BREE 495: Engineering Design 3

Department of Bioresource Engineering

McGill University

Sand Filtration System for Reducing Turbidity of Recycled Drainage Water on Tourne-Sol Farm

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EXECUTIVE SUMMARY

This report details the design and construction of a slow sand filtration (SSF) system to reduce turbidity in recycled drainage water at Tourne-Sol Farm, an organic farm in Les Cèdres, Québec. The farm wants to use recycled drainage water for irrigation due to the high salinity of their well water, but the high turbidity of this recycled water affects the efficiency of their current UV treatment system. A pilot SSF system was designed and prototyped with recycled materials to lower the turbidity levels and reduce the presence of plant pathogens. Cost and time constraints made testing the prototype more challenging. However, overall, most of the design requirements were met and recommendations were given to improve the design of the second SSF.

ACKNOWLEDGMEMTS

We would like to thank Dr. Clark for his consistent and continuous advice on the engineering design process throughout the design process, as well as Dr. Madramotoo for putting us in contact with Tourne-Sol Cooperative Farm and for providing guidance on our project.We would also like to thank Don and Reid at Tourne-Sol for the opportunity to work with them, and for their enthusiastic help and advice in these first stages of engineering design.

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LIST OF ACRONYMS AND ABBREVIATIONS

Colony Forming Unit	CFU
Nephelometric Turbidity Units	NTU
Rapid Sand Filtration	RSF
Slow Sand Filtration	SSF
Ultra-Violet	UV

INTRODUCTION

Tourne-Sol Co-operative Farm is an organic farm in Les Cèdres, Québec. They have 7 hectares of land where they grow various vegetables, including root vegetables and leafy greens, to offer customers organic certified vegetable baskets (Ferme Coopérative Tourne-Sol, 2024). Additionally, they have an organic seed market where 70% of the varieties are grown in their fields (Tourne-Sol Cooperative Farms, 2024).

The farm originally used high-salinity groundwater from a well to irrigate its crops, however, using this water in their greenhouse can damage their plants. Therefore subsurface tile drainage is recycled and used instead. However, the recycled drainage collected at Tourne-Sol Farm has high turbidity levels that prevent the adequate ultra-violet (UV) treatment of the irrigation water and has the potential to harbour plant pathogens. So, the client sought a low-cost, energy efficient filtration system with minimal maintenance required.

This report outlines our design of a slow sand filtration system and the construction of the prototype, designed specifically for the farm's needs. A thorough presentation of design considerations, the final design, cost analysis, and limitations and recommendations are presented.

PROBLEM DEFINITION

DESIGN PROBLEM AT TOURNE-SOL FARM

To recycle their tile drainage water, Tourne-Sol installed a water reservoir comprised of three 18-inch diameter culverts in an underground clay gallery with a capacity of about 30,000 L. The reservoir is the light blue rectangle in Figure 1 and it is connected to the drainage system at two outlets identified by stars in Figure 1. Around 75% of the field drains into the reservoir, the rest is evacuated at two outlets into a waterway at the end of the field. The reservoir also has four surface inlets which collect rainwater or excess water from the field surface. These were identified as probable sources of water exposure to pathogens (Etzinger & Guité, 2024).

The water from the reservoir is pumped into membrane pre-filters, passes through a UV treatment, and is then pumped into the irrigation system of Greenhouse 2, shown in Figure 1. An overhead sprinkler system is currently used for irrigation in the targeted greenhouse (Etzinger & Guité, 2024). However, the current membrane pre-filters constantly get clogged up and require frequent maintenance. The water is therefore not pre-treated adequately, it reaches the UV treatment with turbidity levels that limit the efficacy of removing pathogens. Turbidity-causing materials in water protect smaller-sized bacteria from UV radiation (Farrell et al., 2018).

Figure 1: Aerial view of Tourne-Sol farm with tile drainage and labeled greenhouses

GOAL AND OBJECTIVES

Tourne-Sol organic farm uses well water that contains high levels of salinity, therefore drainage water from surrounding fields is used for irrigation. This water is UV treated to eliminate pathogens, but the turbidity of the recycled water limits its efficacy. So, A slow sand filtration (SSF) system was designed to reduce turbidity in the subdrainage water, improving the UV treatment of the water on Tourne-Sol organic farm. The full requirements can be found in the *Requirements Document* in Appendix 1.

EVALUATION OF POSSIBLE SOLUTION STRATEGIES

OVERVIEW OF METHODS FOR WATER TURBIDITY REDUCTION

Three filtration methods were analyzed for this design: the pre-existing membrane filtration, rapid sand filtration (RSF), and slow sand filtration (SSF). Membrane filters are extremely efficient in constant turbidity reduction but are often subject to fouling if the influent water has high levels of suspended solids (Health Canada, 2005). . While pre-treatment helps reduce the risk of fouling, cleaning the membrane filters is necessary and suggested methods often include the use of chemical cleaners (Cartwright, 2000). RSFs are highly effective at removing turbidity and have a high filter rate but require a high energy input due to frequent backwashing requirements. Additionally, it is not able to remove viruses (Bruni & Spuhler, n.d.).

SSF was chosen as the optimal design based on the criteria shown in Figure 2. While SSFs cannot function with higher turbidity levels in the influent water compared to RSFs and membrane filters, they can effectively remove plant pathogens and other bacteria and reduce turbidity effectively (Health Canada, 2005; Water Sanitation Hygiene Cluster, n.d.). Furthermore, SSFs require simple and infrequent cleaning compared to the membrane and RSF (Page et al., 2006). Building and installation costs were comparable between RSFs and SSFs, but are also site-specific and therefore hard to quantify in the design selection process (Page et al., 2006). However, maintenance costs are lower for SSFs considering the infrequency of cleaning required, minimizing labour and energy costs (Lahlou, 2000).

DESIGN SELECTION

RSF, SSF, and membrane filtration were chosen as the three solution alternatives to be evaluated in the Pugh matrix, shown in Figure 2. Membrane filtration is the current system that Tourne-Sol uses and was designated as the baseline.

Description		**Membrane Filtration (Baseline)**		**Rapid Sand Filtration**		**Slow Sand Filtration**	
Criteria	**Weight factor**	Previous design		Suggested design 1		Suggested design 2	
		Rating	Weighted	Rating	Weighted	Rating	Weighted
Building/ Installation cost	2	0	0	-1	-2	-2	-4
Maintenance Costs	2	0	0	-1	-2	1	2
Freeze Tolerance	2	0	0	1	2	1	2
Cleaning Frequency	1	0	0	-2	-2	2	2
Parts Availability	1	0	0	-1	-1	-1	-1
Space Efficient	3	0	0	-1	-3	-2	-6
Speed of filtration	1	0	0	3	3	1	1
Pathogen Removal	2	0	0	-1	-2	2	4
Turbidity Reduction	3	0	0	3	9	2	6
Net Score			**0**		**2**		**6**

Figure 2. Pugh Matrix

The filtration system was confined to a limited and predefined area, therefore compaction was a key criterion. Furthermore, turbidity reduction was the primary goal of the filter, so of the criteria shown in Figure 2, turbidity reduction was given the highest weight factor (three) alongside space efficiency. Additional criteria with higher weight factors included pathogen removal, building and maintenance costs, and freeze tolerance. These are outlined in further detail in the requirements document (see Appendix 1).

SLOW SAND FILTRATION

The filtration of water in an SSF system consists of a combination of physical and biological processes (Nyberg et al., 2014). The biological layer, known as the *schmutzdecke,* traps particles and degrades organic matter (Lahlou, 2000), while the sand layer allows for sedimentation, straining and screening of the water (Lahlou, 2000; Nyberg et al., 2014). The sand layer provides a large surface area for non-pathogenic organisms to settle and subsequently break down any incoming organic matter, creating the *schmutzdecke* (Maiyo et al., 2023). This a biologically active layer in which the non-pathogenic organisms, including algae, protozoa, plankton, bacterium, and fungus populations, prey on and destroy bacteria and viruses entering the influent water. (Maiyo et al., 2023; Nyberg et al., 2014).

Traditional SSFs have four layers of filter medium: the supernatant water layer, a larger sand layer, a finer gravel layer, and a coarse gravel underdrain. The supernatant water layer creates the pressure head needed to force water flow through the porous layer, and the finer gravel layer prevents sand from entering the coarse gravel underdrain. The underdrain provides support and ensures the uniform downward flow of water in the above layer before the water exits the filter (Maiyo et al., 2023)

Pilot testing is necessary when designing SSFs (Lahlou, 2000). While parameters such as surface area, filter depth, and sand size can be set, the performance will also depend on the influent water quality. Therefore, a pilot phase should be performed to monitor the performance of the SSF prototype (Barrett et al., 1991; Lahlou, 2000).

THE PROTOTYPE

The final prototype, shown in Figure 3 consists of two SSFs that use IBC totes as their containers, with dimensions 1.01m x 1.01m x 1.22 m. The two totes are placed on top of the clean water storage tank, which measures 1.025m x 1.64m x 2.83m, leaving room for the head tank to be positioned beside the two totes.

Figure 3: Final SSF system

The volume of the storage tank was determined to be 6000L and is made of steel; it is a carrot washing structure that we converted into a storage tank. The head tank is cylindrical with dimensions of a height of 0.41m and a diameter of 0.50m. All key dimensions can be seen in Figure 4. The totes' outflow pipes are connected in a U-pipe shape to control the headwater height and feed into the clean water storage tank below.

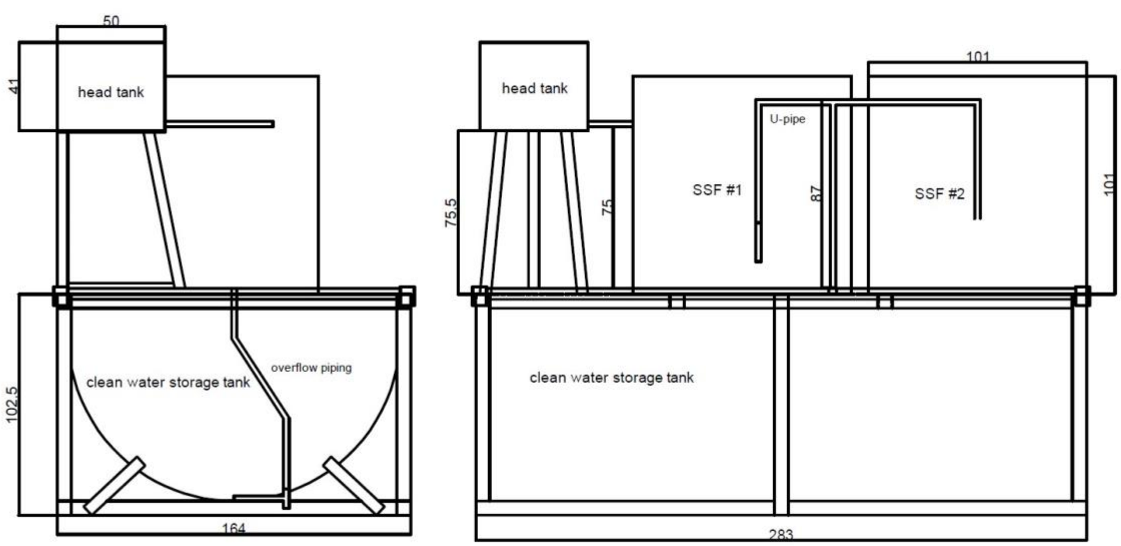

Figure 4: Drawing of final system, dimensions shown in cm

DESIGN PROCESS

Below is the process of how the design decisions were made for the SSF system prototype.

FILTER DESIGN

The design process of the slow sand filter was determined by referencing the Water for the World Designing a Slow Sand Filter Technical Note No. RWS. 3.D.3, intended as a design manual for SSFs used for rural communities' drinking water. It was validated with the American Water Works Association Manual of Design for Slow Sand Filtration, intended as an in-depth engineering manual for larger-scale slow sand filters.

Filter Surface Area

In typical larger-scale SSF design, the required surface area is determined first, and then the SSF container is constructed according to that value (Barrett et al., 1991). However, since we were confined to using recycled materials (recycled plastic containers), we were limited to pre-existing container sizes and thus surface areas. To determine the ideal container for the SSF, we calculated the daily water production based on surface area. The container needed to produce at least 600 L/day to meet irrigation demands. We compared two options: refurbished oil drums and IBC totes. Quick floor plans were drawn for each option (see Appendix 2).

The quantity of water was calculated with the following formula: $Q = A * V$, where V is the velocity of the water which is assumed to be 100 $L^{*}\ m^{-2}\ {*}h^{-1}$ (see Appendix 3 for complete calculations) (Oki et al., 2016). The surface areas were determined using standard dimensions. A standard oil drum has an inside diameter of 0.5715 m and the typical dimension for an IBC tote is 1.219 m by 1.016 m (IBC Tanks, n.d.; ISO, 2002).

One oil drum would produce around 615.6 L of water per day and two oil drums would produce 1231.2 L of water per day which meets the water quantity demand. One IBC tote would produce around 2971 L of water per day and two totes would produce 5942 L of water per day. Although the oil drums are more compact and meet the water quantity requirements, the client preferred IBC totes for the project. Therefore, we designed a system using two IBC totes.

Filter Depth

Engineering manuals recommend a sand depth of 0.5m to 1m for optimal removal of contaminants (Barrett et al., 1991; Water for the World, n.d.). Additionally, experiments suggest that a filter media depth between 60 cm and 90 cm has higher rates of removal of pathogens than a filter media depth of 30 cm (Raudales et al., 2014). Therefore, a sand depth of 66cm was chosen, so that the total filtration bed depth would be 75cm including the support layers, leaving 25cm for headwater and a small freeboard (considering the container height is 1m).

Headwater Height

Several manuals recommend around 0.7m - 1m of headwater above the filter surface, with a maximum height of 1.5m - 2m (Barrett et al., 1991; Calvo-Bado et al., 2003; Lahlou, 2000). However, these are intended for larger-scale projects, often for drinking water. A manual intended for horticultural SSF design recommends a minimum water head maintained at 0.3m while emphasizing that the flow rate will vary with differing water heads and filter sand quality, and this must be determined according to the availability of materials. Additionally, it has been reported that decreasing the flow rate by reducing headwater above the static water level from 30cm to 20cm or 10cm improves bacterial removal (Freitas et al., 2022). As mentioned above, the total filter depth was chosen to be 75cm, leaving about 20cm for the headwater. The minimum headwater height is 6cm (maintained by the U-pipe) to keep the filter surface wet and allow for the inlet to be fully submerged, preventing water disturbance and sand erosion.

Number of filters

A minimum of two filters should be constructed so that when one filter is disconnected for cleaning, the other filter can be used. We designed the system for two filters due to space constraints considering the size of the containers chosen.

Sand Selection

Selecting the right sand for efficient filtration was crucial. Finding a local supplier who could provide a small quantity of affordable sand was challenging. After contacting several companies, we narrowed it down to Pépinière Cité des Jeunes and RONA.

The Pépinière Cité des Jeunes was close to the farm and had a reasonable price. However since the sand was sold in bulk, they did not have the specifications on hand therefore testing was required.. We set up a small-scale version of the SSF to verify flow rate. This method, though not ideal, was necessary due to time constraints. The test showed a velocity of 76.5 L/h*m which was below the required rate (see Appendix 4 for more details). Without further sand specifications, we couldn’t confidentially use this sand.

Initially, purchasing sandbags from RONA seemed too expensive. However, the farm already had some Bomix sandbags from RONA, this helped reduce overall costs. The sand specifications were available online, allowing us to access the sieve analysis and calculate the uniformity coefficient. Most sand particles matched the required diameter (0.3mm to 0.6mm) and had a uniformity coefficient of less than 3 (see Appendix 5 for calculations) (Oki et al., 2016; U.S. Agency for International Development, 1985).

To better predict the flow rate of the SSF, we then calculated the hydraulic conductivity of the selected sand. Since the hydraulic conductivity can only be obtained through testing, we set up an experiment following the ISO standard 17312:2005 for soil quality (ISO, 2005). This standard recommends using a rigid wall permeameter to test hydraulic conductivity. However, lacking access to one, we experimented using a large PVC pipe with a hole at the bottom and the sand from the first SSF tote.

Hydraulic conductivity was determined with the Darcy Law: $Q = K * A * \frac{h}{L}$, where Q is the flow, K is the hydraulic conductivity, A is the cross-sectional area, h is the head loss and L is the distance through which the water travels (Atangana, 2018). Since Q, A, h and L were all know values, we were able to determine K. This experiment was repeated three times and the average hydraulic conductivity value for sand was $8.3 * 10^{-4} \frac{m}{s}$ (see Appendix 6 for details). This value is the right order of magnitude compared to other hydraulic conductivity values of sands (*Hydraulic Conductivity and Permeability of Various Soil Types*, 2024).

However, when we used the SSF specifications to calculate the daily flow rate of the filter, the result was significantly higher than the actual daily value observed. This discrepancy might be due to the *schmutzdecke,* which increases resistance and slows down the flow over time (Barrett et al., 1991). Additionally, our experiment might be flawed due to the lack of proper tools. For this SSF, it seems more prudent to refer to the pilot plant for flow specifications.

Gravel Support

The gravel support has two layers: the upper layer acts as a separation layer, preventing filter media from moving down with the water and the lower layer prevents the smaller gravel and sand from passing through the manifold and going through the outlet tube. Two sizes of gravel were used; smaller gravel above larger gravel. For the smaller gravel, ¼ in was used, and for the larger gravel ¾ in. was selected as it is larger than the underdrain manifold holes while not affecting flow. The separation layer is 4cm and the support layer is 5cm, as shown in Figure 5. These depths were chosen to fully cover the drainage manifold

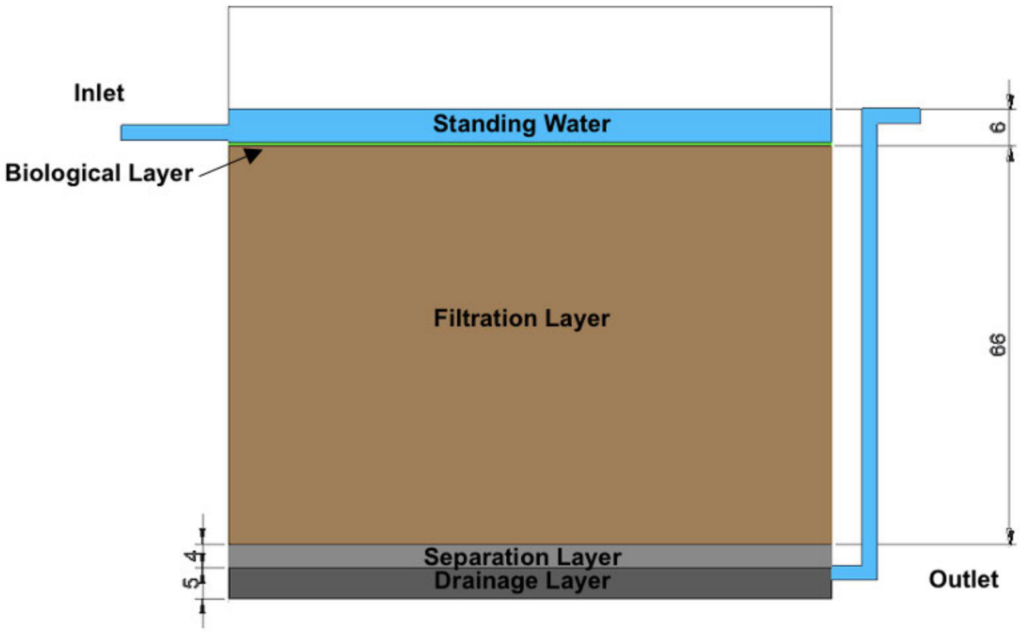

Figure 5: Schematic of the SSF

DESIGNING FOR FLOW CONTROL

Pretreatment

Pre-treatment is typically recommended for slow sand filtration, especially when turbidity levels may vary. In the case of this project, the underground reservoir for the drainage water acts as a large sedimentation tank and the submersible pump is placed a few inches above the bottom to ensure little sediment is upturned while drawing water.

Influent Distribution

The inlet was placed at 75cm so that water enters within the minimum head of 6cm. Manuals recommend various methods of influent distribution that aim to reduce sand erosion and increase aeration. Because the flow into the SSF is so low (due to it being from the surge tank), there is little concern for sand erosion; this tends to be a greater issue in larger systems with greater inflow speeds. However, by designing the inflow to be within the minimum head we minimized water disturbance to reduce upturn of the schmutzdecke and filter bed surface. Additionally, aeration is not a concern at the inlet, as the head tank allows for aeration between the underground reservoir and the SSF.

The head tank is designed to reduce turbulence of flow. The float valve triggers the submersible pump in the reservoir which fills the tank, and the tank drains to the SSF. It is placed higher than the SSF to control headwater depth; if too low, the water will flow into the SSF, and if too high, it will flow back into the head tank. The flow varies slightly depending on the depth of water in the tank, but it means that flow into the SSF can be continuous without constantly running the submersible pump.

Catchment System

The purpose of an underdrain manifold is to support the filter bed, ensure a uniform filtration rate while collecting the filtered water (Water for the World, n.d.). When designing a manifold, the head loss in the main outlet pipe should be small compared to that of the holes in the manifold that collect the water to ensure an even hydraulic loading rate in the SSF (Barrett et al., 1991). To get an exact design, an involved calculation process is required. For our prototype, we evenly spaced the holes, made the holes equal in area, and calculated to ensure that the accumulated area of flow from the holes would be equivalent to the outlet flow to not limit flow in the filter.

Drainage

The piping of the system needed to be configured to allow the SSF to be drained into somewhere other than the clean water tank, for cleaning the system and draining it at the end of the season. The SSF piping includes a ball valve placed after the outlet that prevents water from flowing to the clean water tank and forces it to drain out to the ground.

Capacity for Backfilling

After cleaning the filter, and when starting up in the spring, the SSF will need to be backfilled. In our design, the filer can be backfilled using the same valve configuration used to drain the system. If the secondary valve leading to the U-pipe is closed and the main outlet valve is left open, water can be sent through the filter from the bottom up.

Overflow

Overflow piping exists mainly to control the filtration rate, preventing the headwater form from reaching a depth higher than what is recommended (Water for the World, n.d.). It is also useful in the case of reduced flow due to increased head loss, indicating that the filter should be cleaned (Barrett et al., 1991). Because of the surge tank design, the SSF does not have an overflow outlet. The surge tank effectively controls the flow into the SSF and allows the headwater to drain back into the surge tank if too deep.

There is, however, overflow piping for the clean water tank. In the case that the irrigation is not used for some time if the tank fills completely, excess water will flow back into the reservoir via a shallow buried pipe, allowing the SSF to continue filtering water into the tank.

Designing for Freezing

By designing for draining and backfilling, the prototype is designed for freezing as well. All pipes can be disconnected, separating the SSFs from the greenhouse and clean water tank. The clean water tank can be drained back into the underground reservoir and the SSFs can be drained to the ground.

CONSTRUCTION AND INSTALLATION PROCESS

BUILDING THE SSF

The slow sand filter was constructed using an IBC tote and PVC piping. First, the top metal caging was removed and the plastic was cut out, as shown in Figure 6.

Figure 6. Top Removal of SSF

Then, the inside of the tote was lightly sanded to decrease the smoothness of the plastic. This prevents water from slipping along the smooth sides rather than filtering through the sand. Then, we built the catchment system, shown in Figure 7. We created a closed rectangle out of 1 in

PVC piping and drilled holes ¼ in wide every 1in. These values were chosen so that the SSF's flow would not be impeded by the catchment system.

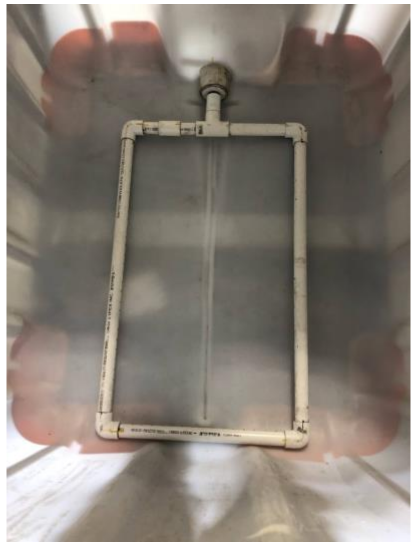

Figure 7. Catchment System

Next, as shown in Figure 8, clean gravel was laid down at a total 9cm depth to prevent sand from escaping through the holes. Once the gravel was levelled, the sand could be added, as seen in Figure 9. Once added, we backwashed the filter with clean water to rinse the sand of dust residues until the outflow water was clear.

Figure 8. Gravel Layer

Figure 9. Sand Layer

BUILDING THE CLEAN WATER TANK

The clean water tank was constructed out of an old, rusty, steel carrot washer, shown in Figure 10. The structure was first metal grinded to remove rust, then painted with rust-resistant paint. Then, the excess metal parts were cut off and any holes were welded closed to make it watertight. Then, a steel lid was constructed, with steel beams laid across the structure for extra support (see Figure 11).

Figure 10. Initial Steel Structure

Figure 11. Final Steel Structure

FLOW DIAGRAM

As shown in Figure 12, the system was designed to include two SSFs, a water storage tank large enough to hold water for multiple days of irrigation, and a surge tank (for flow control) within the predetermined space.

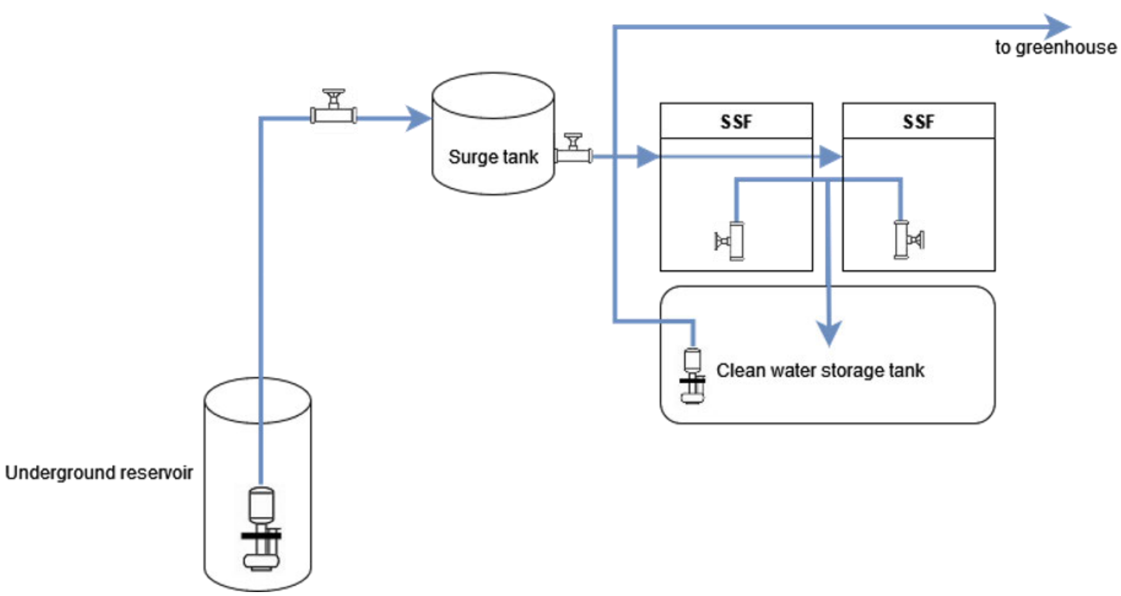

Figure 12: Flow diagram

Influent water is drawn from the underground reservoir, which holds collected tile drainage water with a capacity of 30000L. A ½ HP pump draws water up to the head tank, shown in Figure 12 when triggered by a float valve in the surge tank. The float valve sits on the surface of the water; once the water reaches a low level, indicating the minimum headwater level, the switch is triggered, and the surge tank is refilled. The surge tank then feeds the SSF by gravity. For the prototype, the surge tank is connected only to the first IBC tote, as shown in Figure 12 When the second SSF is built it will be connected to the second IBC tote as well. The influent water filters through the SSF by gravity, exits via the outlet pipe, and flows into the clean water storage tank. Using a ¾ HP submersible pump in the storage tank, the filtered water is then sent to the greenhouse where it passes through the UV sterilizer and into the greenhouse's irrigation system.

COST ANALYSIS

The material cost for building the SSF using on-farm materials was estimated for our case and for a scenario where new components would be needed, including a float switch, sump pump, plumbing fittings, a steel tank, and steel for a clean water reservoir. Costs were calculated based on receipts and the client estimated the value of new materials based on his experience in buying scrap metal and other parts. The overall cost of the system implemented on the farm was $1,137.38, as shown in Table 2. Although this slightly exceeded our initial budget, all costs were approved by the client before purchasing. Building a similar SSF with new materials would cost $2,248.63.

The increased cost for sand in the new material scenario was due to the need for approximately 36 bags to achieve the desired volume (see Appendix 7 for calculations). In contrast, for the on-farm scenario, the client already had around ten bags from previous projects, which reduced the number of additional bags needed. Additionally, the client received a discount on the sandbags, further lowering the overall cost. The sand cost only covers the amount needed for one tote as other alternatives are being looked at for the second SSF tote. The overall cost would therefore increase by a few hundred dollars once that sand is purchased. Excavation and gravel costs were not included in the price list as the gravel was already on site, and the excavation was done for free by someone working with the farm. The cost of excavating would vary depending on specific requirements.

The cost does not include the manual labor needed to build the SSF. Significant time and effort were invested in salvaging materials and making them usable in the system. If new materials were purchased, the manual labor required would be lower (Page et al., 2006). Maintenance and electricity costs for running the SSF are minimal and were also excluded. Finally, water testing costs were not included as they are an optional step to ensure the system functions adequately.

Table 1. Cost for SSF with Recycled Materials vs New Materials

Materials	**Quantity**	**SSF with Recycled Materials**	**SSF with New Materials**
Sand	36 bags	$193.75	$350
IBC totes	2	$200	$200
Float switch	1	$0	$35
Sump Pump	1	$0	$120
Plumbing Parts & Fittings	NA	$411.68	$411.68
Other Plumbing Materials	NA	$0	$100
Clean Water Reservoir			
Paint and Supplies	NA	$331.95	$331.95
Steel to make reservoir lid	~4.65 m^2	$0	$200
5000 L steel reservoir	1	$0	$500
Total		**$1 137.38**	**$2 248.63**

RESULTS

FLOW TESTING

The pilot SSF produced approximately 1500 L/day, significantly exceeding the required 600 L/day. Consequently, the flow rate per area of the pilot SSF is 61.2 $L^* m^{-2} {}^*h^{-1}$, (see Appendix 8 for calculations). Although this value is below the recommended range of 100 $L^* m^{-2} {}^*h^{-1}$to 300 $L^* m^{-2} {}^*h^{-1}$, slower filtration can enhance the effectiveness of filtration(Oki et al., 2016). Therefore, the lower flow rate is not a concern, as the filter still meets the water production requirements.

WATER QUALITY TESTING

To adequately meet the farm's irrigation water quality and quantity demands, we needed to measure the water's turbidity, the number of coliforms, and the presence of plant pathogens. The testing window was short, as the *schmutzdecke* requires two weeks to a few months to reach maturity, and the system had to be drained before freezing began in mid-October (Barrett et al., 1991; Government of Canada, 2024). Additionally, our budget constraints limited the number of tests we could conduct.

Turbidity Testing

The initial requirement for the turbidity testing was based on the Canadian Guidelines for drinking water. The aim was to have effluent water at 1 NTU so the UV filter could work effectively. This requirement was a bit too precise for the turbidity testing we had available. When measured according to EPA Method 180.1, turbidity testing typically involves comparing the intensity of light scattered by the water sample and the intensity of light scattered by a control sample. In the range of 0-40, NTU samples can be measured without dilution; in the range of 40-1000, they should be diluted. (*Method 180.1: Determination of Turbidity by Nephelometry*, 1993).

Readings are taken with a turbidimeter, consisting of a nephelometer (an instrument for measuring the concentration of suspended solids) a light source for illuminating the sample, and one or more photo-electric sensors with a readout device. The light source should be at a 90-degree detection angle. These measurements are represented by NTUs (*Method 180.1: Determination of Turbidity by Nephelometry*, 1993). However, these turbidity meters cost around $1000 - $2000, which is outside the project budget, and the measurement process is very technical and outside of the project scope (*Turbidity Meters*, n.d.). So, turbidity values were estimated visually. Figure 13 shows the difference in the turbidity of the sample taken before vs after the SSF.

Figure 13: Water before vs after the SSF (October 24th, 2024)

Microbiological Contaminant Testing

The SSF needed to reduce the number of coliforms and fecal coliforms in the water, as most vegetables produced in the greenhouse are eaten raw. While the microorganism levels didn't need to be zero—since the water would pass through a UV filter and the vegetables would be washed both on the farm and by the customer—the client still wanted to minimize coliform levels. Due to our lack of expertise and access to the proper tools for water quality testing, we recommended that the testing be conducted by a professional laboratory. This ensures that water quality testing is performed in a standardized manner. When water sampling was done, a microbiologist employed at the farm followed a standardized protocol to collect and ship the water to the desired laboratory. Ideally, we would have performed multiple tests at three stages: before the SSF, after the SSF, and after the UV filter, to compare coliform levels. However, each test costs around $100, and the protocols are designed for potable water testing (H2Lab, 2024). When levels exceed potable water standards, coliforms are not counted, making the results less useful for our client.

The reservoir water was tested by H2Lab in July 2020 and by Groupe Environex in August 2021. After passing through the SSF, the water was tested again by H2Lab in September 2024. In 2021, the number of coliforms was too high for drinkable water and was therefore not determined (ND), so we used the 2020 values for comparison. We acknowledge that the time difference affects the adequacy of the comparison, but budget constraints limited our options.

Ideally, coliform levels should be below 1000 CFU/100ml. The testing did not indicate a reduction in coliforms (Table 2), likely because the s*chmutzdecke* contains various microorganisms that end up in the water (Lahlou, 2000). These microorganisms destroy harmful ones, but the tests do not differentiate between beneficial and harmful organisms. Identifying the different bacteria would require extensive testing, which is beyond the scope of this project.

No specific requirements were set for *E. coli* levels, but they were at 0 in both 2020 and 2024, which is ideal. The requirement for fecal bacteria was less than 100 CFU/100ml, and there was a reduction from 2020 to 2024, with the water after the SSF containing only 1 CFU/100ml, meeting the irrigation water standards.

Table 2 Microorganisms in the water before vs after the SSF

Parameters	Reservoir Drain Water (2020)	Reservoir Drain Water (2021)	After SSF Water (2024)	Requirements
Total Coliforms (CFU/100 mL)	>80	ND	ND	1000 CFU/100 ml
Atypical Colonies (CFU/100 mL)	NA	ND	>200	NA
E. Coli (CFU/100 mL)	0	ND	0	NA
Enterococcus (CFU/100 mL)	>60	ND	1	100 CFU/100 ml

Plant-Pathogen Testing

We initially aimed to test for plant pathogens before and after the SSF, but we encountered several challenges in finding affordable and useful testing options. The client was particularly interested in plant pathogens due to their potential impact on productivity and profits. We approached several laboratories at the Macdonald campus, but none offered the specific testing we needed. We then contacted Guelph University, which has a plant pathogen testing laboratory for farms. However, their testing was priced at around $240 per sample and was qualitative indicating only the presence or absence of plant pathogens in the water (AFL, 2024). This option was too expensive and did not meet our needs. Our final alternative was to conduct the testing ourselves in a greenhouse experiment, but the client disconnected the system before we could collect the water samples. The client operated the filter throughout the summer and did not report any noticeable changes in issues related to plant pathogens.

MAINTENANCE AND CLEANING

Maintenance of the SSFs involves cleaning the *schmutzdecke* from the filter bed surface. Cleaning frequency is typically every few months but can vary as it depends on inflow water quality and flow rate. It can be determined more accurately over time as the filters are used. Head loss is a clear indication of when to clean an SSF; when head loss reaches the overflow valve this indicates that cleaning is necessary (Barrett et al., 1991).

SUSTAINABILITY CONSIDERATIONS

It is important to identify the environmental, economic, and social impacts of this project to evaluate its sustainability in a broader context, in addition to its impacts on the farm specifically.

ENVIRONMENTAL IMPACTS

Building an SSF system for Tourne-Sol farm ensures they can continue to recycle their tile drainage water effectively and efficiently. In doing so, less groundwater is extracted, and less agricultural runoff is generated. While these are not the primary motivations behind the filtration system, the positive environmental impacts still apply. Tile drainage recycling can reduce nutrient levels in a farm's surrounding waterways by decreasing drainage output and agricultural runoff (Reinhart, 2019). Additionally, it can reduce flood risk and contribute to a more resilient farm landscape by mitigating water losses (Reinhart, 2019).

ECONOMIC IMPACTS

Most of the system's expenses are attributed to the construction and installation phases. These initial costs can be substantial, but they are a one-time investment. Once the system is up and running, maintenance and energy requirements are relatively low and should not incur significant ongoing costs (Page et al., 2006). This makes the system economically viable in the long term.

Over time, the system is expected to enhance farm productivity by providing a consistent and reliable source of higher-quality irrigation water. This improvement in water quality can lead to healthier crops and potentially higher yields. Additionally, by reducing the risk of produce loss due to poor-quality irrigation water, the system can contribute to more stable and predictable farm operations. Ultimately, this can lead to increased profitability for the farm.

SOCIAL IMPACTS

Slow sand filters (SSFs) demand minimal and infrequent maintenance and cleaning (Barrett et al., 1991). When functioning effectively, SSFs provide a dependable and straightforward system, which is particularly advantageous for small-scale farms. They do not necessitate the presence of a technician, additional staff, or specialized knowledge for operation. This simplicity is designed to enhance operational efficiency for farm employees (Etzinger & Guité, 2024).

LIMITATIONS

The report identifies several limitations in the prototype and design, primarily due to time and budget constraints. These include inaccurate hydraulic conductivity testing because of insufficient equipment, challenges in finding suitable local sand suppliers, limited access to affordable and comprehensive water testing options, and the absence of flow meters and piezometers, which are essential for precise monitoring and measurement.

RECOMMENDATIONS

HYDRAULIC CONDUCTIVITY TESTING

With more time and resources available, we recommend rigorously following the ISO standard 17312:2005 or finding an alternative testing method for hydraulic conductivity. More accurate hydraulic conductivity allows for a more efficient design of the SSF and could be beneficial for optimizing the system (Barrett et al., 1991).

SAND SUPPLIERS

Finding a suitable sand supplier could help lower the overall costs of the second filter and improve its efficiency. Suppliers in the west of the Montreal area didn't meet the project's needs, but it might be possible to find more appropriate companies in areas slightly further from the farm. Although there would likely be delivery costs, identifying additional sand suppliers could help optimize the project. While this isn't an option for the current project, specialized suppliers like Northern Filter Media in Illinois provide sand with detailed specifications specifically for filter media purposes ("Northern Filter Sand," n.d.). Contacting such companies could help identify possible sand sources closer to the farm.

PLANT PATHOGEN TESTING

Plant pathogen testing could have been conducted in the greenhouse at the Macdonald Campus. Seeds from the farm, particularly from vegetables prone to issues like damping off, could be used in an experimental setup. One set of plants would be irrigated with water from the greenhouse, while another set would be irrigated with water filtered through the SSF. By comparing plant growth over a few weeks—measuring plant height, leaf count, and the presence of damping off—we could assess any differences. Water samples from the reservoir, post-filtration, would need to be collected and stored according to standard guidelines, and the experiment should adhere to typical greenhouse plant growth experiment protocols (ISO, 2024; Poorter et al., 2012). While this might not be the most accurate way to test for plant pathogens it could provide us with results at a low cost.

FLOW MONITORING

To better understand the flow rate of the SSF over time, flow meters should be installed in the system. Although this wasn't a priority for this project, it would greatly aid in the monitoring and maintenance of the SSF. Installing a flow meter on the outlet side would allow for daily records of the treated water volume (Barrett et al., 1991).

HEADLOSS MEASUREMENT

To more accurately monitor the filters, piezometers could be installed. They could be used to more accurately determine when the SSFs need cleaning. For optimal results, two piezometers should be provided for each filter. The piezometer tubes should have diameters of 2.5-5.0 cm (1-2 in.), with float balls and scales provided (Barrett et al., 1991)

CONCLUSION

Tourne-Sol Co-operative Farm, an organic farm in Les Cèdres, Québec sought a filtration system for its recycled drainage water, used in their greenhouse, to reduce turbidity and ideally plant pathogens as well. This report outlined the design decision progress that led to the choice of an SSF system, as well as the process and considerations of the design. The system was designed to have two SSFs, a clean water storage tank, and a head tank that controls the inflow. One SSF was constructed for the pilot phase. The installation and construction process, costs, and limitations were explained. Water testing was conducted that showed a reduction in fecal coliforms, and a visual reduction in turbidity was found and a visual but more precise testing would provide a more in-depth analysis. Additionally, quantitative plant pathogen testing would provide a better indication of its efficacy. Finally, recommendations for optimization include more precise flow monitoring with flow meters, finding a better sand supplier, and performing hydraulic conductivity testing before building the second SSF filter.

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APPENDICES

APPENDIX 1. REQUIREMENTS DOCUMENT

Obj 1) Must meet farm's irrigation water quality and quantity demands.

Req 1.1) Must reduce turbidity.

Spec 1.1.1) The turbidity of the effluent water should be around 1 NTU.

Req 1.2) Must limit the number of coliforms in the water.

Spec 1.2.1) The count of fecal coliforms should be under 100 per 100 ml of irrigation water.

Spec 1.2.2) The count of total coliforms should be under 1000 total coliforms per 100 ml of irrigation water.

Req 1.3) Must limit the plant pathogen in the irrigation water

Req 1.4) Must filter enough water to meet irrigation schedule demand.

Spec 1.4.1) The rate of filtration should be 1800 L/3 day.

Req 1.5) Must have adequate filtered water storage reservoir.

Spec 1.5.1) The reservoir must store at least 2000 L of water.

Obj 2) Must be cost-efficient.

Req 2.1) The cost of constructing the pilot project should be under 1000$

Obj 3) Must be compact.

Req 3.1) Must be fit within designated space.

Spec 3.1.1) The width of the filter and the storage must not exceed 6 ft.

Spec 3.1.2) The length of the filter and the storage must not exceed 17 ft.

Obj 4) It must be decommissioned in the cold months and recommissioned in the warm months.

Req 4.1) Parts must be easily disconnected and reconnected.

APPENDIX 2. INITIAL FLOOR PLANS

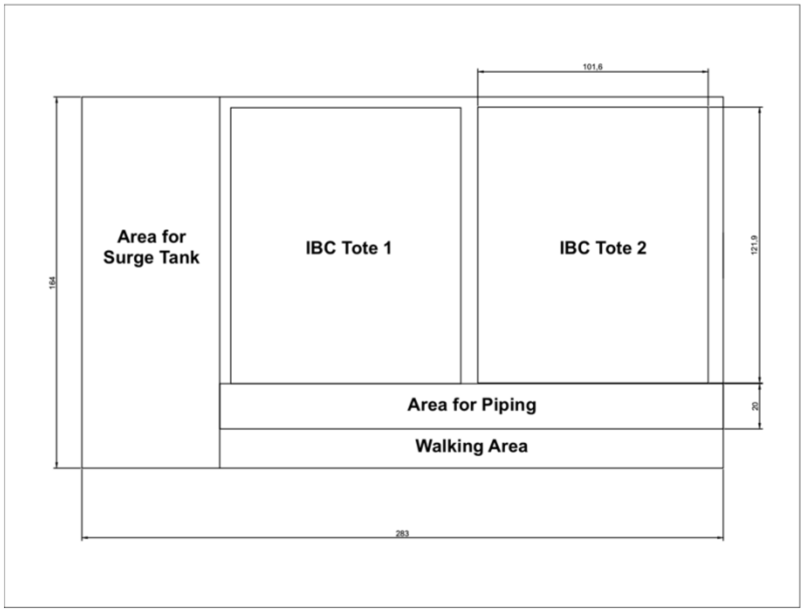

Figure 14. IBC Tote Floor Plan

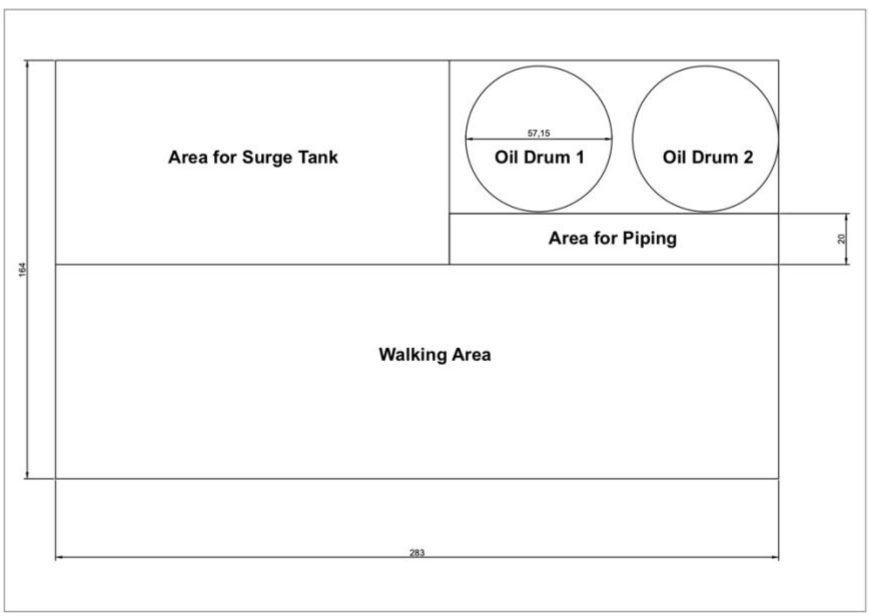

Figure 15. Oil Drum Floor Plan

Dimensions Figures 14 and 15 are in cm.

APPENDIX 3.. FLOW RATE CALCULATIONS FOR OIL DRUMS AND IBC TOTES

Oil Drums:

$$D_i = 0.5715\ m$$

$$A = \pi * \left(\frac{D}{2}\right)^2 = \pi * \left(\frac{0.5715}{2}\right)^2 = 0.2565\ m^2$$

$$For\ one\ drum:\ Q = A * V = 0.2565\ m^2 * 100 \frac{L}{m^2 * h} * 24 \frac{h}{day} \approx 615.6 \frac{L}{day}$$

$$For\ two\ drums:\ Q = 615.6 \frac{L}{day} * 2 = 1231.2 \frac{L}{day}$$

IBC Totes:

Typical size: 48 in x 40 in = 1.219 m x 1.016 m

$$A = W * L = 1.219\ m * 1.016\ m = 1.238\ m^2$$

$$Q = A * V = 1.238\ \ m^2 * 100 \frac{L}{m^2 * h} * 24 \frac{h}{day} \approx 2971 \frac{L}{day}$$

$$For\ two\ totes:\ Q = 2971 \frac{L}{day} * 2 = 5942 \frac{L}{day}$$

APPENDIX 4. SAND TESTING EXPERIMENT FOR SAND FROM PÉPINIÈRE LA CITÉ DES JEUNES

A small scale system SSF as shown in Figure 16 was set up to try to estimate the velocity of the water if this sand was used in the pilot SSF.

Figure 16. Small-Scale SSF Setup for Sand Testing

Calculations for the experiment:

$$D_i = 0.275\ m$$

$$A = \pi * \left(\frac{D}{2}\right)^2 = \pi * \left(\frac{0.275}{2}\right)^2 = 0.0594\ m^2$$

$$T = 33\ min * \frac{1h}{60\ min} = 0.55\ h$$

$$V = 2.5\ L$$

$$Velocity = \frac{2.5\ L}{0.55\ h * 0.0594 m^2} = 76.5 \frac{L}{h * m}$$

APPENDIX 5. UNIFORMITY COEFFICIENT CALCULATIONS

$$coefficient\ of\ uniformity = \frac{diameter\ through\ which\ 60\%\ of\ material\ passes}{diameter\ through\ which\ 100\%\ of\ material\ passes}$$

d60 was assumed to be 0.315 as 60% is in the 50 to 65% passing range and linear interpolation was used to find d10 as 10 % is between 15 to 25 % and 0 to 3% range of percent passing (Daubois, n.d.).

1. Linear interpolation

$$average\ \%\ passing\ 15 - 25 = \frac{15 + 25}{2} = 20$$

$$average\ \%\ passing\ 0 - 3 = \frac{0 + 3}{2} = 1.5$$

$$d10 = \frac{10 - 1.5}{20 - 1.5} * (0.160 - 0.080) + 0.080 = 0.117\ mm$$

2. Coefficient of uniformity

$$\frac{d60}{d10} = \frac{0.315\ mm}{0.117\ mm} = 2.69 < 3$$

APPENDIX 6.. HYDRAULIC CONDUCTIVITY TESTING

Darcy's Law:

$$K = \frac{\Delta V * L}{\Delta h * A}$$

Table 3 Hydraulic Conductivity Values from Testing

Trial	**D (m)**	**A (m^2)**	**L (m)**	**Δh (m)**	**ΔV (m^3)**	**Δt (s)**	**K (m/s)**
1	0.1	0.007853982	0.05	0.09	0.00041	40	0.000725039
2	0.1	0.007853982	0.05	0.09	0.000572	50	0.000809214
3	0.1	0.007853982	0.05	0.09	0.000545	40	0.000963772
						Mean	0.000832675

APPENDIX 7. PRICE OF SAND FOR NEW MATERIALS SCENARIO

$\frac{Price\ (\$)}{bag}$ = 9.69$ (RONA, n.d.)

$\rho = 1625\ kg/m^3$ (Daubois, n.d.)

1 bag = 30 kg

1. Number of bags needed

$$\#\ of\ bags = \frac{0.666\ m^3 * 1625\frac{kg}{m^3}}{\frac{30kg}{bag}} = 36\ bags$$

2. Price for 36 bags

$$36\ bags * \frac{\$9.69}{bag} \approx 350\$$$

APPENDIX 8. PILOT SSF DAILY FLOW RATE PER AREA

$$A = W * L = 1.02\ m * 1.0\ m = 1.02\ m^2$$

$$V = \frac{Q}{A} = \frac{1500\frac{L}{day} * \frac{1day}{24h}}{1.02\ \ m^2} \approx 61.2\frac{L}{day}$$