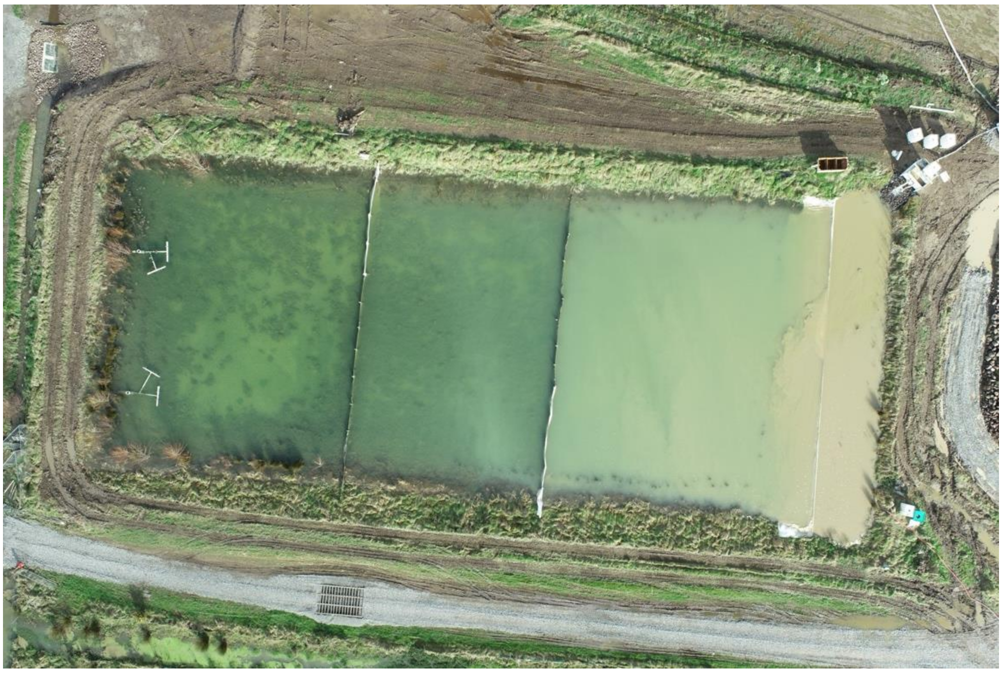
Treatment of Loess Soil Sediment-Laden Stormwater Runoff, with the Aid of Flocculants, Coagulants and Geotextiles



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Declaration of Competing Interest

I declare that I have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Jon Tomsett, Cirtex
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Davie Lovell Smith
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My Father, Girlfriend, and Flat

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Abstract

Loess soils are common in New Zealand; their high erodibility and relatively fine particle size make them challenging to remove from suspension in stormwater runoff. The use of traditional sediment retention basins has proven to be ineffective and costly when dealing with these types of sediment laden flows. The study's objective is to assess whether the combination of flocculants, coagulants and geotextile filtration fences within a sediment retention basin can effectively remove suspended solids from stormwater runoff and decrease the size of traditional basins.

Three primary testing methodologies were employed: turbulent, laminar lab testing and an in-situ test. The optimal poly-aluminium chloride flocculant dose of 8mL/L was established using bench testing. The turbulent lab tests had calculated total suspended solids reduction of up to 125 mg/L for the geotextile, while the laminar test had reductions of up to 112 mg/L. During the in-situ testing, the filtration fences had observed reductions between 40 mg/L and 350 mg/L. The testing found that geotextile filtration fences can remove significant amounts of suspended solids from loess sediment-laden stormwater runoff.

These results indicated that the combination of flocculants, coagulants and geotextile filtration fences can reduce the size of traditional sediment retention basins while maintaining or even improving the suspended solid removal performance. This approach offers a cost- and area-effective solution for erosion and sediment control, making it a viable alternative to current practices.

Introduction

Effective and timely erosion and sediment control practices are essential in minimising soil erosion, maintaining water quality and removing suspended solids (SS) in runoff (Farjood, 2016). The Canterbury Regional Council has an Erosion Sediment Control Guideline that outlines methods for achieving environmentally friendly sediment control practices (ECAN, 2007). It is recognised that full containment of sediment runoff is never entirely achievable. The recognised limitation of sediment into natural waterways is 50 mg/L, as detailed in the Canterbury Regional Council discharge consents.

Effective and timely erosion and sediment control practices are crucial in maintaining a low environmental impact on the surrounding environment, maintaining water quality, minimising soil erosion and reducing suspended solids (SS) in runoff (Farjood, 2016). The Canterbury Regional Council Erosion Sediment Control Guideline 2007 describes the measures that must be taken to achieve these goals of lowering environmental impacts. This guideline also defines the criteria for constructing a sediment retention basin, which is the most common way of dealing with sediment-laden stormwater runoff (ECAN, 2007). There are also many other ways of controlling or mitigating erosion and sediment, which are reported in this guideline.

However, sediment-laden stormwater runoff is impossible to avoid for large-scale earthwork activities. Engineers and contractors should utilise erosion sediment control devices during these activities. This runoff generally contains contaminants, including sediments, nutrients, heavy metals, and hydrocarbons (Westerbeek-Vopicka, 2009), increasing the turbidity and SS of the natural waterways. Removing these contaminants is crucial as they can cause adverse effects on aquatic organisms and the surrounding environment and cause problems within water purification centres (Bilotta & Brazier, 2008).

Loess soils can be found all over New Zealand (Berryman, 1993), covering a significant area of the Earth's land surface, approximately 10% (Muhs, 2007). Figure 1 is a map of New Zealand's South Island with a colour-coded legend showing the amount of loess soils found in these areas. This map shows a significant amount of loess soils found in the southern and eastern regions of New Zealand's South Island, with the majority located in the Canterbury Plains and Otago's Southeastern basins. The thickness of these deposits varies greatly geographically, with deposits more than a meter deep covering approximately 10% of the area of the South Island. These deposits are usually blanketing pre-existing landscapes. Some loess deposits expand down 20 or even 40 meters in the lowlands south of Timaru or on the Banks Peninsula. Many of these deposits are located at the base of slopes next to mountain ranges or hilly areas (Yates et al., 2017). It should also be noted that the variation in thickness is immense, as they can go from a couple of centimetres to hundreds of meters thick (Muhs, 2007).

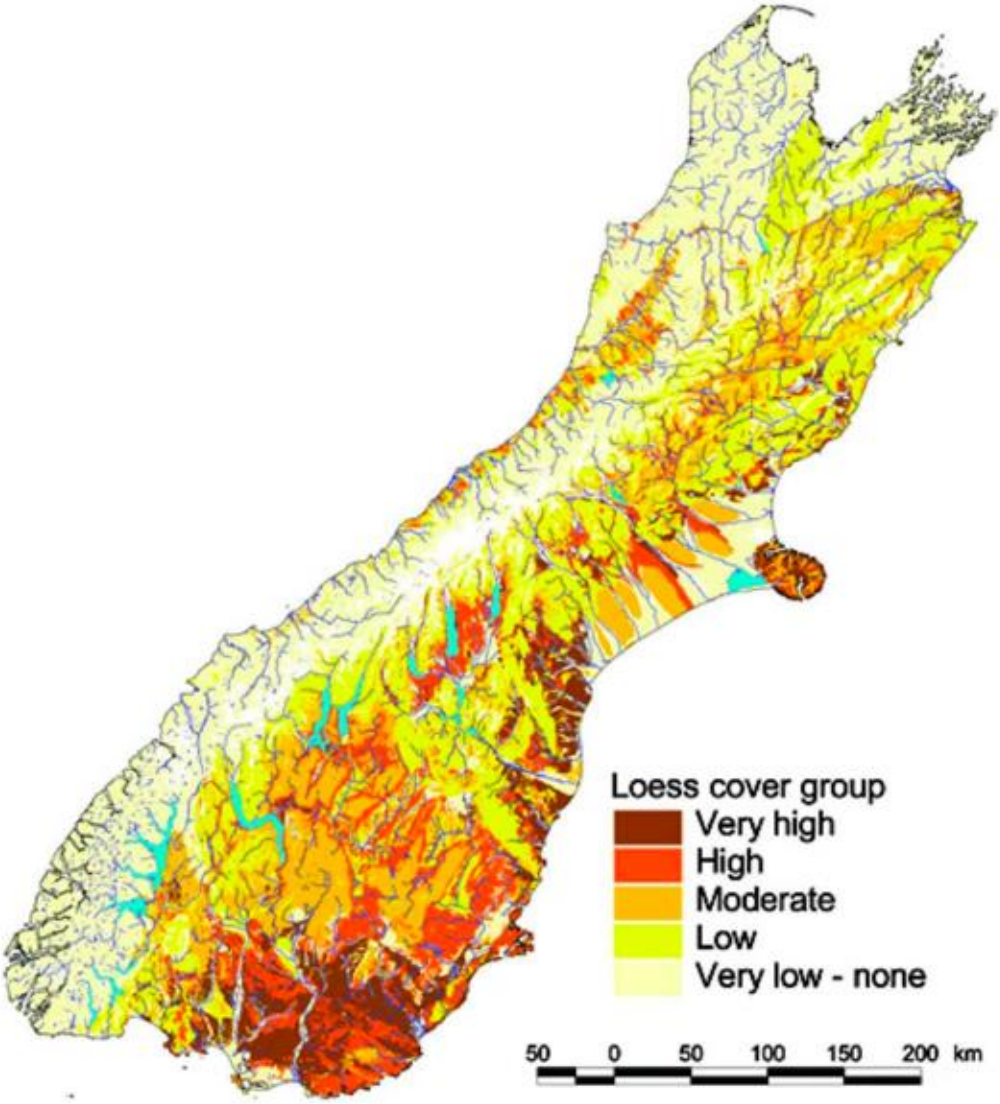

Figure 1: Loess cover groups for the South Island of New Zealand (Jochen Schmidt, 2005).

The long-established way of defining loess soils is silt-sized particles ground from crystalline rocks by glacial movement. These fine particles are deposited into tills, which are accumulations of unsorted materials that have been grouped by glacial ice. The materials are then reworked by the fluvial process in the surrounding natural water channels, where, finally, they are entrained, transported, and then deposited by the winds sweeping through the area (Muhs, 2007). These winds spread the loess soils across plains and basins, pushing them up against steep regions of mountains and hillslopes.

Loess soils are dominated by silt and clay-sized particles, which are particles lower than approximately 0.05mm. A particle size distribution of loess soils in the Canterbury, New Zealand region is detailed in Figure 2. On average, 60 to 90% of loess soils are silts and clays. The amount of clay ranges between 3% to 45%, and sand contents vary between 0% to 28%, with the silts filling in the rest. This is relevant for all in-situ and colluvium loess (Yates et al., 2017). Due to the small particle size of this sediment and its low settling velocity, loess soils can stay in suspension for long periods, making them extremely hard to remove from basins and stormwater runoff (Radermacher et al., 2015).

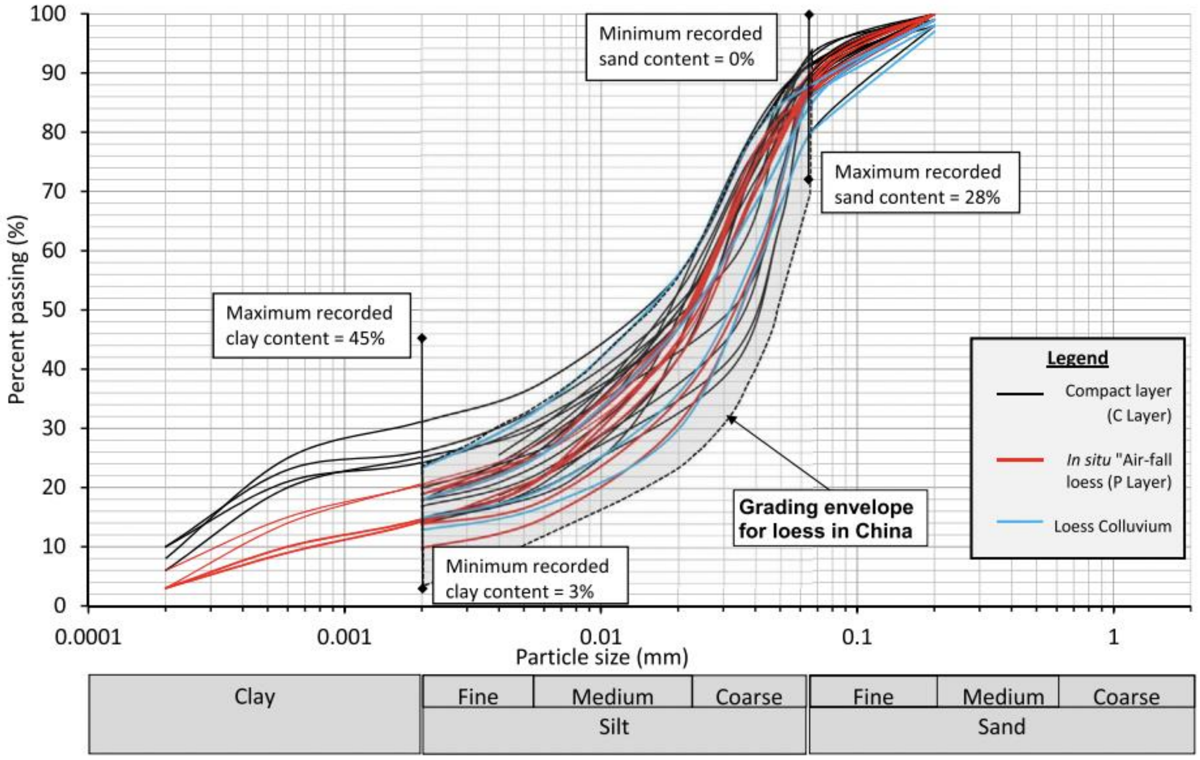

Figure 2: Particle size distribution for Canterbury loess deposits (K. Yates, 2017).

Loess soils, when dry, tend to exhibit the behaviours of soft rock, with its shear strength and failure linked closely with and controlled by the fissures within the soil mass. However, this strength is lost when there is even a slight increase in moisture content (2-3%). This reduction in shear strength will generally lead to erosion and widespread slope movement for these soils. Because of this susceptibility to changes in water content, loess soils are particularly sensitive to seasonal and climatic changes. Warmer temperatures lead to fracturing of the soil mass, increasing the loess soil's permeability. While colder weather, periods of high rainfall and other causes of increased moisture content are usually a precursor to slope and soil failure. Some of the observed failures include soil creep, debris flow, and tunnel gully erosion (Yates et al., 2017). This susceptibility to erosion makes it a common soil type to be picked up in waterways and decant basins.

Until approximately 2014, flocculants and coagulants were not permitted or consented to be used in the Canterbury Region (B. Gray, personal communication, October 15, 2024). Even today, before the commission of any chemical treatment, a Chemical Treatment Plan (CTP) must be provided to the Canterbury Regional Council for certification. Compliance with the Erosion and Sediment Control Toolbox for Canterbury 2017 must be met (ECAN, 2024).

The combination of flocculants and coagulants reduces the total suspended solids (TSS) within sediment-laden water by neutralising the electric charge placed on the fine particles. The flocculant encourages them to clump together; these clumps are known as micro-floc, and the coagulant undertakes the process (Davis et al., 2006). Flocculation is the process of bringing these micro-flocs into sizeable groups to drop out of suspension due to gravity (Ebeling et al., 2003).

The traditional method of dealing with sediment laden flows was large sediment retention basins. The implementation of flocculants has allowed the basins to be reduced in size. The purpose of this investigation is to determine whether the basins can be reduced in size again by filtration with geotextile fabrics. Nonwoven geotextiles are used for their filtration and soil separation properties (Ferdous & Kabir, 2013). Their performance is influenced by factors such as thickness and permeability (Reddy et al., 2010).

Sediment retention basins are constructed through excavation and embankment formation. They are used to attenuate water flows and let sediment drop out of suspension through gravity, improving water quality (ECAN, 2007). Typically consisting of a sediment forebay, a central basin, and a decant throttle control. These treatment basins are simple and effective at removing heavy sediments (Farjood, 2016). These are ineffective when dealing with loess soils (WRC, 2009).

Traditional Decant Basin

A sediment retention basin is constructed either by excavation or through the formation of embankments. It is made to retain sediment emitted from construction sites and other works. These basins are often temporary (ECAN, 2007). A typical retention basin will consist of a sediment forebay, a main basin area and an outlet device (Farjood, 2016). They are known for their effectiveness in improving water quality and being a stormwater flow management tactic, removing particulates, organic matter, and metals (Farjood, 2016). Sediment retention basins have become widely implemented (Westerbeek-Vopicka, 2009). A general schematic of one of these basins is shown in Figure 3.

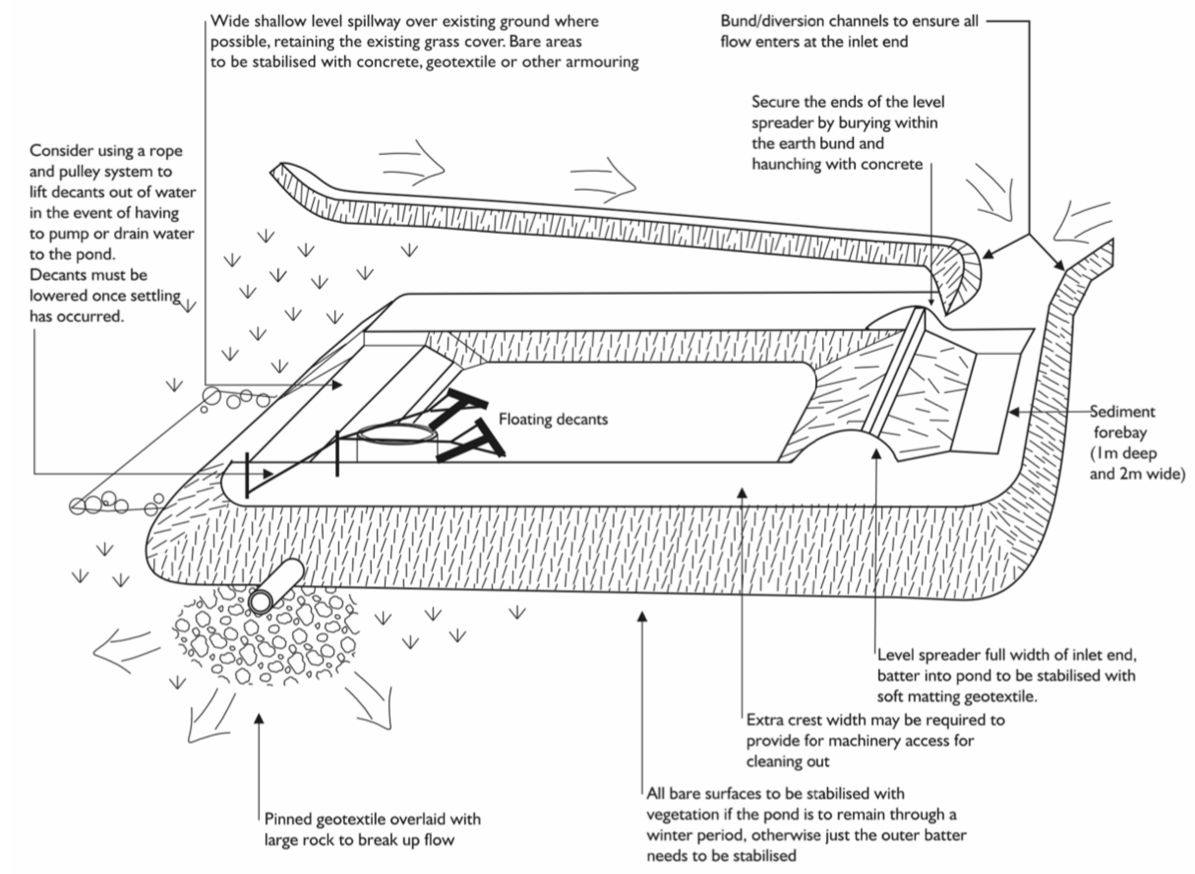

Figure 3: Schematic of a sediment retention basin, Auckland Regional Council 1999, (ECAN, 2007).

Sediment retention basins have a residual volume of stormwater runoff that contains higher sediment concentrations, and this volume never gets discharged. As the stormwater runoff is attenuated in the basin and decelerated, the sediment can drop out of suspension due to gravity (Kadlec & Knight, 1996). At the far end of the basin, a decant device drains the top water level, which is the cleanest (ECAN, 2007). A floating decant arm apparatus is shown in Figure 4.


Figure 4: Floating Decant Arms within a Sediment Retention Basin (Cirtex Civil, 2024).

In a report by Yazdi et al. (2021) investigating the efficacy of a retention basin, the inflow and outflow TSS was measured and recorded. The inflow TSS varied between 10 and 113 mg/L, and the outflow TSS varied between 4 and 15 mg/L. It showed that sediment retention basins are efficient in reducing SS from stormwater runoff. This is shown in better detail in Figure 5, with the orange representing the warmer months and the blue representing the colder months' values. In the colder months, the TSS was reduced by 62%, while in the warmer months, the TSS was decreased by 74%. However, outflow TSS was relatively similar all year round (Yazdi et al., 2021).

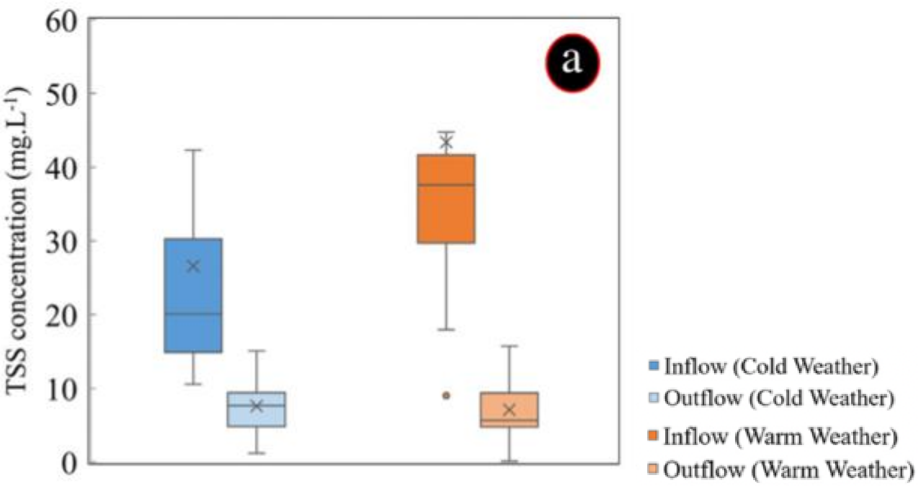

Figure 5: Removal effects for TSS (Mohammad Nayeb Yazdi, 2021).

Sediment retention basins with all excavation, side slopes, and surrounding bunds take up a significant area of land. With steep land being a considerable erosion and sediment control problem, there may not be enough land to construct them on, depending on the slope's angle, length, and consistency. A 10-hectare catchment is typically suggested as an upper limit. These sediment retention basins can also be blocked with floating debris and need regular clearing (ECAN, 2007).

Coagulation / Flocculation

Flocculants, also known as coagulants, help to decrease the total suspended soils (TSS) within sediment-laden water through coagulation, generally in a decent basin. Electric charges on fine particles cause them to repel each other, keeping them suspended within stormwater runoff. This problem can be solved with the process of coagulation. Coagulation is the process of decreasing or neutralising the negative electric charge on SS, which then encourages the particles to aggregate and form micro floc (Davis & Hafner, 2006). Flocculation is the process of combining the micro-floc groups to create a more significant agglomeration through either physical mixing or the binding action of flocculants (Ebeling et al., 2003).

The classic coagulation and flocculation process consists of three separate steps. The suitable chemicals are added to the wastewater, stirred, and mixed at high speeds. The wastewater is then moderately mixed to form large flocs, which are easier to settle out. Finally, the flocs formed can settle out and separate from the water column (Tchobanoglous & Burton, 1991). The process is shown in Figure 6. The coagulation/flocculation process is essential in water treatment, especially when dealing with sediment-laden stormwater runoff going towards natural streams or into a city stormwater system. The process is cost-effective, easy to operate, and energy-efficient (Amuda et al., 2005).

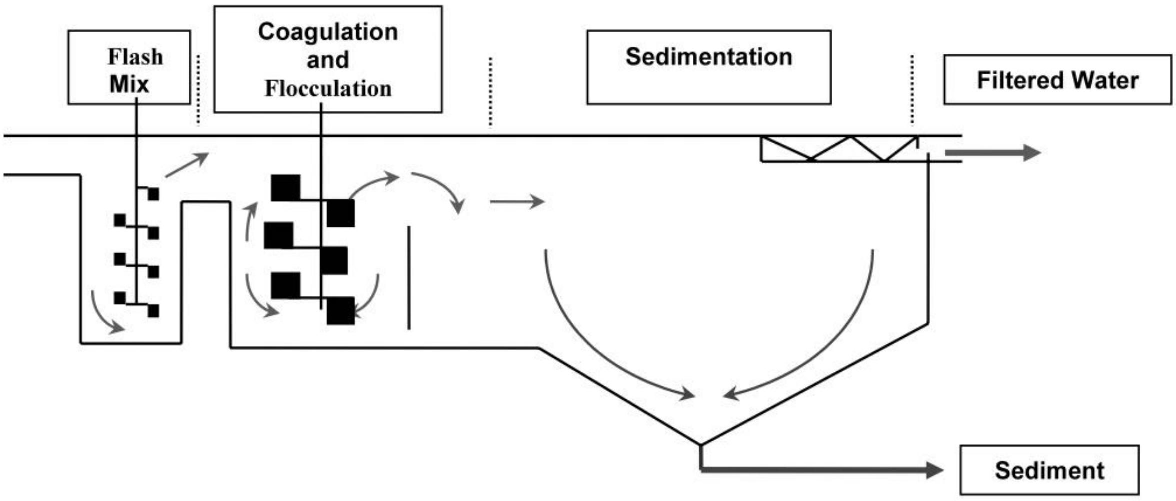

Figure 6: The coagulation and flocculation process (James M. Ebeling, 2003).

TSS removal efficiency was optimal when used between 500 and 750 mg/L of coagulant. Approximately 74% of TSS was removed when the coagulant was used. This then jumped to 94% when 25mg/L of flocculant was added (Amuda et al., 2005). A paper by Daud et al. (2015) tested four different types of coagulants at varying dosages. The different dosages were used because they were all tested at their optimal dosage size. It was found that TSS removal ranged between 88 and 97%, depending on the type of coagulant used. Poly-aluminium Chloride (PAC) was the most effective at its optimal dosage.

Poly-aluminium Chloride (PAC) is produced by partial hydrolysis of acid aluminium chloride solution using a specific reactor, such as a membrane reactor (Li et al., 2010). It has many advantages in the clarification of water and wastewater, such as rapid aggregation velocity, larger and heavier flocs, and less dosage required (Yarahmadi et al., 2009). Therefore, PAC is one of the most commonly used coagulants in New Zealand (ARC, 2004) and has been widely used worldwide for over 30 years (Yarahmadi et al., 2009). A usual PAC dosage is commonly applied using either its granular form or a pre-prepared liquid concentration.

Geofabric as filters

Geofabrics, also known as geotextiles, can be characterised into one of two groups: woven or nonwoven. Woven geofabrics are formed by intertwining two or more sets of fibres or filaments to pass across each other at right angles. There are four main weaving methods to create specific geotextiles. However, woven geofabrics are typically unsuitable for most drainage and filtration applications. Nonwoven geofabrics can be needle-punched to form a bond between the strands. Nonwoven geofabrics are generally not as strong as their counterpart- woven geofabrics. While this is true, their filtration and separation properties are far more significant. Most geotextiles are made from polypropylene, but polyester can also be used in manufacturing.

The functions of geotextiles can usually be divided into five main categories: separation, filtration, drainage, protection, and reinforcement (Ferdous & Kabir, 2013). Geotextiles can be used in many ways to help mitigate and suppress erosion and sediment (US Army, 1995). Some geotextiles control soil erosion by imitating the helpful properties of vegetation in a stream or on a slope (Rickson, 1990). It has also been shown in earlier studies of geotextiles that their presence can significantly enhance the capacity of pollutant and suspended sediment removal in a filtration system (Reddy et al., 2010).

It was found that discharge through the geofabric was able to be increased as the thickness of the geofabric was decreased. But while the flow rate increased, the clarity of the filtered water decreased as more fine soil particles could travel through (Reddy et al., 2010). The sediment clogging and binding behaviour in the geofabric was observed to occur more with increased geotextile thickness. This was due to the larger thickness, causing a smaller filtration opening size, which in turn caused a higher retention rate. The accumulation of these fine particles would build up in the geofabric filter over the service time, causing the permeability of the geofabric filter to decrease until it could not meet the engineering requirements. A diagram of the build-up of soil particles within the geofabric is shown in Figure 7 (Xu et al., 2022)(Palmeira et al., 2008). For the experiment that Xu and the other researchers at Tongji University completed, it was found that there were apparent reductions in permeability for the first 10 days, which slowed to a gentle decline until 60 days, staying constant for the last 30 days.

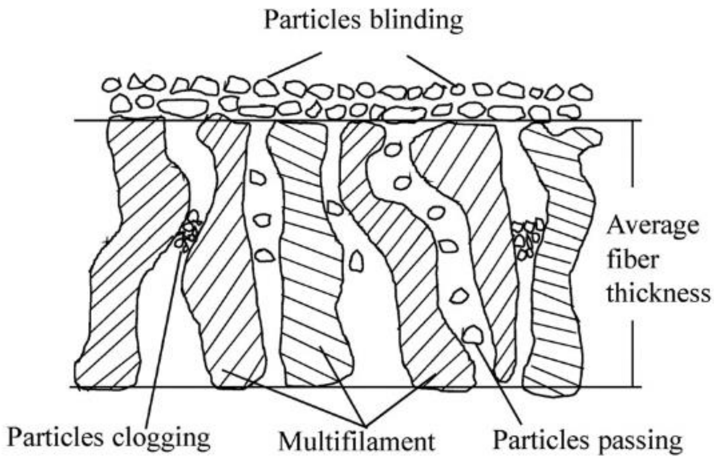

Figure 7: How soil particles clog geofabric filters (Chao Xu, 2022).

Over the years, more studies have been done on the retention and filtration capabilities of geofabric filters. A study by the American Society of Civil Engineers found that geotextiles were able to capture upwards of 75% of the TSS (Franks et al., 2012). This was found to be comparable to the tests done on sand filter systems by M. Barrett in 2003. Barrett (2003) has also tested geofabric as a filter, finding that a 75% removal efficiency could be upheld for periods of more than 6 months. They discovered that filtration efficiency is dictated by the number, size, and characteristics of accessible pores and the thickness of the geofabric. In addition, the removal efficiency is dictated by the SS characteristics, hydraulic and filtration characteristics of the fabric, and the maintenance of the system (Barrett et al., 1998).

Geotextiles are said to follow a process known as 'ripening' during the accumulation of suspended solids. As the geotextile amasses soil particles, clogging the pores of the fabric. The removal efficiency of the filter increases as the retention capacity is enhanced (Anwar et al., 2018). Thus, the longer the geotextile is utilised within a sediment retention basin, it is expected that the removal efficiencies will increase.

Cirtex® is a company that provides geosynthetics and civil and infrastructure materials. Cirtex® also contains an advanced research and development sector. One of Cirtex® manufactured lines of geotextiles is called the 'Duraforce® AS Series Geotextile,' comprising five grades of needle-punched nonwoven geotextiles. All grades have similar equivalent opening sizes, permittivity, and flow rate values while also being compliant with NZTA F/7 requirements for strength and filtration (Cirtex, 2019). In the tests undertaken by Barrett (1998), it was found that the nonwoven geofabric had the best TSS removal efficiency (%).

Geotextile Fences

The design of the filtration fence needs to take into consideration stability and head pressure, and it needs to be completely sealed around all edges. The proposed design consists of fence posts or waratahs that hold up a mesh stock fence, supporting the geotextile fabric. The fabric needs to be orientated to face the oncoming flow. The base of the fabric is wrapped onto the base of the basin and then covered with 200mm of compacted soil, sealing the base of the fence and ensuring all flows drain through the fabric. The 200mm of compacted soil has a secondary function of retaining the bottom 200mm of flow in the basin, acting as a decant at each fence (Figure 8).

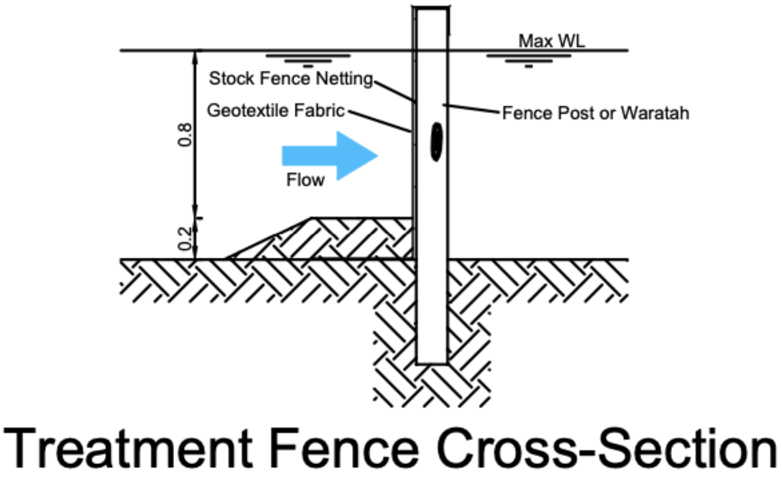

Figure 8: Geotextile Filtration Fence Cross-Sections.

An experiment was conducted to evaluate the reduction of TSS utilising geotextile fences (Oliveira et al., 2020). The apparatus used to assess this is shown in Figure 9. The geotextile fences were secured at the bottom, allowing for a solid geotextile fence with no edge gaps.

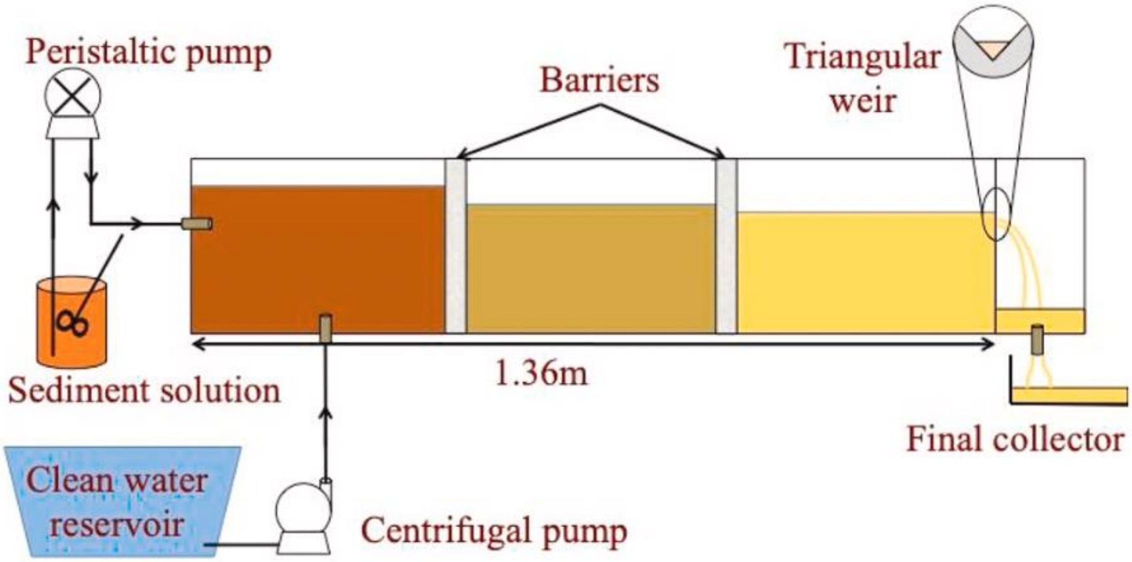

Figure 9: Geotextile fence filtration testing apparatus *(Oliveira, de Moura, Cavalieri, & Tiezz, 2020).*

For this test (Oliveira et al., 2020), more than 80% of the soil used particle size was smaller than 20µm. There were then three bays where the water would flow through. Each is separated with a geofabric filter and a triangular weir to act as an outlet. The results of the sediment mass retained in the geotextile fence, decanted, or in the outlet are shown in Figure 10.

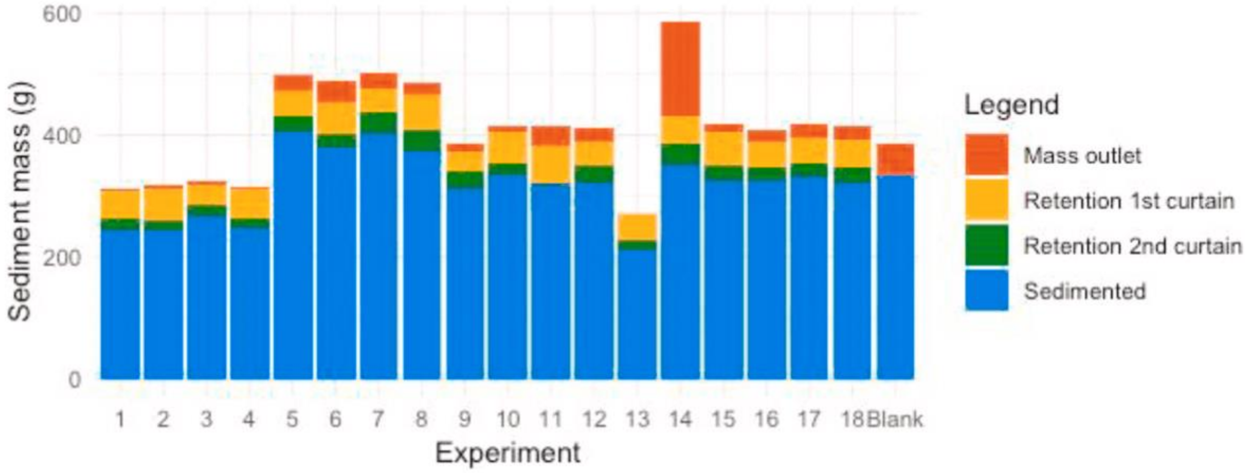

Figure 10: Sediment mass collected for all 19 tests *(Oliveira, de Moura, Cavalieri, & Tiezz, 2020)*.

It is shown that the majority of the sediment was retained within the system. Most of this was due to the suspended solids decanting and falling because of the gravity within the water column. A significant amount is retained within the two geotextile fences, with a more considerable amount retained within the first curtain. Due to the small particle size, some sediment could still make it through to the outlet with an abnormally large amount in test 14. Test 14 was still able to retain 73.8% of the SS. This shows that all systems have a breaking point with load, and it was met in test 14. The rest of the experiments, except for the blank, had an average retention rate of approximately 85% (Oliveira et al., 2020).

There was another comparison between using the sediment particle curtains in Tests 15, 16, 17, and 18 and having no fences in test 'blank', as shown in Figure 11. This comparison shows that using sediment particle curtains significantly improves the SS retention rates.

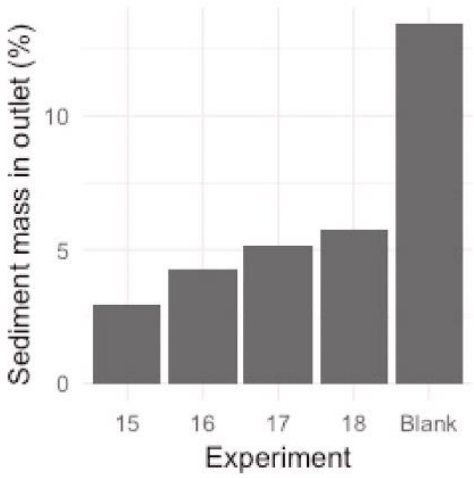

Figure 11: Comparison between using sediment particle curtains and not (Eduardo Paniguel Oliveira, 2020).

Silt fences are temporary barriers made of woven geotextile, used to capture coarse sediments carried in sheet flow, detaining the flow and allowing sediment to settle out of suspension. However, they cannot deal with concentrated flows of sediment-laden stormwater runoff. They should not be used to filter sediment out of stormwater runoffs (ECAN, 2024). There is relatively little research supporting the science of silt fences. Common problems with silt fences often revolve around the lack of maintenance and installation. When these are disregarded, it can lead to unnecessary silt being deposited into aquatic ecosystems (Cooke et al., 2015). Therefore, silt fences should not be considered a 'one size fits all' solution. They should be selected with careful evaluation of the intended function with knowledge of the site and final use. Silt fences are highly dependent on the sediment's physical and chemical properties, as well as the site's overall condition (Thompson et al., 2006). For these reasons, silt fences won't be investigated as an option for geotextile filtration fences in sediment retention basins.

Combination

As partly shown in the experiment above (Oliveira et al., 2020), a combination of sediment retention basins and geotextile filtration fences could be a better solution than either of them by themselves. This was shown when comparing the test with and without the geotextile filtration fences. Figure 12 shows a photograph of the apparatus at work. It outlines the amount of suspended solids that are removed with the combination of these two factors, as it is such a large amount that the effects can visibly be seen.

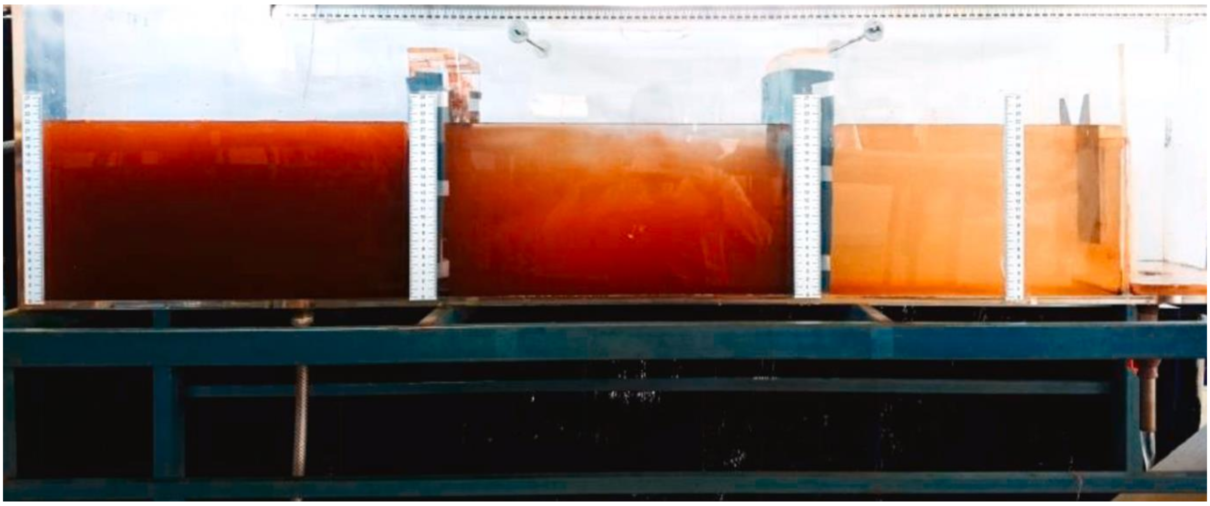

Figure 12: Test apparatus while running the experiment *(Oliveira, de Moura, Cavalieri, & Tiezz, 2020).*

Overview

Traditionally, sediment retention basins have been utilised to manage sediment-laden stormwater runoff (Farjood, 2016). These have proven to not always be effective when dealing with loess soils due to the particle's low settling velocity and their ability to remain in suspension for extended periods (WRC, 2009)(Yazdi et al., 2021). The inefficacies that come with loess soils in sediment retention basins are that the basin must be expanded to allow time for the sediment particles to drop out of suspension. Since they have been permitted through Regional Council consents, flocculants and coagulants have been shown to reduce the TSS of sediment-laden stormwater runoff significantly. Their ability to do so has increased sediment retention basin efficacies (Yarahmadi et al., 2009). With these increases in efficacy, the size of sediment retention basins has decreased, but the basins are still extensive and have the possibility for further refinements (Kang et al., 2015).

Nonwoven geotextiles can capture significant amounts of SS for periods of more than 6 months (Barrett, 2003). Geotextiles can retain fine sediment particles and are usually used for their filtration and soil separation properties (Ferdous & Kabir, 2013). It was found that geotextile filtration fences could be a possible refinement to decrease the current sediment retention basin size. The combination of nonwoven geotextile filtration fences, flocculants and coagulants has been shown to work in lab testing situations, although this does not use loess soils (Oliveira et al., 2020). The combination ability to remove significant amounts of soil particles from suspension within stormwater runoff offers a practical solution for reducing the size of sediment retention basins, allowing for a cheaper alternative to erosion and sediment control. There is a gap in the literature surrounding the combination of flocculants and geotextile filtration fences for the treatment of loess soil sediment-laden stormwater runoff in sediment retention basins.

Objective of the Study

To investigate the combination of flocculants and geotextile filtration fences in the treatment of loess soil sediment-laden stormwater runoff, and through this investigation, determine the possibility of minimising the size of stormwater sediment retention basins.

Methodology

Initial

1,000L of loess soil sediment-laden stormwater runoff was obtained from a construction site in Belfast, Christchurch. A laboratory experiment was then undertaken to obtain the untreated sample’s benchmark TSS, turbidity, electroconductivity, pH and temperature values.

Coagulant / Geofabric Types

The geotextile filter that had been chosen for testing was the AS280 from Cirtex®. As stated previously, the ‘Duraforce® AS Series Geotextiles’ aligns with the results from Barrett’s (2003) experiments.

The flocculant that had been chosen for testing was Wai Mā PAC from EnviroCo®. Again, as previously examined, PAC is a coagulant commonly used worldwide and has many advantages in the clarification of wastewater (Yarahmadi, et al., 2009). The Wai Mā PAC is a liquid application type of PAC produced by a Christchurch company called EnviroCo® (EnviroCo, 2024).

Bench Testing

Bench testing is the preliminary experiment used to determine the flocculant dose rate for a specific concentration of sediment-laden stormwater runoff. Two methodologies were undertaken. The first, as recommended by EnviroCo®, consisted of progressively adding 1mL doses of flocculant to 1L of sedimented runoff until flocculation could be visibly seen. This resulted in a dose rate of 8mL/L. The second methodology consisted of taking multiple 1L samples of the sediment-laden stormwater runoff and adding a different dose of the PAC flocculant to each sample. Six different doses were trialled for this, ranging from 0mL/L to 10mL/L. The tests were left for 1 hour, with measurements taken at 5 minutes, 30 minutes, and 1 hour (Woods & Stewart, 2022).

The bench testing was undertaken to determine the PAC dose for future trials. ECAN recommends this, and this is how EnviroCo® calculates the appropriate amount of flocculant necessary. The visual results of the second methodology are shown in Figure 13, and the measured results are examined in Table 1. This outlined the dose rate for the final tests to be 8mL/L, as at the 1-hour mark, this dose had produced the lowest TSS and turbidity measurements of 357 mg/L and 269 NTU, respectively. This gives a flocculant dose rate of 8000 mL/cu.m. This is consistent with the initial methodology.

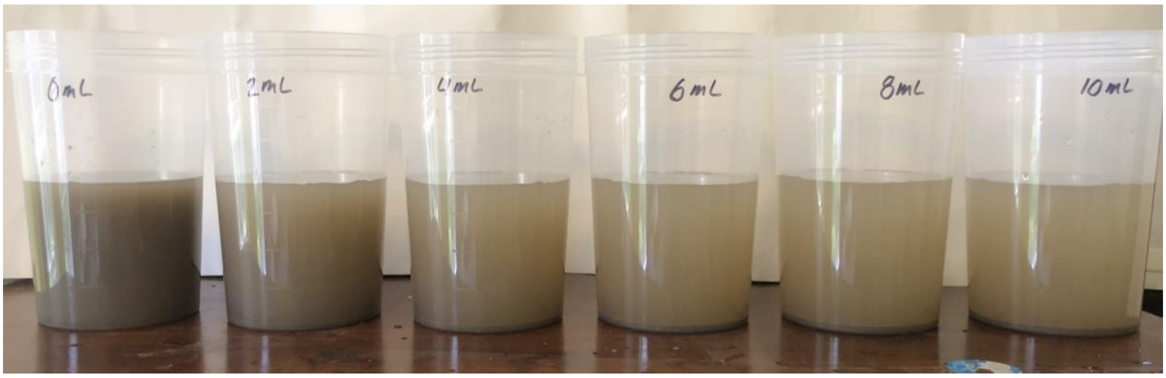

Figure 13: Bench testing visual results.

Table 1: Bench testing measured results.

Bench Testing							
		Dose (mL)					
		0	2	4	6	8	10
5 minutes	Total Suspended Solids (mg/L)	1500	1500	1500	1500	1500	1500
	Turbidity (NTU)	735	837	881	774	722	710
30 minutes	Total Suspended Solids (mg/L)	1500	1490	979	667	686	551
	Turbidity (NTU)	755	777	549	408	383	369
60 minutes	Total Suspended Solids (mg/L)	1500	1070	620	431	357	412
	Turbidity (NTU)	776	659	428	280	269	271

Apparatus

The testing was comprised of two lab tests and an in-situ test. The two lab tests were split into turbulent and laminar tests. The apparatus that was used for both tests was developed based on the standard method experiment ASTM D5141 (ASTM, 2018). However, it was varied, whereby the rectangle flume shape was replaced with a circular PVC pipe. This will only affect the experiment, as the circular pipe doesn't have a wide surface area for the sediment to drop out of suspension and rest on like the rectangular flume. The in-situ test was conducted using a sediment retention basin at the Belfast construction site where the initial samples were taken.

Turbulent

The PVC pipe used was 1,000mm long and had a diameter of 100mm, with an attached 90-degree PVC bend at the inlet. One layer of the AS280 geosynthetic was tightly clamped around the outlet, allowing for no movement of the fabric once in place. A 10mm PVC collar was attached under this at the outlet to act as a lip.

The system had one inlet for the loess soil sediment-laden stormwater runoff to be injected in. This came from a container that has acted as a sedimentation basin, allowing the flocculant to act for the specified amount of time. This container had an outlet located 20% of the way up so that the heavily sediment water that would not be picked up by floating decants would not flow through the apparatus. This was replicated for the filtration fence design, with the lower 20% of the basin being caught on a batter at each filtration fence. The water then flowed out of this outlet through the pipe and the geotextile, where it was collected for testing. A final working apparatus is in Figure 14.

Figure 14: Final working turbulent testing apparatus.

Laminar

For the laminar test, the pipe set-up was almost identical, except at the outlet end, where a sheet of plastic trapped the water within the apparatus. Similar to the turbulent test, there was one inlet for the loess soil sediment-laden stormwater runoff. This runoff was added to the apparatus with the flocculant load already mixed, where it was then trapped and left for the flocculant to act over the specified amount of time. Once this plastic sheet was removed, the water flowed through the pipe and geotextile and was collected for testing. A final working apparatus is shown in Figure 15.

Figure 15: Final working laminar testing apparatus.

In-situ

The in-situ testing was undertaken in Belfast, Christchurch, at a construction site with a pre-prepared sediment retention basin. This sediment retention basin was constructed using the standard method from ECAN. The basin consisted of an initial mud tank that was used to filter off the stone. This then flowed into a forebay, which was used to filter any of the larger particles. The runoff continued to flow through a pipe, where it was combined with the calculated flocculant load (8 mL/L). The sedimented water and flocculant mix then passed into the main body of the sediment retention basin, which measured approximately 70 m in length and 10m in width. This was split into four sections by three geotextile filtration fences for the sedimented water and flocculant mix to run through. The outlet system used was a floating decant, which allowed the water to then run into a nearby natural stream (Figure 16).

Figure 16: Empty sediment retention basin used for the in-situ testing.

The flocculant was dosed between the forebay and the main body of the sediment retention basin. The sediment-laden stormwater runoff ran through a pipe between these two parts of the basin, and an ultrasonic sensor was at the end of this pipe. This ultrasonic sensor measured the distance from the top of the pipe to the bottom. Knowing the area of the end of the pipe and the distance that the water had risen made it possible to calculate the flow rate of the stormwater runoff. The reading was sent to a small onsite computer that calculated the right time to inject the flocculant. The flocculant was injected with the help of a solar-powered dosing pump (ARC, 2004). The flocculant mixed with the sediment-laden stormwater as it flowed through the pipe and into the sediment retention basin. The flocculant dosing apparatus is a solar-powered flow-activated flocculant delivery system called an electronic dosing device (EDD). The flow accurately controlled the predetermined rate programmed into EDD. The EDD is attached to the top of an IBC (Good Rich, 2024). This dosing apparatus (left) and ultrasonic sensor (right) are shown in Figure 17.

Figure 17: Flocculant 1000L IBC and onsite computer (left), Ultrasonic Sensor Set-up (right)

Equipment

The total suspended solids (TSS) measurements were conducted using the 'InsiteIG Portable Meter (IPM) PSSL, S/N TPM1028', this is shown in Figure 18 as No. 1. This has a TSS measurement range of 0 – 1500 mg/L, an accuracy of ±5% of the reading of ±2 mg/L depending on what is greater, and a resolution of 0.1 mg/L (InsiteIG, 2024).

The turbidity measurements were found using the 'Thermo Scientific Eutech TN-100 Waterproof Turbidimeter, S/N 3014880', this is shown in Figure 18 as No. 4. The range for turbidity measurements is 0 – 2000 NTU, which has an accuracy of < 0.1 NTU for 0.02 NTU standard; ±2 % of reading ±1 digit for 0 to 500 NTU; ±3 % of reading ±1 digit for 501 to 2000 NTU, a possible resolution of 0.01 NTU, and an operating range of 0 - 50°C (Thermo Scientific, 2024).

The 'Lutron PCD-431 Conductivity Meter, AL.51337' was used for the electroconductivity measurements measurements. This is shown in Figure 18 as No. 3. The range for conductivity measurements is 2000 µS – 20 mS and has an accuracy of ±3% full scale plus one decimal place. It has an operating temperature range of 0 - 50°C (Inspect USA, 2024).

The pH measurements were conducted using the 'Testo 260-pH1, A/N 0650 2061, S/N 111400289/0624', which is shown in Figure 18 as No. 2. This has a measurement range of 0 – 14 pH, an accuracy of ±0.02 pH, and a resolution of 0.01 pH. It also has an operating temperature range of 0 - 60°C (Testo, 2024).

The temperature of samples could be measured by both the ‘Lutron PCD-431 Conductivity Meter, AL.51337’ (3) and the ‘Testo 260-pH1, A/N 0650 2061, S/N 111400289/0624’ (2). The average of these two measuring instruments was taken for the temperature. The ‘Testo 260-pH1’ has a measuring range of 0 - 60°C, an accuracy of ±0.4°C, and a resolution of 0.1°C (Testo, 2024). The ‘Lutron PCD-431 Conductivity Meter’ has a measuring range of 0 - 60°C, an accuracy of 0.8°C, and a resolution of 0.1°C (Inspect USA, 2024).

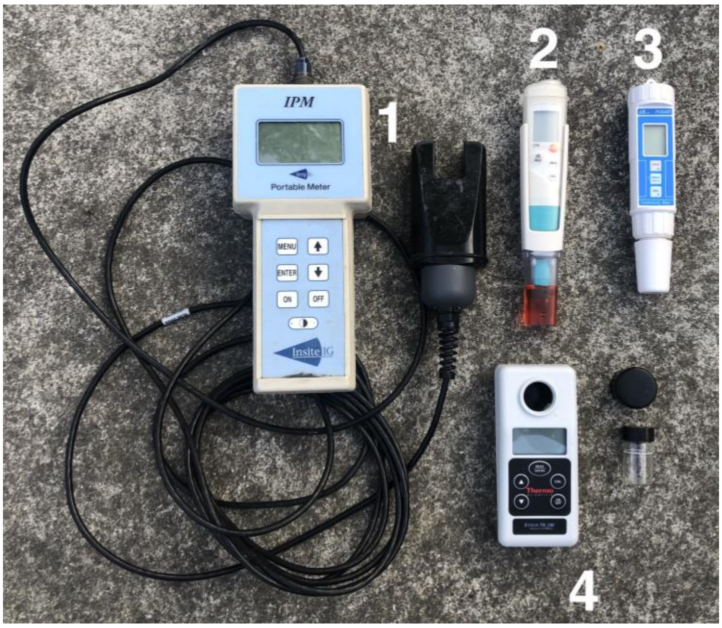

Figure 18: InsiteIG Portable Meter (1), Testo 260-pH1 (2), Luton PCD-431Conductivity Meter (3), Thermo Scientific Eutech TN-100 Waterproof Turbidimeter (4).

Testing & Reporting

The samples were analysed using five parameters, namely total suspended solids (TSS), turbidity, electroconductivity, temperature, and pH. The analytic data quality of these parameters was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of standard operating procedures, calibration with standards, analysis of blanks, and analysis of replicates.

Turbulent Test

Four tests were undertaken for the turbulent lab testing. These all consisted of leaving the flocculant to act for different periods. This consisted of 4, 2, 1, and 0.5 hours of acting time. The flocculant was combined with the sediment-laden stormwater runoff in the treatment basin container, where it was left to rest and activate.

Measurements were taken at the start of the test, from the top water level of the treatment basin container (Figure *19*, 1) and at the outlet of the treatment basin container (Figure *19*, 2) immediately upon starting the flow. This was done because the water has a higher TSS the deeper the measurement is taken because of the way that sediment drops out of suspension due to gravity. The average of these two tests was calculated to get an understanding of the water flowing through the test. This then gives the best representation of the water that will be tested on. The first of the liquid to come out of the apparatus outlet (Figure *19*, 3) and the last of the liquid (Figure *19*, 4) was also measured. This was done again to get an average and, therefore, the best representation of the filtered runoff. The average measured inflow values were compared to the average of the outflows. The location of testing is shown in Figure 19. It is recognised that basins are affected by wind, and purely laminar flow is not practically available.

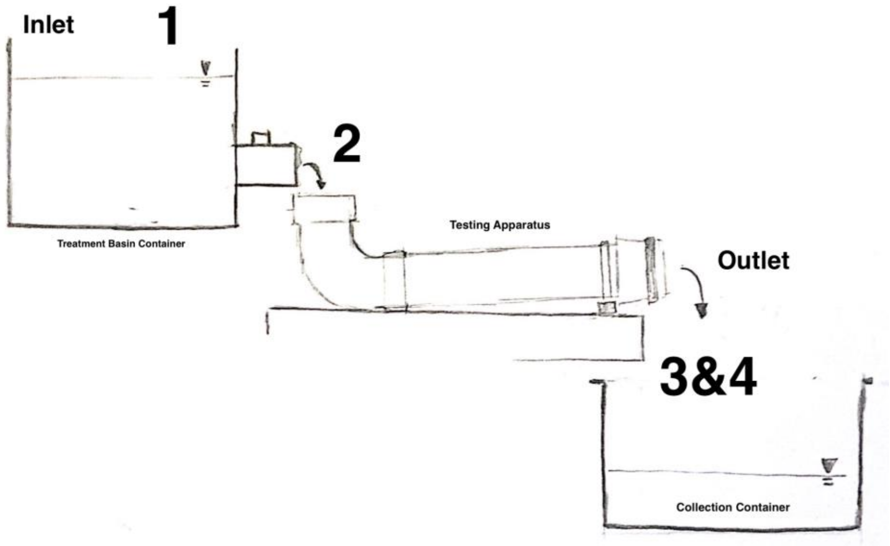

Figure 19: Testing locations for turbulent lab tests.

Laminar Test

Four tests were also undertaken for the laminar lab testing. These consisted of leaving the flocculant to act for different periods. This consisted of 4, 2, 1, and 0.5 hours of acting time for the flocculant. The flocculant was mixed with the sediment-laden stormwater runoff in a bucket, which was then poured into the inlet of the apparatus, where it was left to rest and activate.

The initial mix before the testing started was not measured as it is assumed that these measurements would yield the same results as the turbulent test results due to this being conducted in the same way and with the same mixes. Measurements were taken for the initial (Figure *20*, 5) and the final runoff (Figure *20*, 6) that flowed from the outlet of the apparatus. This was done to get the average and, therefore, the best representation of the final filtered runoff. The location of testing is shown in Figure 20.

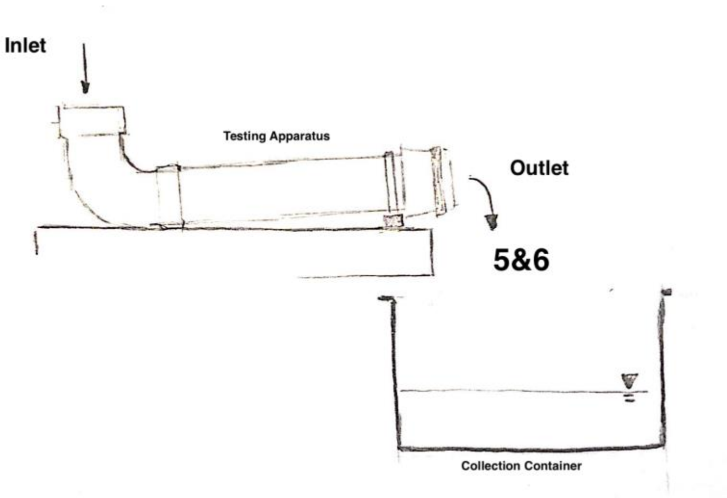

Figure 20: Testing locations for laminar lab tests.

In-situ Test

The in-situ test consisted of two separate tests where the measurements were taken 10 hours apart. The first test was taken once the mud tank had fully depleted. The second test was taken the following day once there was no more flow coming from the forebay. There were seven locations where measurements were taken during this test. The first was taken from the forebay (Figure *21*, 1), and the rest were taken before and after each geofabric filtration fence (Figure *21*, 2-7).

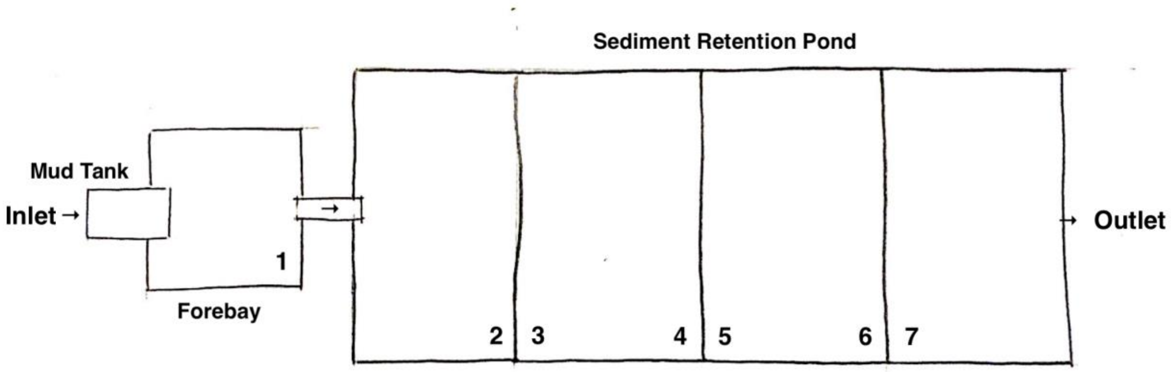

Figure 21: Testing locations for in-situ testing.

Results for all lab and in-situ tests were recorded in an Excel sheet and compared against each other. These results were graphed and tabulated. Results will be compared, and conclusions will be reached in the results report.

Results

Initial Testing

Base Sample

As previously described, initial samples of the sediment-laden stormwater runoff were taken and sent to Hills Laboratory. Table 2 shows these base sample measurements and the averages of them. The TSS average value was used for the turbulent and laminar flow calculations.

Table 2: Base Sediment-Laden Stormwater Testing.

	Sample Name:	CH10 18-Sep-2024 8:30 am	CH11 18-Sep-2024 8:30 am	CH12 18-Sep-2024 8:30 am	Average
	Lab Number:	3674257.1	3674257.2	3674257.3	
Turbidity	NTU	1,990	2,000	1,930	1,975
pH	pH Units	7.6	7.6	7.6	8
Electrical Conductivity (EC)	mS/m	19.8	19.8	19.8	20
Total Suspended Solids	g/m3	1,590	1,600	1,590	1,595

Lab Testing

Channel Travel Time Calculations

Figure 22 is a cross-section of the in-situ treatment basin that was used during the in-situ testing. This was used as the basis for the calculated travel time of the stormwater runoff through each section of the treatment basin.

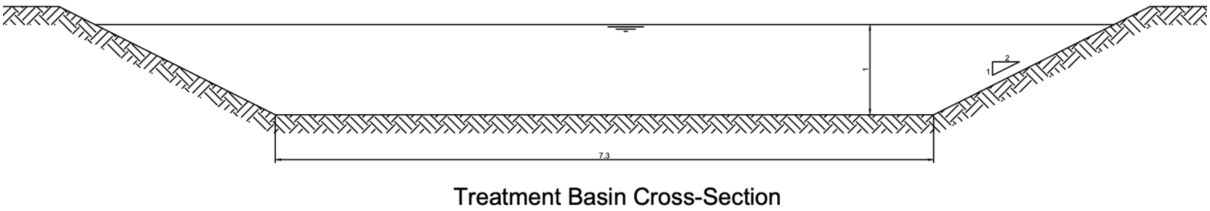

Figure 22: In-situ Treatment Basin Cross Section.

The bay length, width, height, side slope, and channel slope were measured by a surveyor, and these measurements are shown in Appendix 1. From these measurements, the area, wetted perimeter, and hydraulic radius could all be calculated, as well as the flow, velocity, and velocity grade using Manning's 'n'. Manning's 'n' represents the loss of energy in open channels. Using these values, the time it took for the stormwater runoff to travel through each bay was calculated using Equation 1. Table 3 outlines that the travel time for the stormwater runoff has been calculated for all four bay sections. All travel times have been estimated to be marginally less than an hour long.

$$Travel\ Time\ (hr) = \frac{Bay\ Length\ (m) \Big/ Velocity\ (Manning's)(\frac{m}{s})}{3600} \quad \text{Equation 1}$$

Table 3: Calculated Travel Times for 5 L/s Flow for In-situ Treatment Basin Sections.

Trapezoid Channel	Section 1	Fence 1	Section 2	Fence 2	Section 3	Fence 3	Section 4
Distance	0		0		140		240
Mannings n	0.025		0.025		0.025		0.025
Bottom width (m)	7.3		7.3		7.3		7.3
Depth (m)	1		1		1		1
Side Slope (1/?)	2		2		2		2
Channel slope	2.48026E-08		2.48026E-08		2.48026E-08		2.48026E-08
Area	9.300		9.300		9.300		9.300
Wetted Perimeter	11.772		11.772		11.772		11.772
Hydraulic Radius	0.790		0.790		0.790		0.790
Flow (Mannings) (m^3/s)	0.0501		0.0501		0.0501		0.0501
Velocity (mannings) (m/s)	0.0054		0.0054		0.0054		0.0054
vel grad	0.0000000017		0.0000000017		0.0000000017		0.0000000017
Bay length (m)	18.51		15.98		17.04		18.6
Travel time in Bay	0.96		0.82		0.88		0.96

Turbulent Test

The test results were tabulated and shown in Appendix 2. The results of both initial tests were averaged, as were the results of the outlet measurements. Allowing for the measurements taken before and after the sediment-laden stormwater runoff had gone through the geofabric filter to be compared.

Figure 23 shows the effects of flocculant and rest periods on the TSS levels within sediment-laden stormwater. There is a significant drop in TSS from the original starting TSS level at 0 hours to the first measurement at 0.5 hours. This is because the flocculant acts quickly with the larger and heavier suspended solids within the stormwater, allowing them to drop out of suspension. As time progresses, these drops begin to mellow due to the particles still in suspension becoming progressively smaller in particle size and, therefore, harder to drop out of suspension.

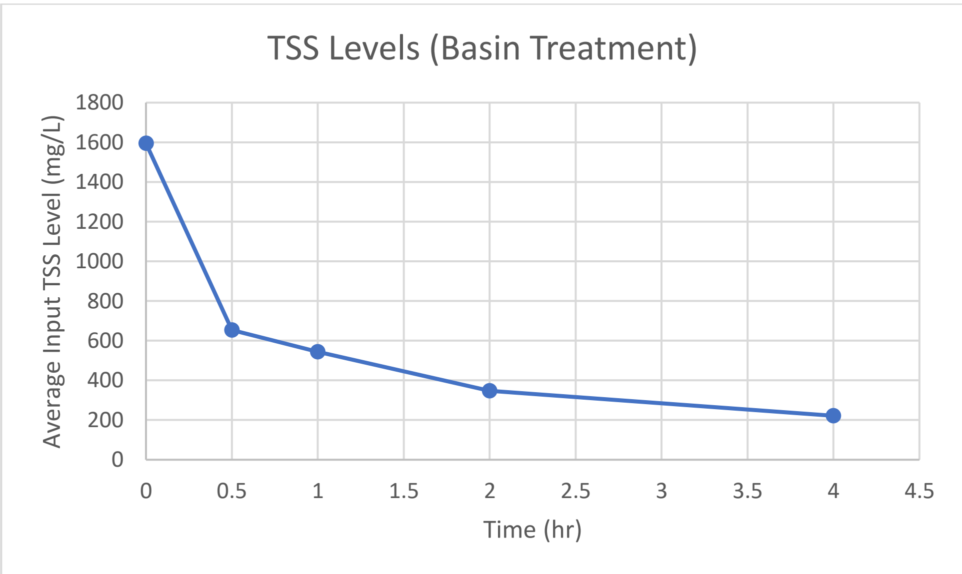

Figure 23: Change in TSS Levels of Turbulent Test Input (After Flocculated Basin Treatment).

Figure 24 shows the average input TSS from the Laminar flow test plotted against the drop in TSS due to the geotextile filter. There is a relatively linear relationship between the TSS level of the input stormwater and the number of suspended solids that have been filtered out. As the input TSS decreases, so does the number of suspended solids filtered. Demonstrating that with a lower TSS input, removing large TSS concentrations is more complicated. The 1-hour test has been increased from a drop in TSS value of 30 mg/L to 70 mg/L as it was deemed a significant outlier, with the other three results being in a relatively linear formation. This was seen as acceptable.

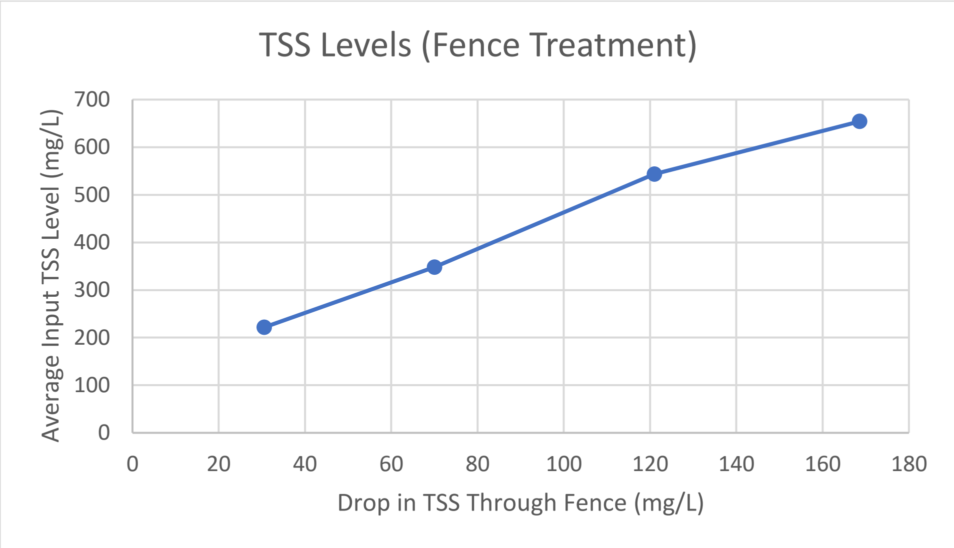

Figure 24: Average Input TSS Level Against Average Output TSS Level for Turbulent Test (Geotextile Filtration Treatment)

Using the calculations of travel times through the treatment basin section bays from Table 3 and the two graphs, Figure 23 and Figure 24, it was possible to calculate a progression of drops in TSS, as if these results had been thorough the same apparatus as the in-situ test (Table 4). This is better shown through the visualisation of a graph in Figure 25.

Table 4: Calculated TSS Values from Turbulent Test Data

Calculated from Turbulent Data							
	Section 1	Fence 1	Section 2	Fence 2	Section 3	Fence 3	Section 4
Initial TSS	1595	553	428	321	260	204	178
Final TSS	553	428	321	260	204	178	145
Drop	1042	125	107	61	56	26	33
% drop	65.33	22.60	25.00	19.00	21.54	12.75	18.54

Figure 25 shows the graph separated into four distinct areas, each separated by a vertical drop in TSS. This is where the stormwater runoff has filtered and passed through a geotextile filtration fence. Both Figure 25 and Table 4 show that the fence placed before removes approximately the same amount of TSS from the stormwater runoff as the bay itself. This indicates that instead of having a bay that is 18 metres long, it is possible to place a geotextile filtration fence to remove the same amount of TSS in a fraction of the space. These fences have been calculated to remove approximately 18% of TSS.

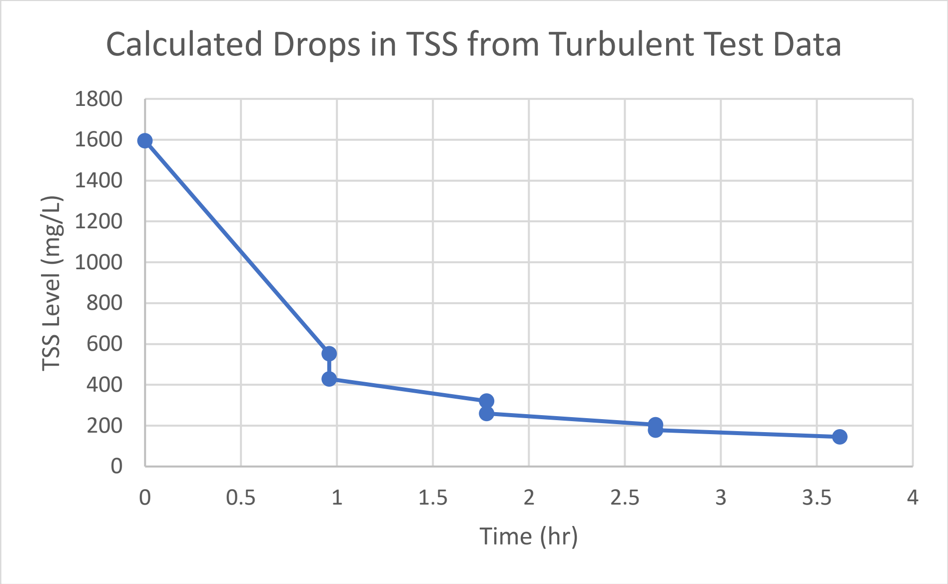

Figure 25: Calculated TSS Values from Turbulent Test Data.

Laminar Test

All test results are tabulated and shown fully in Appendix 3. The initial results were taken from the turbulent test. The results of the outlet measurements were averaged, allowing for the measurements taken before and after the sediment-laden stormwater runoff had gone through the geofabric filter to be compared.

Figure 26 shows the effects of flocculant and rest periods on the TSS levels within sediment-laden stormwater. As earlier specified in Figure 23, there is a significant initial drop in TSS due to the heavy particles being dropped out of suspension quickly because of the initial flocculant mixing. This continues to mellow, as stated before, due to the particle size becoming progressively smaller and, therefore, becoming more challenging to drop out of suspension with just the flocculant acting.

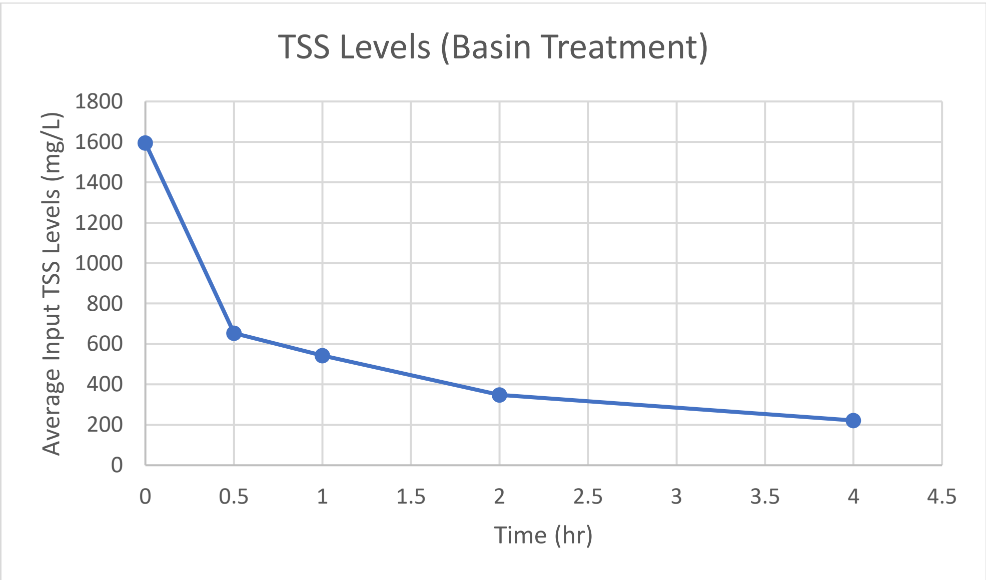

Figure 26: Change in TSS Levels of Laminar Test Input (After Flocculated Basin Treatment).

Figure 27 shows the average input TSS from the turbulent test, and Figure 26 is graphed against the drop in TSS due to the geotextile filter. The graph has a linear progression similar to the graph in Figure 24. The 0.5-hour test has been excluded from this graph due to it being a significant outlier and the other three results being in a relatively linear formation. The graph also shows that as the input TSS decreases, so does the number of suspended solids filtered by the geotextile. Again, expressing that with a lower TSS input, it is more difficult to remove large concentrations of TSS.

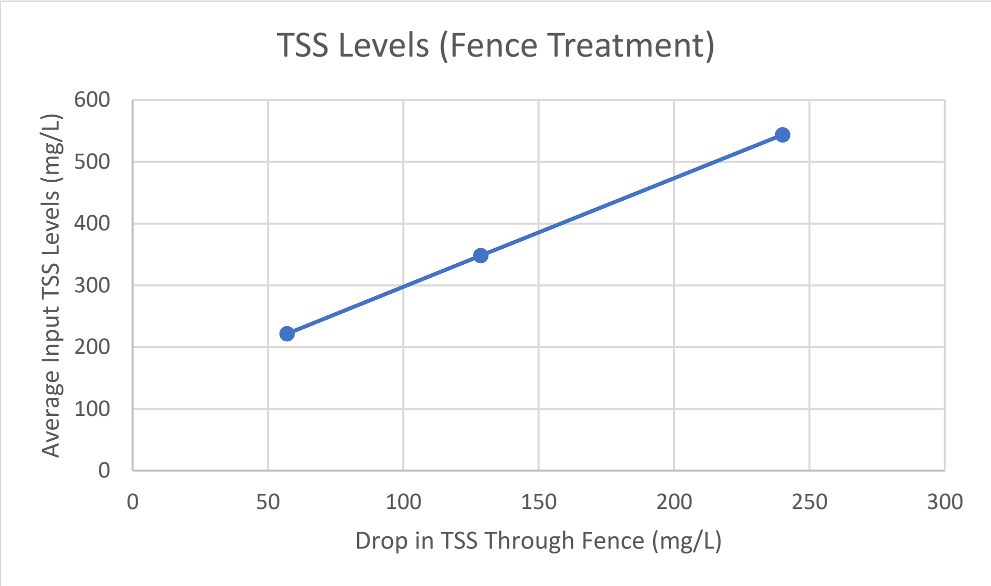

Figure 27: Average Input TSS Level Against Average Output TSS Level for Laminar Test (Geotextile Filtration Treatment)

Using the calculations of travel times through the treatment basin section bays from Table 3 and the two graphs, Figure 26 and Figure 27, it was possible to calculate a progression of drops in TSS as if these results had been through the same apparatus as the in-situ test Table 5. This is shown through the visualisation of a graph in Figure 28.

Table 5: Calculated TSS Values from Laminar Test Data

Calculated from Laminar Data							
	Section 1	Fence 1	Section 2	Fence 2	Section 3	Fence 3	Section 4
Initial TSS	1595	320	208	185	149	125	
Final TSS	320	208	185	149	125	123	
Drop	1275	112	23	36	24	2	
% drop	79.94	35.00	11.06	19.46	16.11	1.60	

The TSS reduction calculations for the laminar flow have only been able to be calculated for the first three geotextile filtration fences and bay sections. This is due to the testing data from the laminar lab test, provided in Figure 26 and Figure 27, not being extensive enough as the recorded TSS values do not go low enough.

It is still observed that the geotextile filtration fences have the ability to remove significant levels of TSS from the stormwater runoff, as shown through the vertical drops in TSS (Figure 28). This is due to the stormwater runoff flowing through the filtration fences and the suspended solids being caught. The calculated TSS removal efficacies of the filtration fences are shown to be approximately 18%. Again, this indicates that this can potentially reduce the size of sediment retention basins.

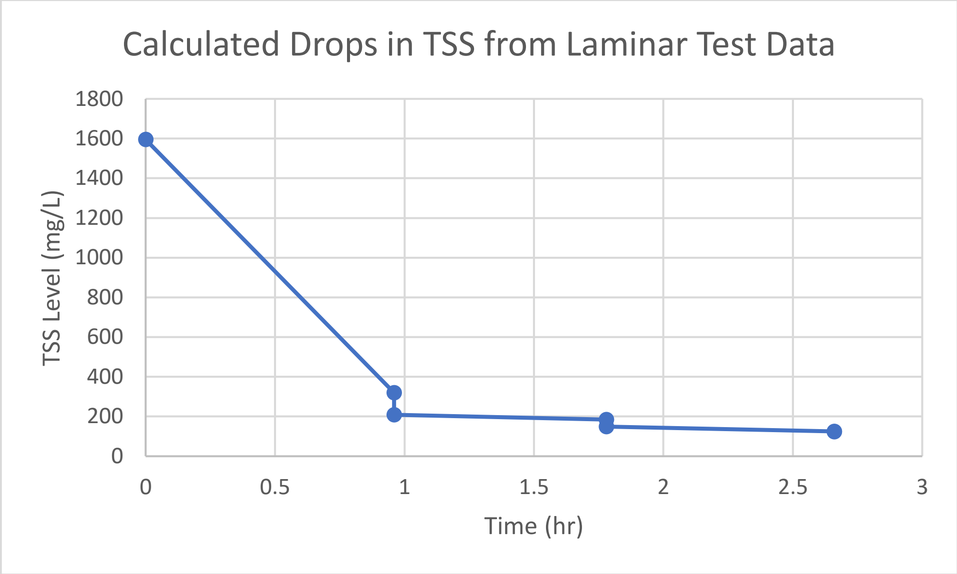

Figure 28: Calculated TSS Values from Laminar Test Data.

Field Testing

In-situ Test: Observed

Figure 29 shows the TSS measurements from the seven locations of the in-situ testing, comparing the two different testing times. It is important to note that the TSS meter used has an upper limit of 1500 mg/L. Due to the link between TSS and turbidity and the greater range on the turbidity meter, the turbidity measurements can act as an estimation for the shape of the graph.

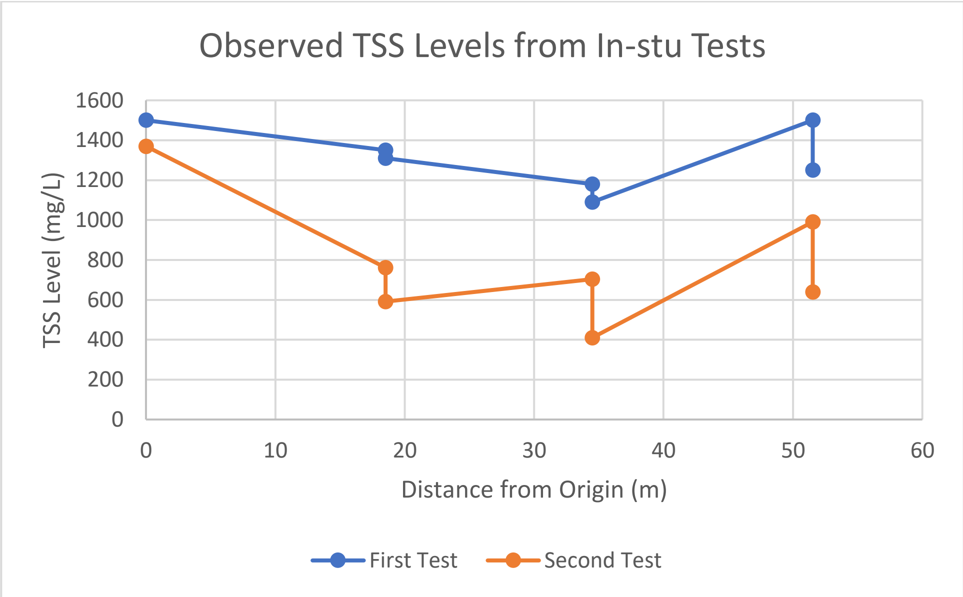

Figure 29: TSS measurements at the seven locations for the two in-situ tests.

When comparing Figure 29 and Figure 30, it is easy to see the correlation between the TSS and turbidity, with both tests following the same trends. As both graphs show, there is a large drop in TSS and turbidity from test location one to location two. This is due to the initial flocculation process taking out a significant amount of heavy sediment from the stormwater runoff.

After each geotextile filtration fence, it is shown that there has been a drop in both turbidity and TSS. The TSS decreased from 40 – 350 mg/L through each filtration fence, and the turbidity decreased between 20 – 180 NTU through each filtration fence.

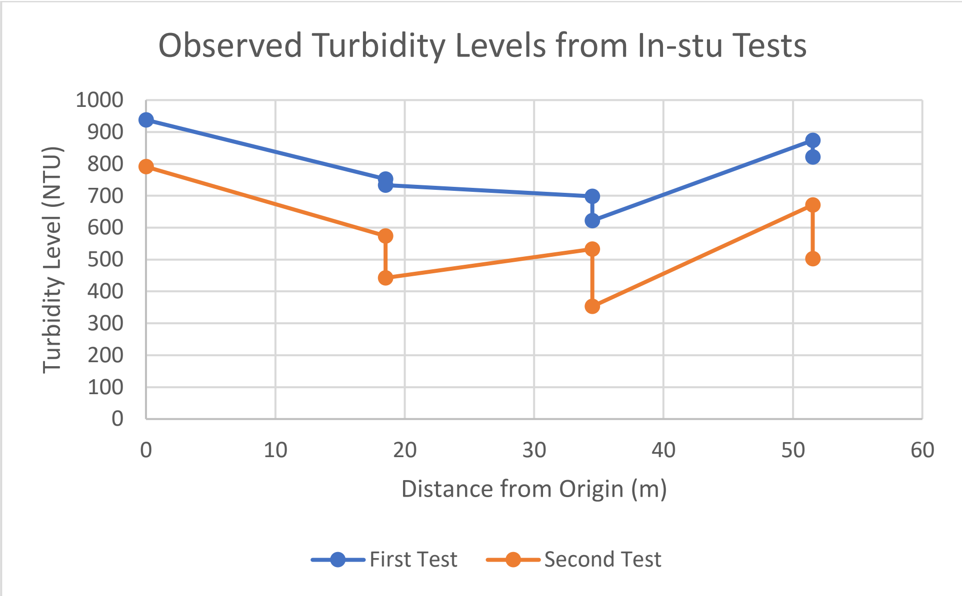

Figure 30: Turbidity measurements at the seven locations for the two in-situ tests.

These drops in TSS for both in-situ tests are outlined in Table 6. For both tests, there was a significant drop as the water travelled through section one, as this is where the water flows from the forebay and into the main basin while getting dosed with flocculant. It is expected that this will be the most significant drop in TSS.

The following values in Table 6 show the drop in TSS through the first geotextile filtration fence. For the first test, it is observed that there is a drop of 40mg/L or approximately 3% of the initial TSS. For the second test, it is far greater with 170mg/L, 22% of the initial TSS value. This shows that the geotextile filtration fence can filter out a percentage of the TSS. The same filtration happens at the second and third fences, with the first test dropping by 90mg/L (7.63%) and then 250mg/L (16.67%), respectively. The second test has drops of 294 mg/L (41.79%) and 350 mg/L (35.35%) at the second and third fence, respectively.

The values for section two show an interesting revelation as the second test has an increase in TSS over this period. Unfortunately, when the sediment retention basin was built, and it was possible to conduct the in-situ testing, no significant rainfall occurred. Therefore, when there was a slight rainfall on the 17th of September, the opportunity to conduct testing had to be taken. Because of the low rainfall, minimal water flowed through the basins, and a depth of approximately 100mm was recorded. Due to the low volume, the sediment was unable to drop out due to gravity efficiently enough. In addition, the new stormwater runoff was flowing over previously bare land, and therefore, it picked up and mixed with the soils at the bottom of the basin. All of this resulted in an increase in the TSS over the section areas. The same can be said for section three, where this outcome occurs in both tests.

Table 6: Observed drops in TSS during in-situ testing.

Observed (17th December)						
	Section 1	Fence 1	Section 2	Fence 2	Section 3	Fence 3
Initial TSS	1500	1350	1310	1180	1090	1500
Final TSS	1350	1310	1180	1090	1500	1250
Drop	150	40	130	90	-410	250
% drop	10.00	2.96	9.92	7.63	-37.61	16.67
Observed (18th September)						
	Section 1	Fence 1	Section 2	Fence 2	Section 3	Fence 3
Initial TSS	1370	761	591	704	410	990
Final TSS	761	591	704	410	990	640
Drop	609	170	-113	294	-580	350
% drop	44.45	22.34	-19.12	41.76	-141.46	35.35

Discussion

The values in Table 4 and Table 5 show a strong correlation between the geotextile filtration fence and a reduction in TSS. The filtration fence placed before a section of the basin removes approximately the same number of suspended solids as each other. This shows that, theoretically, the combination of flocculants and geotextile filtration fences will successfully reduce the size of a sediment retention basin due to its combined ability to remove significant amounts of suspended loess soil particles. This is supported by the testing conducted by Oliveira et al. (2020).

As aforementioned, the turbulent lab test had an outlier for the 1-hour test with a value of 30 mg/L. This was increased to 70 mg/L as the other three results formed a relatively linear line, and it was seen as acceptable to assume that this was a more suitable value for this test. In addition, the 0.5-hour test result was excluded for the same reason in the laminar lab test. It was a significant outlier, and the other three results formed another relatively linear line. This was again seen as acceptable.

The same ideas were implemented from the lab testing for the in-situ testing, ensuring that the calculation could be compared to the in-situ testing. Table 5 shows that for both tests on the 17th and 18th of September, there were drops in TSS every time the stormwater runoff flowed through a geotextile filtration fence.

The 17th of September test had reductions of 40 mg/L, 90 mg/L, and >250 mg/L for geotextile filtration fences one, two, and three, respectively. The 18th of September test showed that the reductions for fences one, two, and three were 170 mg/L, 294 mg/L and 350 mg/L, respectively.

There were some interesting results for both tests. The TSS level increased as the stormwater runoff and flocculant mixture flowed through the sediment retention basin. This happened in section three for the 17th of September test and sections two and three for the 18th of September test. This was due to the lack of significant rainfalls within the testing period, and therefore, the sediment retention basin could not be filled all the way. Thus, the depth of the stormwater runoff in the basin during testing was approximately 100mm. This low volume of stormwater meant the sediment was not able to drop out of suspension efficiently. In addition, it is mixed with loose soil particles on the basin bed, therefore increasing the TSS.

When comparing the geotextile filtration fences' ability to remove suspended solids to a stand-alone sediment retention basin, it was shown that a single layer of geotextile could remove a similar or increased amount of suspended solids as approximately 200 cubic meters of open basin volume. This supports the idea that the current size of sediment retention basins can be further reduced due to the combination of flocculants and geotextile filtration fences, as a filtration fence fills less than 5 cubic meters, similar removal capabilities were observed by Anwar et al. (2018).

The combination of the results from the lab and in-situ tests showed similar results in the ability of geotextiles to remove significant amounts of suspended solids from stormwater runoff. This suggests that current sediment retention basin volume can be reduced in size using the combination of flocculants and geotextile filtration fences.

When comparing this to a forestry situation, the addition of geotextile filtration fences has increased the efficiency of the current sediment retention practices. With this increase in efficiency, the size of these sediment retention basins can be reduced, reducing costs and the area dedicated to the basin. This will allow companies to implement these sediment retention basins as superior erosion sediment controls, decreasing the negative environmental impacts of construction and excavation. These will be able to be placed in areas with restricted space and access, such as tight gullies, which are often experienced in hillside forestry blocks.

Limitations

There were a couple of limitations concerning the testing for this research. As expressed within the results, some of the testing equipment used had upper limits that were reached. This was because the equipment used was portable, and its purpose was to conduct basic field testing. This limited the accuracy of the higher results, as they weren’t able to be effectively measured. This was especially relevant during the in-situ TSS measurements.

As previously discussed, there was no significant rainfall around the time of the testing for the in-situ sediment retention basin. This restricted the testing in many ways, but especially in the sense that there was insufficient water for the flocculant to act most efficiently. Since the sediment retention basin was unable to be filled, there was no water that could be skimmed from the top of the basin by the floating decants. This meant that no water was able to be tested as it flowed out of the sediment retention basin and into the natural stream nearby, giving no data for final products. The result was that no samples could be compared to the ECAN restriction of 50 mg/L (ECAN, 2007).

Recommendations

There are several simple recommendations for any further testing that would be conducted. The use of higher-grade testing equipment would allow for the full range of measurements to be captured. The samples could also be taken to a testing laboratory for the highest grade of measurement if needed.

In the literature review, a lab test conducted by Eduardo Paniguel Oliveria was reviewed. This lab test was unable to be undertaken due to the constraints of the apparatuses being self-made and designed. Although this specific lab test could not be used during this testing, it is recommended that if these tests were to be conducted again, this would be the most effective way of lab testing the theory as it best matches the sediment retention basin design (Oliveira et al., 2020). It was stated by Anwar et al. (2018) that as geotextile accumulates suspended solids, clogging the pores of the fabric, a process known as ‘ripening’ occurs. The removal efficiency of the geotextile filter increases as the soil particles amass because the retention capacity has increased. Both the lab and in-situ testing didn't last long enough to see the results of this process. It is recommended that an extended study period be undertaken for future testing to understand the effects of 'ripening' on the removal of loess soils.

As stated in the limitations, the lack of significant rainfall greatly affected the overall results from the in-situ testing. This could be fixed by having more time to wait for a substantial or predicted rainfall to get these improved test results, but unfortunately, that was not possible during this research due to time constraints.

Furthermore, there is the possibility of crafting an equation for the construction of these sediment retention basins with the applications of both flocculants and geotextile filtration fences. Significantly more testing would have to be done to have a strong baseline for the equation to be built.

Conclusion

Through the lab testing and the calculations that came from the observed results, estimations were able to be made for how much TSS a geotextile filtration fence was able to remove. These estimations showed that geotextile filtration fences can remove significant amounts of suspended solids.

The laminar test had reduction values up to over 110 mg/L per fence, which was estimated to be more than what some basin sections could do over the length of approximately 20 metres. The turbulent test also reinforced this theory, with the calculated fences removing up to over 120 mg/L for some fences. This was again more than some basin sections could do over an approximate 20 metres.

An in-situ experiment was then conducted to test whether these estimations would continue when exposed to real-life situations. Measurements were taken on two separate occasions, spaced approximately 10 hours apart. These tests had reductions in TSS ranging from 40 mg/L to >250 mg/L and 170 mg/L to 350 mg/L for the 17th and 18th of September tests, respectively.

Although there were limitations within the tests, the connection between the combination of flocculants and geotextiles and the significant reduction of suspended solids from sediment-laden stormwater runoff was shown.

Although there were limitations for the tests, all show that there is a connection between the combination of flocculant and geotextile filtration fences and the reduction in significant amounts of suspended solids. When comparing the filtration fence's ability to remove suspended solids to the stand-alone basin section, it is shown that a single layer of geotextile can remove a similar, and at times, an increased number of suspended solids than approximately 200 cubic metres of open basin area. This supports the suggestion that the combination of these factors can reduce the size of the current sediment retention basin design. The fence will take less than 5 cubic metres in length of space.

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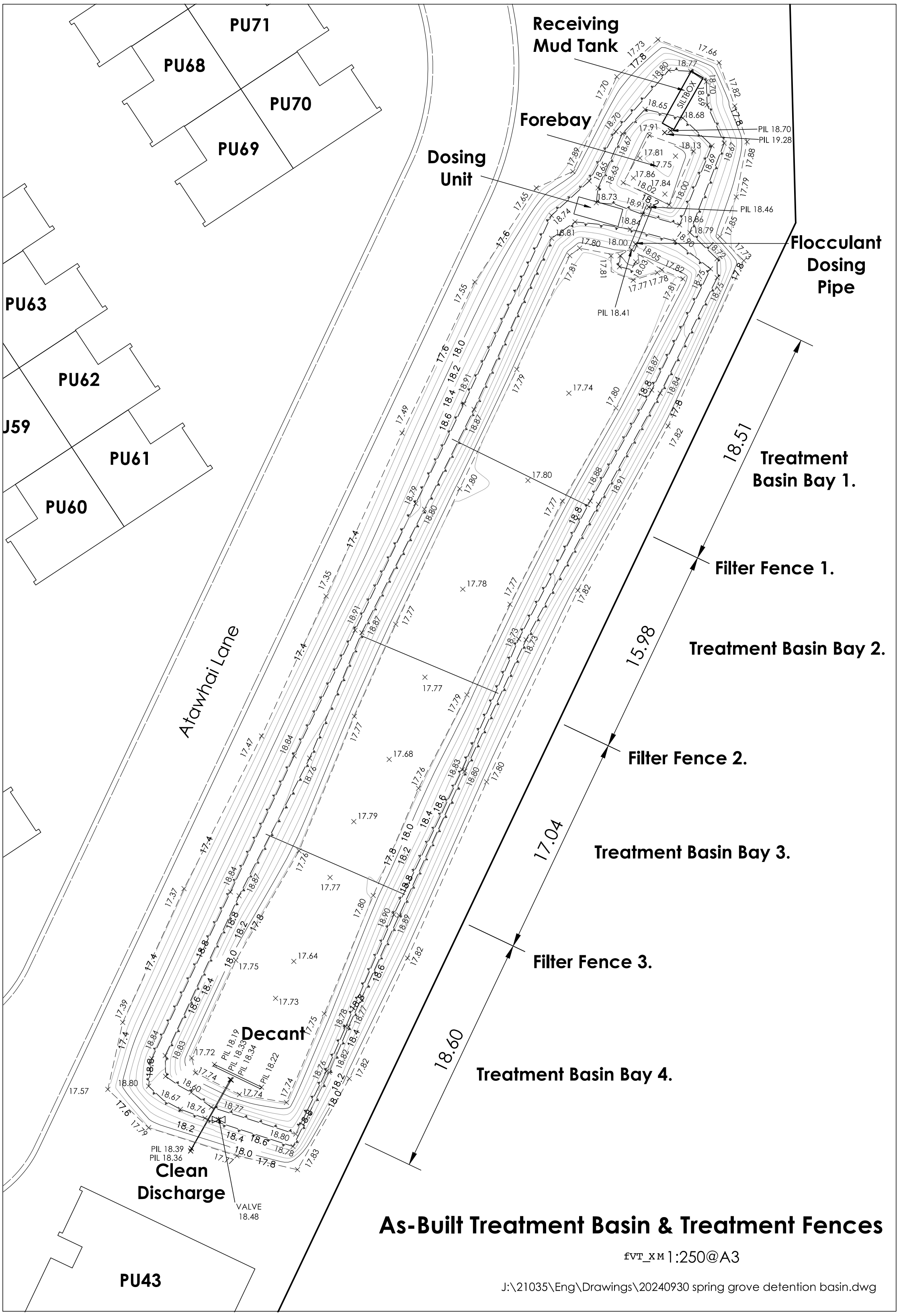
Appendix

Appendix 1: As-Built Treatment Basin and Filtration Fences



Appendix 2: All measured results for the turbulent tests.

22nd September				
	Left For 4 Hours			
	Inptu (Top)	Input (Bottom)	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	180	263	213	169
Turbidity (NTU)	106	166	133	101
Electroconductivity (µS)	3200	3220	3210	3220
Temperature (ºC)	11.5	11.3	11.2	11.2
pH	4.47	4.48	4.47	4.48

22nd September				
	Left For 2 Hours			
	Inptu (Top)	Input (Bottom)	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	256	440	359	277
Turbidity (NTU)	168	286	249	199
Electroconductivity (µS)	3120	3080	3050	3120
Temperature (ºC)	11.4	11.4	11.7	11.8
pH	4.57	4.52	4.5	4.5

22nd September				
	Left For 1 Hour			
	Inptu (Top)	Input (Bottom)	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	394	693	463	382
Turbidity (NTU)	290	443	321	267
Electroconductivity (µS)	3140	3130	3140	3140
Temperature (ºC)	11.6	11.7	11.7	11.7
pH	4.5	4.47	4.49	4.47

22nd September				
	Left For 0.5 Hours			
	Inptu (Top)	Input (Bottom)	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	486	822	586	385
Turbidity (NTU)	316	517	395	266
Electroconductivity (µS)	3640	3640	3610	3600
Temperature (ºC)	11.4	11.4	11.6	11.4
pH	4.48	4.48	4.49	4.48

Appendix 3: All measured results for the laminar tests.

22nd September		
	Left For 4 Hours	
	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	229	100
Turbidity (NTU)	120	53.6
Electroconductivity (µS)	3500	3590
Temperature (ºC)	16.4	15.7
pH	4.38	4.37

22nd September		
	Left For 2 Hours	
	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	270	169
Turbidity (NTU)	158	91.9
Electroconductivity (µS)	3390	3360
Temperature (ºC)	14.4	14.5
pH	4.43	4.41

22nd September		
	Left For 1 hour	
	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	409	198
Turbidity (NTU)	257	114
Electroconductivity (µS)	3000	3040
Temperature (ºC)	15.4	14.9
pH	4.44	4.44

22nd September		
	Left For 0.5 Hours	
	Output (Start)	Output (End)
Total Suspended Solids (mg/L)	699	277
Turbidity (NTU)	428	187
Electroconductivity (µS)	3360	3430
Temperature (ºC)	14.3	13.8
pH	4.46	4.45

Appendix 4: All measured results for the in-situ tests.

17th September (21:00 - 21:30)							
	Section						
	1	2	3	4	5	6	7
Total Suspended Solids (mg/L)	1500	1350	1310	1180	1090	1500	1250
Turbidity (NTU)	938	752	733	698	622	874	822
Electroconductivity (µS)	123	149	153	166	176	184	185
Temperature (ºC)	9.7	7.9	7.9	7.6	7.6	6.9	7.1
pH	8.47	7.78	7.53	7.44	7.4	7.32	7.28

18th September (07:00 - 08:00)							
	Section						
	1	2	3	4	5	6	7
Total Suspended Solids (mg/L)	1370	761	591	704	410	990	640
Turbidity (NTU)	791	574	443	533	353	671	503
Electroconductivity (µS)	53	84	83	89	106	108	126
Temperature (ºC)	5.6	2.6	3	2.7	2.9	2.8	3
pH	8.2	7.78	7.5	7.63	7.38	7.34	7.28