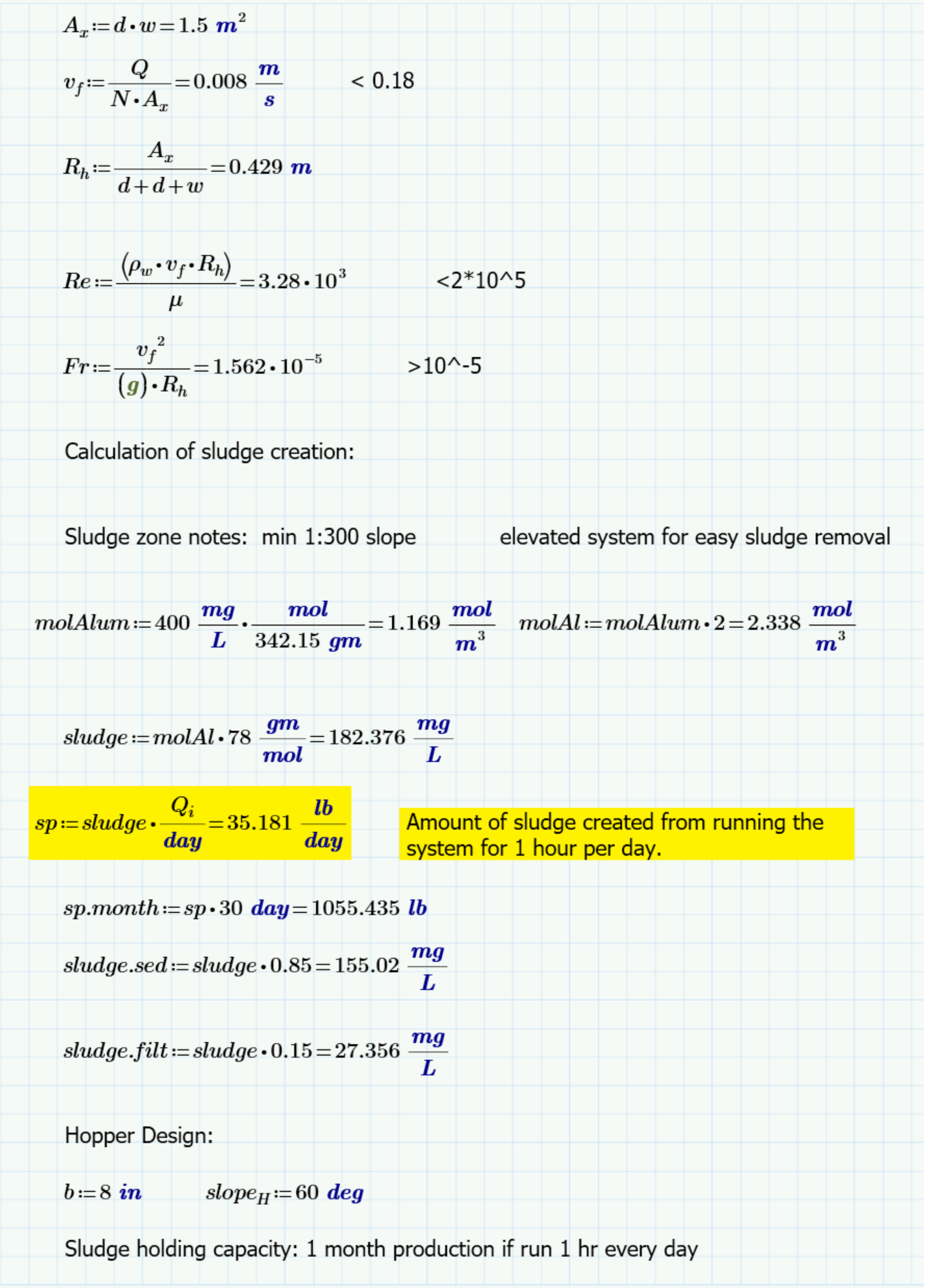
$Q := \frac{(Q_i)}{\tau} = 87500\ \frac{L}{hr}$ Flow rate of system per hour. Running full days' worth in 1 hour to meet system checks.

$A_{top} := \frac{Q}{v_c} = 25.735\ m^2$

$L := \frac{A_{top}}{w \cdot N} = 8.578\ m$ $L := 15\ m$ Length of sedimentation tank

$\frac{L}{w} = 10$ $\frac{L}{d} = 15$

Figure A-10a. Sedimentation Basin Design Calculations.



$$A_x := d \cdot w = 1.5\ \mathbf{m}^2$$

$$v_f := \frac{Q}{N \cdot A_x} = 0.008\ \frac{\mathbf{m}}{\mathbf{s}} \qquad < 0.18$$

$$R_h := \frac{A_x}{d + d + w} = 0.429\ \mathbf{m}$$

$$Re := \frac{\left(\rho_w \cdot v_f \cdot R_h\right)}{\mu} = 3.28 \cdot 10^3 \qquad <2*10\text{^}5$$

$$Fr := \frac{{v_f}^2}{(g) \cdot R_h} = 1.562 \cdot 10^{-5} \qquad >10\text{^}-5$$

Calculation of sludge creation:

Sludge zone notes: min 1:300 slope elevated system for easy sludge removal

$$molAlum := 400\ \frac{\mathbf{mg}}{\mathbf{L}} \cdot \frac{\mathbf{mol}}{342.15\ \mathbf{gm}} = 1.169\ \frac{\mathbf{mol}}{\mathbf{m}^3} \qquad molAl := molAlum \cdot 2 = 2.338\ \frac{\mathbf{mol}}{\mathbf{m}^3}$$

$$sludge := molAl \cdot 78\ \frac{\mathbf{gm}}{\mathbf{mol}} = 182.376\ \frac{\mathbf{mg}}{\mathbf{L}}$$

$$sp := sludge \cdot \frac{Q_i}{\mathbf{day}} = 35.181\ \frac{\mathbf{lb}}{\mathbf{day}}$$

Amount of sludge created from running the system for 1 hour per day.

$$sp.month := sp \cdot 30\ \mathbf{day} = 1055.435\ \mathbf{lb}$$

$$sludge.sed := sludge \cdot 0.85 = 155.02\ \frac{\mathbf{mg}}{\mathbf{L}}$$

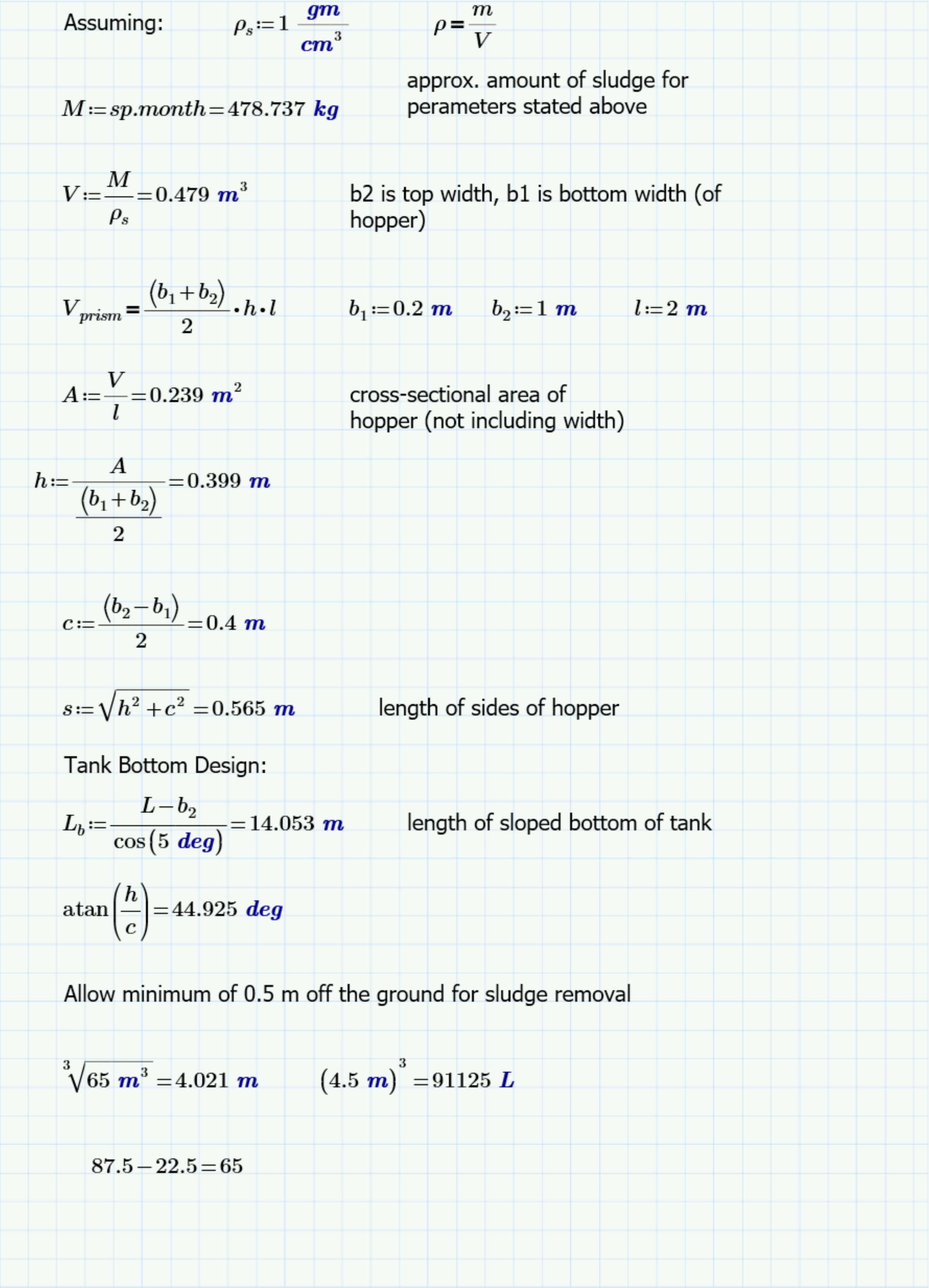
$$sludge.filt := sludge \cdot 0.15 = 27.356\ \frac{\mathbf{mg}}{\mathbf{L}}$$

Hopper Design:

$$b := 8\ \mathbf{in} \qquad slope_H := 60\ \mathbf{deg}$$

Sludge holding capacity: 1 month production if run 1 hr every day

Figure A-10b. Sedimentation Basin Design Calculations.



Assuming: $\rho_s := 1 \frac{gm}{cm^3}$ $\rho = \frac{m}{V}$

$M := sp.month = 478.737\ kg$ approx. amount of sludge for perameters stated above

$V := \frac{M}{\rho_s} = 0.479\ m^3$ b2 is top width, b1 is bottom width (of hopper)

$V_{prism} = \frac{(b_1 + b_2)}{2} \cdot h \cdot l$ $b_1 := 0.2\ m$ $b_2 := 1\ m$ $l := 2\ m$

$A := \frac{V}{l} = 0.239\ m^2$ cross-sectional area of hopper (not including width)

$$h := \frac{A}{\frac{(b_1 + b_2)}{2}} = 0.399\ m$$

$$c := \frac{(b_2 - b_1)}{2} = 0.4\ m$$

$s := \sqrt{h^2 + c^2} = 0.565\ m$ length of sides of hopper

Tank Bottom Design:

$L_b := \frac{L - b_2}{\cos(5\ deg)} = 14.053\ m$ length of sloped bottom of tank

$$\operatorname{atan}\left(\frac{h}{c}\right) = 44.925\ deg$$

Allow minimum of 0.5 m off the ground for sludge removal

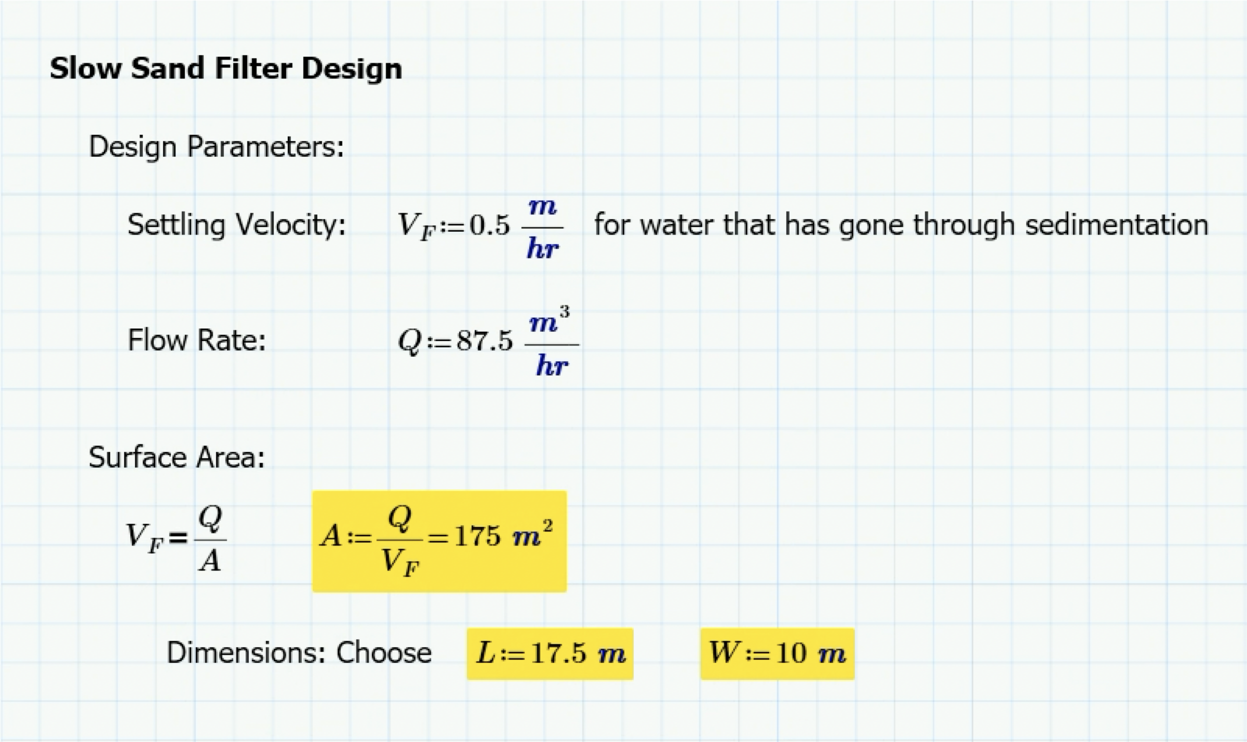
$\sqrt[3]{65\ m^3} = 4.021\ m$ $(4.5\ m)^3 = 91125\ L$

$$87.5 - 22.5 = 65$$

Figure A-10c. Sedimentation Basin Design Calculations.

Table A-7. Slow sand filter design criteria.

PARAMETER		VALUES
Number of pre-filters (n)		≤ 2
V_F Filtration rate (flow/area) (m/h)		
FL		0.1 – 0.2
Sedimentator or pre-filter + FL		0.15 – 0.3
Sedimentator + pre-filter + FL		0.3 – 0.5
Area of a filter (A)		$A = Q / (n \times V_F)$
Minimum cost coefficient (K)		K = 2n / (n+1)
Length of filter (m)		L = √(area x K)
Total height of the gravel bed (m)		0.1 – 0.3
Layers	*thickness (m)*	*size (mm)*
First layer (gravel)	≤ 0.05	1.5 – 4.0
Second layer (gravel)	≤ 0.05	4 - 15
Third layer (gravel)	≤ 0.15	10 – 40
Height of the sand bed (m)		0.3 – 0.4
Effective diameter of the sand (D_{10}) (mm)		0.15 – 0.4
Uniformity coefficient (D_{60}/D_{10})		1.8 – 3
Height of free border (m)		0.2
Height of supernatant layer (m)		1 – 1.5



Slow Sand Filter Design

Design Parameters:

Settling Velocity: $V_F := 0.5 \frac{m}{hr}$ for water that has gone through sedimentation

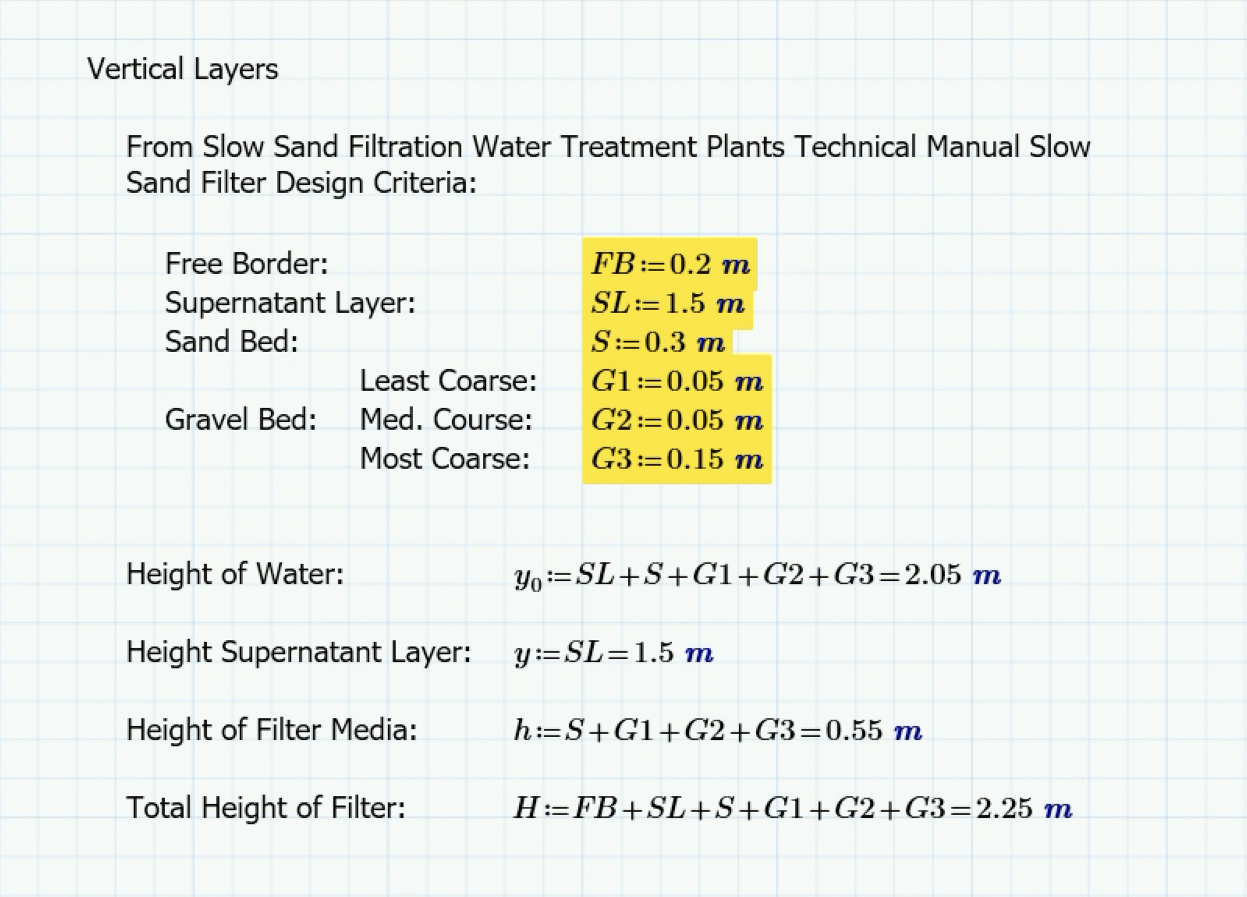
Flow Rate: $Q := 87.5 \frac{m^3}{hr}$

Surface Area:

$V_F = \frac{Q}{A}$ $A := \frac{Q}{V_F} = 175\ m^2$

Dimensions: Choose $L := 17.5\ m$ $W := 10\ m$

Figure A-11a. Slow sand filter design: surface area and dimensions.



Vertical Layers

From Slow Sand Filtration Water Treatment Plants Technical Manual Slow Sand Filter Design Criteria:

Free Border: $FB := 0.2\ \mathbf{m}$

Supernatant Layer: $SL := 1.5\ \mathbf{m}$

Sand Bed: $S := 0.3\ \mathbf{m}$

Gravel Bed:

- Least Coarse: $G1 := 0.05\ \mathbf{m}$
- Med. Course: $G2 := 0.05\ \mathbf{m}$
- Most Coarse: $G3 := 0.15\ \mathbf{m}$

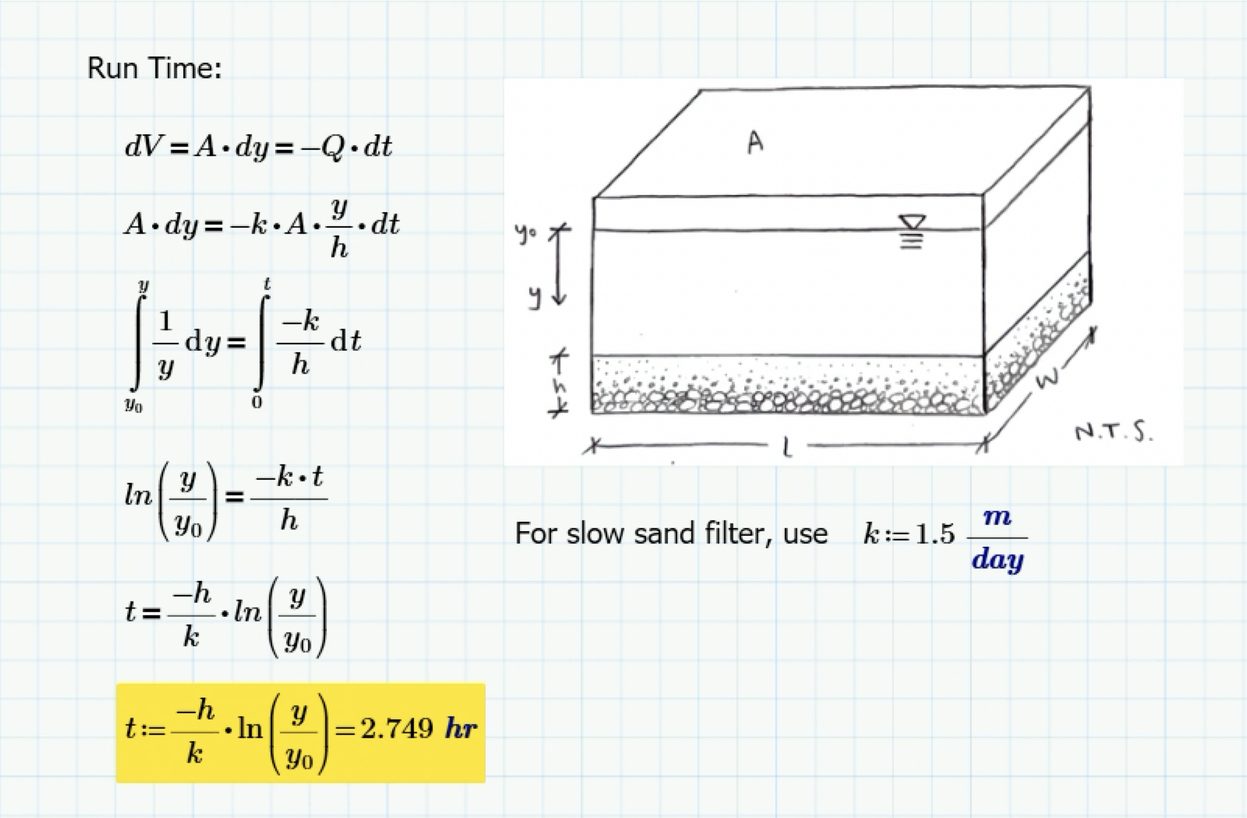
Height of Water: $y_0 := SL + S + G1 + G2 + G3 = 2.05\ \mathbf{m}$

Height Supernatant Layer: $y := SL = 1.5\ \mathbf{m}$

Height of Filter Media: $h := S + G1 + G2 + G3 = 0.55\ \mathbf{m}$

Total Height of Filter: $H := FB + SL + S + G1 + G2 + G3 = 2.25\ \mathbf{m}$

Figure A-11b. Slow sand filter design: heights of vertical layers.



Run Time:

$$dV = A \cdot dy = -Q \cdot dt$$

$$A \cdot dy = -k \cdot A \cdot \frac{y}{h} \cdot dt$$

$$\int_{y_0}^{y} \frac{1}{y} \, dy = \int_{0}^{t} \frac{-k}{h} \, dt$$

$$ln\left(\frac{y}{y_0}\right) = \frac{-k \cdot t}{h}$$

$$t = \frac{-h}{k} \cdot ln\left(\frac{y}{y_0}\right)$$

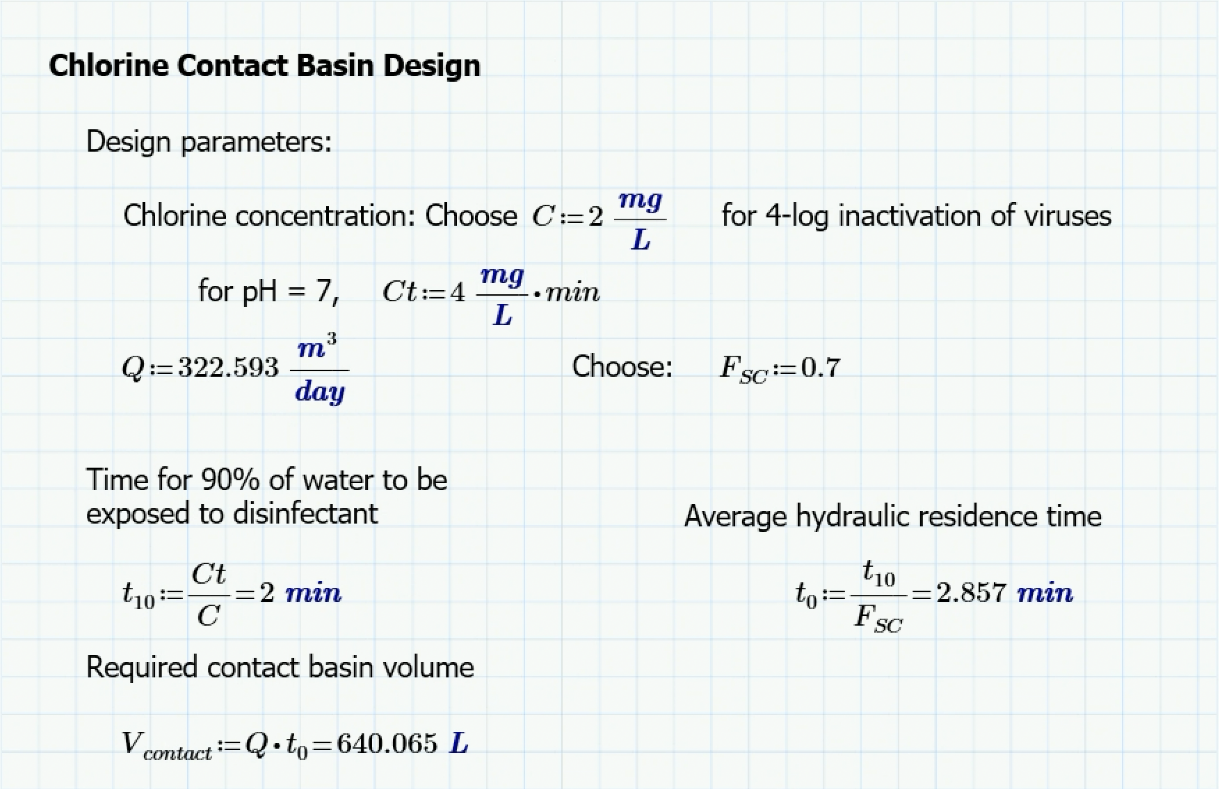
$$t := \frac{-h}{k} \cdot \ln\left(\frac{y}{y_0}\right) = 2.749 \ hr$$

For slow sand filter, use $k := 1.5 \ \frac{m}{day}$

Figure A-11c. Slow sand filter design: run time.

Table A-8. Ct Values (mg*min/L) for inactivation of viruses by free chlorine.

pH 6 to 9 Log inactivation	Temperature, °C					
	0.5	5	10	15	20	25
2.0	6	4	3	2	1	1
3.0	9	6	4	3	2	1
4.0	12	8	6	4	3	2



Chlorine Contact Basin Design

Design parameters:

Chlorine concentration: Choose $C := 2\ \frac{mg}{L}$ for 4-log inactivation of viruses

for pH = 7, $Ct := 4\ \frac{mg}{L} \cdot min$

$Q := 322.593\ \frac{m^3}{day}$

Choose: $F_{SC} := 0.7$

Time for 90% of water to be exposed to disinfectant

$$t_{10} := \frac{Ct}{C} = 2\ min$$

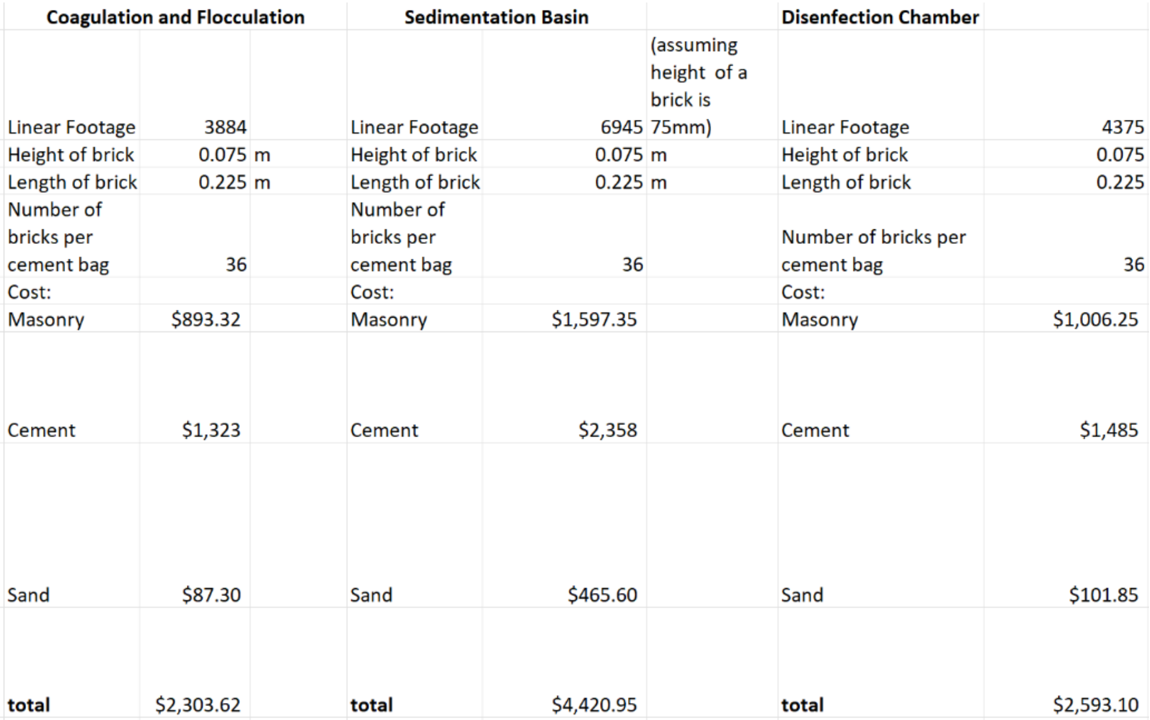
Average hydraulic residence time

$$t_0 := \frac{t_{10}}{F_{SC}} = 2.857\ min$$

Required contact basin volume

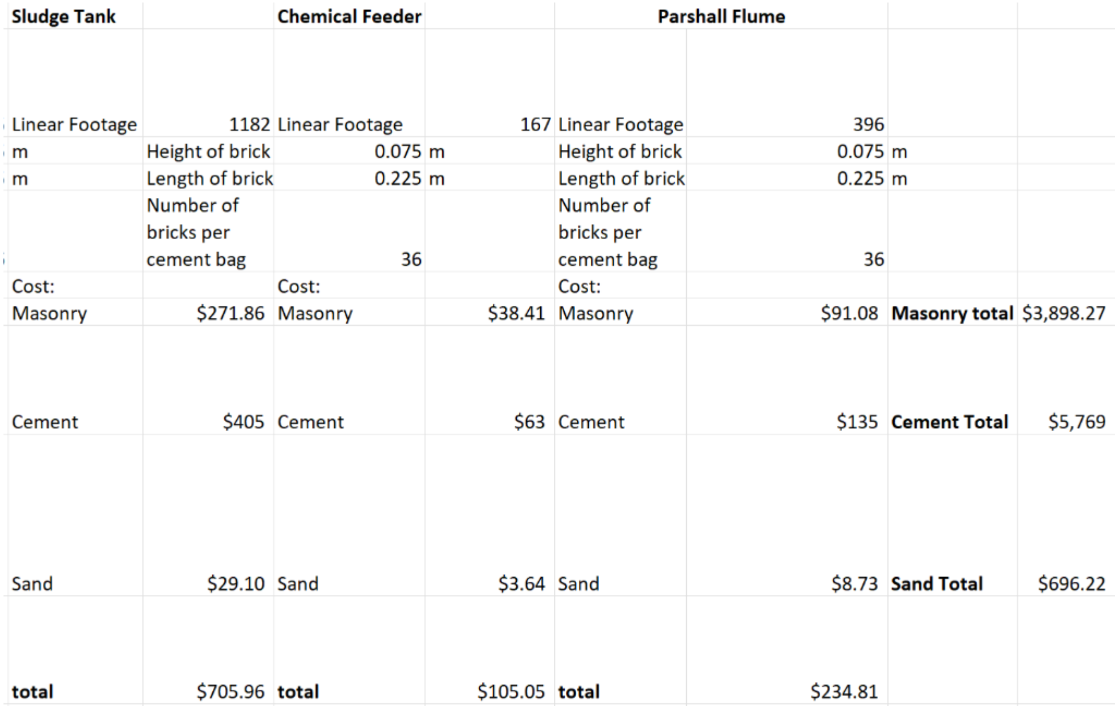
$$V_{contact} := Q \cdot t_0 = 640.065\ L$$

Figure A-12 Chlorine contact basin requirements calculations.



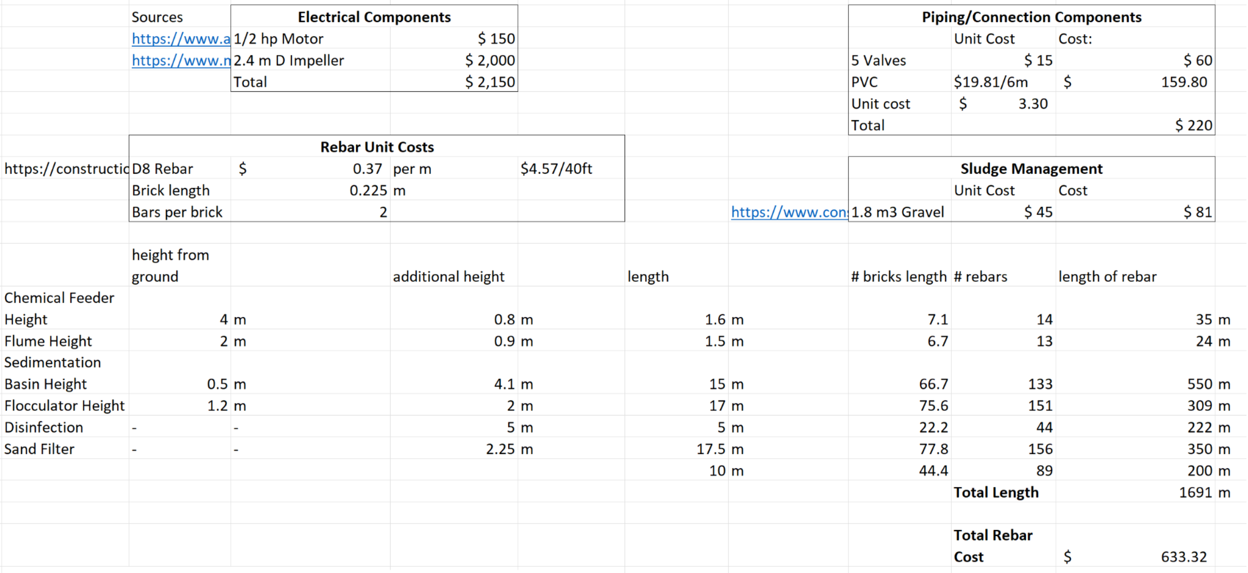
Coagulation and Flocculation			**Sedimentation Basin**			**Disenfection Chamber**	
Linear Footage	3884		Linear Footage	6945	(assuming height of a brick is 75mm)	Linear Footage	4375
Height of brick	0.075	m	Height of brick	0.075	m	Height of brick	0.075
Length of brick	0.225	m	Length of brick	0.225	m	Length of brick	0.225
Number of bricks per cement bag	36		Number of bricks per cement bag	36		Number of bricks per cement bag	36
Cost:			Cost:			Cost:	
Masonry	$893.32		Masonry	$1,597.35		Masonry	$1,006.25
Cement	$1,323		Cement	$2,358		Cement	$1,485
Sand	$87.30		Sand	$465.60		Sand	$101.85
total	$2,303.62		**total**	$4,420.95		**total**	$2,593.10

Figure A-13a. Cost estimate: masonry, cement, and sand for coagulation and flocculation, sedimentation, and disinfection.



Sludge Tank		Chemical Feeder		Parshall Flume			
Linear Footage	1182	Linear Footage	167	Linear Footage	396		
m	Height of brick	0.075	m	Height of brick	0.075	m	
m	Length of brick	0.225	m	Length of brick	0.225	m	
	Number of bricks per cement bag	36		Number of bricks per cement bag	36		
Cost:		Cost:		Cost:			
Masonry	$271.86	Masonry	$38.41	Masonry	$91.08	**Masonry total**	$3,898.27
Cement	$405	Cement	$63	Cement	$135	**Cement Total**	$5,769
Sand	$29.10	Sand	$3.64	Sand	$8.73	**Sand Total**	$696.22
total	$705.96	**total**	$105.05	**total**	$234.81		

Figure A-13b. Cost estimate: masonry, cement, and sand for sludge tank, chemical feeder, and Parshall flume.



	Sources	**Electrical Components**					**Piping/Connection Components**			
	https://www.a	1/2 hp Motor	$ 150					Unit Cost	Cost:	
	https://www.n	2.4 m D Impeller	$ 2,000				5 Valves	$ 15	$ 60	
		Total	$ 2,150				PVC	$19.81/6m	$ 159.80	
							Unit cost	$ 3.30		
							Total		$ 220	
	Rebar Unit Costs									
https://constructic	D8 Rebar	$ 0.37	per m	$4.57/40ft			**Sludge Management**			
	Brick length	0.225	m					Unit Cost	Cost	
	Bars per brick	2				https://www.con	1.8 m3 Gravel	$ 45	$ 81	
	height from ground		additional height		length		# bricks length	# rebars	length of rebar	
Chemical Feeder Height	4	m	0.8	m	1.6	m	7.1	14	35	m
Flume Height	2	m	0.9	m	1.5	m	6.7	13	24	m
Sedimentation Basin Height	0.5	m	4.1	m	15	m	66.7	133	550	m
Flocculator Height	1.2	m	2	m	17	m	75.6	151	309	m
Disinfection	-	-	5	m	5	m	22.2	44	222	m
Sand Filter	-	-	2.25	m	17.5	m	77.8	156	350	m
					10	m	44.4	89	200	m
								Total Length	1691	m
								Total Rebar Cost	$ 633.32	

Figure A-13c. Rough cost estimate: electrical, piping and rebar.