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Abstract

With increasing urbanization, the effect of urban runoff on vulnerable recipients increases. Commonly, open wet ponds have been used for treatment of road surface runoff. With increasing urbanization and a focus on reducing the impact new development has on nature, more area-conservative solutions are needed. This thesis focuses on and studies an underground sedimentation facility for the treatment of road surface runoff water. The main focus of the thesis is examining the TSS removal efficiency of the facility, determining what central tendency measure is the most accurate, and finally comparing the facility efficiency to other methods and to legal requirements. Secondary, a theory of short circuit was examined and any effect dividing walls in the sedimentation pipes might have on the efficiency. Sampling was done from January 2021 until early May 2021, whenever sufficient precipitation events occurred. An issue with the measurement instrument in addition to a limited number of events lead to the number of events sampled being lower than wished, but still enough to draw a conclusion. The overall TSS removal efficiency of the sedimentation pipes was concluded to be 65% - 68%. Based on other studies, by including the gully pots before the facility it is expected to reach a TSS removal efficiency of at least 80%. Both site-mean concentration and total median value is shown to be useful for determining the particle load to the facility. Site mean concentration is however recommended due to the varying load and length of runoff events.

The runoff showed first flush tendencies when expected and the facility showed effectiveness in reducing extreme measurements.

No significant short circuit adding an increased strain on one of the pipes was found. However more sampling at different flow intensities is recommended to draw a final conclusion.

The facility is concluded to be comparable in efficiency to other treatment methods but with a lower maintenance demand and areal footprint. The facility is optimal for further testing and method development. By further examining the efficiency of the facility at different points, using different parameters and removal methods, the facility can be used for further study to optimize or develop urban runoff removal methods.

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Magnus Gausel Lode

Sandnes, June 2021

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Abbreviations

AADT Annual average daily traffic

CMS Cubic meters per second

COD Chemical oxygen demand

DS Dissolved solids

EMC Event mean concentration

EPA Environmental protection agency

FWMC Flow-weighted mean concentration

IVF intensity, duration, frequency (intensitet, varighet, frekvens)

M(V) Mass-volume

NTU nephelometric turbidity units

PAH Polycyclic aromatic hydrocarbons

PCB Polychlorinated biphenyl

PSD Particle size distribution

SÅ Precipitation measurer at Stangelandsåna

SD Standard deviation

SMC Site mean concentration

SS Suspended solids

SW Stormwater

SWMM Storm water management model

TDS Total dissolved solids

TS Total solids

TSS Total suspended solids

UiS University of Stavanger

YR Precipitation measurer at Sandnes Rovik

1. Introduction

Traditionally, stormwater has either been combined with sewer pipes in combined sewer networks and led to sewage treatment plants, or it has been released directly into a recipient. Combined sewer networks have led to overflow events at wastewater treatment plants where not only stormwater has been released untreated, but also raw sewage (Hvitved-Jacobsen et al., 2010). Increasing urbanization means more runoff water goes into the sewage and due to this, separation of sewage and stormwater pipes are becoming more and more common. Norway had 32 000 km of separated sewage pipes in 2019 (Statistisk sentralbyrå, 2019). Further focus on the effects pollution and particles have on a receiving watercourse has led to the development of treatment methods tailored for urban/road runoff.

Runoff from roads can contain pollutants deposited by cars or related activities, such as road maintenance. The degree of necessary pollutant removal is dependent on the vulnerability of the recipient and deposition degree (determined by traffic amount AADT) (Åstebøl & Dalen, 2020). Total suspended solids (TSS) is the constituent with the most effect on the recipient and the simplest guideline for the amount of other pollutants (Åstebøl & Dalen, 2020). Most pollutants found are to some degree bound to suspended particles. Removal of SS is therefore one of the most efficient and simplest ways of removing other pollutants as well (Åstebøl & Dalen, 2020; Hvitved-Jacobsen et al., 2010).

The Norwegian public roads administration has two levels of pollutant removal for road runoff dependent on the annual average daily traffic (AADT). The first step has the function of removing particles and particle bound pollutants. Step two has a function of removing dissolved solids. They do not dictate how these pollutants are to be removed, but step 1 removal should reach a TSS removal rate of minimum 80% (Statens Vegvesen, 2018).

The objective of this thesis is to examine a pilot project for treatment of road runoff. This facility consists of three sedimentation pipes placed underground with a gully pot at the start and end, and a flow limiting outlet at the end. This facility is unusual since most primary treatment (step one treatment) facilities in Norway are open, wet sedimentation ponds (Åstebøl & Dalen, 2020). The analyzed facility is designed for several research areas. It is designed to test and develop different removal methods, and to examine removal techniques in a controlled environment. The main goal of the project is to develop a removal concept that can be tailored for the area and recipient (Azrague & Sivertsen, 2019). The focus of this thesis is to examine the efficiency of the facility as is, compare it to other removal methods such as open sedimentation pools and suggest areas for further study. The focus is therefore put on examining TSS removal rate, developing methods for reporting, and presenting recommendations for what and how further analyzes should be carried out. The thesis focuses heavily on how there are different methods for determining an overall concentration for the facility. The use of mean vs median is looked at as well as the difference between an overall mean and the use of event-mean and site-mean. Also, what effect does volume have on these calculations.

The precipitation area for the facility is expected to receive a traffic volume of around 12 000 AADT (P. Møller-Pedersen, personal communication, August 26, 2020). By the Norwegian standard in the N200 handbook (Statens Vegvesen, 2018, p. 200) a road with this traffic level and a vulnerable recipient, particle bound pollutants removal is required. By studying the facility, gathering preliminary data on TSS and by suggesting an optimal method for estimating the site concentration, the hope is that this master thesis can be used for further study on the facility.

1.1. Expectations

Usually a master thesis has a topic question it attempts to answer or a theory it attempts to prove or disprove. As this is a case study the aim of the thesis is to present sampling methods usable for the facility, present why the facility is built and what its aim is, to examine if the facility holds up to the legal requirements and provide data for further study and development. Some expectations and theories regarding the facility is therefore developed beforehand: For the facility to fulfill the particle removal requirements it must have a reduction of 80% or close to 80% (Statens Vegvesen, 2018, p. 200). There is also an expectation to see a reduction in extreme measurement between the inlet and the outlet and closer values on the outlet compared to the inlet. This was to be compared to literature on gully pots and to an open sedimentation pond connected to a later stretch of the same road. An issue with access to the inlet of this open pond combined with instrumentation fault, meant this was also compared to other literature.

Further, three sets of exploratory tests are performed. The first examines the difference between the three inlet pipes since it is theorized that there is a short circuit from the main inlet to the middle pipe, leading to a higher particle load. There was also an interest in seeing the effect of different setups of dividing walls within the pipes. Comparative sampling was therefore also performed on the outlet pipes. Lastly, samples were collected to see the particle size distribution (PSD) on the inlet and outlet.

2. Theoretical background

In contrast to point release sources such as effluents from wastewater treatment plants, characterizing pollutants from road runoff and other urban drainage sources can be much more difficult. This is due to the large variability in precipitation and its low predictability. A long period of continuous rainfall can diffuse the pollutants to the point of not being a concern, while a long period of low to no precipitation can lead to a large First flush event, where a high concentration of pollutants is released in a short time (Hvitved-Jacobsen et al., 2010). In this section the following is presented: characteristics of road runoff, why it is necessary to treat, statistical methods used in the thesis, how precipitation/flow is estimated and finally what treatment methods are usually used for road runoff.

2.1. Road runoff characteristics

Road and urban runoff are characterized mainly by organic pollutants, Heavy metals, and suspended solids. In a smaller degree there is also found nutrients such as nitrogen and phosphorous, pathogenic microorganisms and biodegradable organics (Hvitved-Jacobsen et al., 2010). Further the characteristics of solids/particles, organics and heavy metals will be presented and their effects on a recipient water will be discussed.

2.1.1. Particles

Suspended solids (SS) in runoff water contains a mix of inorganic and organic particles. A large concentration released to a recipient can lead to deposition to the bottom which in turn can displace bottom dwellers and reduce biodiversity. (Hvitved-Jacobsen et al., 2010)

Organic particles can have a detrimental effect by increasing biodegradation in the recipient, leading to clouding and depletion of dissolved oxygen. This effect is also often seen in recipients of runoff from farmland. Here the runoff has increased concentration of nutrients such as phosphorous and nitrogen. This leads to eutrophication and oxygen depletion

(Bilotta & Brazier, 2008). Oxygen depletion can in worst case lead to a population decline in macrophytes, invertebrates and fish (Bilotta & Brazier, 2008).

Suspended solids are known to bind and transport many other pollutants such as heavy metals, PAHs, and PCBs. The removal of SS is therefore known to function as a proxy when estimating the concentration of particle bound pollutants, and removal of SS can also lead to increased removal of said pollutants. (Rügner et al., 2019)

2.1.1.1. sedimentation/deposition/ Sediment effect of waterways

The primary purpose of sedimentation of stormwater is to remove a considerable part of organic solids in the water before it is released to the recipient water (Metcalf & Eddy, Inc, 2014). The settling speed of a particle is dependent on the size of the particle, its specific gravity and the drag exerted by the fluid it is in. This relationship is explained by Stoke's law. Application of Stoke's law in real systems is hard due to the mix of organic and inorganic compounds, and the variety of flow regimes. In theory Stoke's law is valid for 1 – 100 µm size particles but in reality, the reduction in settling speed due to diffusion makes it valid for particles from around 40 – 100 µm (Hvitved-Jacobsen et al., 2010, p. 105). This will vary from system to system and is best found by testing. The varied nature of runoff, particles and systems makes the application of Stoke's law hard in reality and deposition of solids is easiest found by empirical observations (Hvitved-Jacobsen et al., 2010, pp. 103–105).

An increase of suspended solids has been shown to have a negative effect on macrophytes, invertebrates and salmonoids (Bilotta & Brazier, 2008). At low concentrations (<100 mg/l) it can lead to reduction in productivity and biomass for macrophytes, reduction in population size and density in invertebrates, and egg mortality and reduced foraging activity in salmonoids. At high concentrations (>100 mg/l) it can lead to severe damage and low to no production in macrophytes, high reduction of populations in invertebrates and high population reduction and mortality in salmonoids. (Bilotta & Brazier, 2008)

2.1.1.2. TSS and Turbidity

Total suspended solids (TSS) is defined as the part of the total solids (TS) that is retained on a specific filter after being dried. TS is defined as what is left of a sample after evaporation. The filter size varies, but is usually chosen around 1 µm nominal pore size (Metcalf & Eddy, Inc, 2014) Dissolved solids are often classified as particles in a solution that will not settle on their own. Given the fact that some dissolved solids *can* settle given enough time, some sources rather define dissolved solids as particles that will pass through a given/chosen filter size (Standards methods committee, 1997).

From Metcalf & Eddy, Inc, (2014), turbidity is a measurement of the light scattering properties of a solution of particles. A light is shined on the solution, and the amount of light scattered is measured. This is presented in nephelometric turbidity units (NTU). For some particles, the light will reflect differently from different parts of the particle, creating inference patterns. These can be additive in the direction of measurement. The wavelength of the light source will also affect readings and the creation of inference patterns by making it more sensitive to particles the closer they are in size to the wavelength of the light. Some particles will also adsorb some of the light or have a very low reflective ability. These factors mean two samples from different sources could have a different particle size distributions and particle amount even with a similar turbidity value. For a given site/type of solution, a correlation should be investigated between turbidity and TSS if turbidity measurement are to be used for TSS estimation. (Metcalf & Eddy, Inc, 2014, pp. 83–85)

2.1.2. Organics – effects in water

Organic pollutants are often released into the environment in trace amounts. These can stem from a variety of sources, and in many cases the direct source can be difficult to find. Due to the high amount of different organic pollutants that can be found in road runoff water, it is often normal to focus on the most prevalent micropollutants such as Polyaromatic Hydrocarbons (PAHs). These can also be used as an indicator for the presence of other micropollutants. (Hvitved-Jacobsen et al., 2010)

A literature study found that there could be at least 656 different organic micropollutants in stormwater runoff (Eriksson et al., 2005).

According to Hvitved-Jacobsen et al., (2010) PAHs have been found to be present in amounts up to 10 mg/l. Since these occur in these large concentrations, they are often used as an indicator for the presence of other micropollutants that occur in smaller, harder to detect amounts. PAHs are, as many other organic micropollutants, hydrophobic and can adsorb to particles in the runoff water. Sedimentation of suspended particles is therefore a way to remove some organic pollutants. This hydrophobic nature also means these pollutants are necessary to remove, since they can be bioaccumulating in the fatty tissue of organisms. (Hvitved-Jacobsen et al., 2010, pp. 222–223)

2.1.3. Heavy metals

From the paper by Tchounwou et al., (2012) Heavy metals are defined as metallic elements with a relatively high atomic weight and a density more than 5 times that of water. i.e. 5 g/cm^3. Most heavy metals are toxic to humans and other animals at relatively low doses and are classified as carcinogenic to humans. Today, most heavy metals can be found in above natural concentrations in many systems such as soils, waterways, and the atmosphere near human activity. An increase in industrial sources such as mining and smelting is believed to be a major source of pollution. Other sources such as pharmaceutical, agricultural, and internal combustion are also reported to release heavy metals. higher occurrences of heavy metals have also been known to occur due to natural phenomena such as volcanic eruptions and weathering of heavy metal-containing rocks and surfaces. (Tchounwou et al., 2012)

2.1.3.1. Distribution of metals found in road runoff

From urban runoff four heavy metal constituents are generally considered:
Copper (Cu), Lead (Pb), Zinc (Zn) and Cadmium (Cd) (Hvitved-Jacobsen et al., 2010, p. 70).

In many studies Nickel (Ni) and Chromium (Cr) are also included.

Others can be found in runoff but these heavy metals are focused on since they are often found in potentially toxic concentrations in urban runoff. (Hvitved-Jacobsen et al., 2010, p. 70)

The speciation of the heavy metal pollutants is important when considering their toxicity. For heavy metals, their toxicity is often related to their likelihood of existing as free ions or in molecular form. This makes them more bioavailable. When bound to particles they are generally less toxic but this binding is important for transport. (Hvitved-Jacobsen et al., 2010, p. 90) Toxic heavy metals in road runoff stem mainly from traffic activities such as tire wear, fluid leakages, degradation of the road and road maintenance (Sansalone & Buchberger, 1997).

Heavy metals have been shown to be bioaccumulating in biota such as fish. Many of these heavy metals are necessary micro-nutrients for many animals, but an increase of the concentration in the animals environment can lead to increased uptake, even to toxic levels. (Mehana, 2014)

Several studies show particle bound heavy metals have a highest concentration on particles below 45 µm and the concentration decreases with increasing size (Nie et al., 2008; Sansalone & Buchberger, 1997; Wang et al., 2006). Another article by Tuccillo, (2006) shows Cu, Zn, Pb and Cr concentrations were the highest for > 5 µm and dissolved phase. A limited trial in the article using a 20 µm filter suggest most might be over 20 µm. A third article by Stone & Droppo, (1996) shows Zn and Pb concentration for river bed sediments were the highest on particles <8 µm. Cu concentrations were found to be the highest on particles between 8-12 µm. estimates in the article suggest most heavy metals are bound to solids smaller than 31 µm.

There are some differences/contradictions between sources, but most agree heavy metals bound to particles is bound to smaller size fractions (<45 µm). exactly at what size-fractions they are mostly bound differs from source to source, but it is safe to say that a treatment facility must be effective at removing the smallest possible size fractions to be effective in removing heavy metals.

2.1.3.2. Testing for metals in runoff and Particle size distribution (PSD)

Most particles in road runoff are smaller in size, some articles have shown up to 70-80% of TSS to be <50 µm and 50% have been shown to be <20 µm (Li et al., 2006). Li et al., tested PSD in road runoff from some highways in Los Angeles and found that 90% were <10 µm. Most larger particles are released during first flush events then decline in distribution (Hvitved-Jacobsen et al., 2010).

Heavy metals generated from traffic activities can partition into fractions which can be dissolved or particulate bound. These particulate bound fractions can then be removed by removing the particulate. This can for example be by sedimentation or filtration. Removal of dissolved heavy metals will require filtration with a filter size smaller than the heavy metals (Hvitved-Jacobsen et al., 2010). Knowing the size of the particulates the heavy metals are bound to is important to know if a purification process is effective in removing heavy metals.

Small and colloidal particles have large specific surface area and have therefore a high affinity for binding soluble species. As the size and mass of the particle increases, the specific surface area decreases and the particle can therefore bind less heavy metals (Hvitved-Jacobsen et al., 2010).

2.1.3.2.1. Coulter Principle

In a coulter counter, particles that are to be measured are mixed in an electrolyte solution which is then passed through a glass aperture. Here the flow of the solution is controlled to be mostly constant. The aperture is placed between two electrodes and the electrolyte solution is passed through. When a particle passes between the electrodes, some of the electrolyte is displaced leading to a resistance change. This change can then be measured, and the change will be proportional to the particle size. The number of voltage pulses measured will also give how many particles passes through. (Beckman Coulter Inc, n.d.)

2.1.4. Road salt/snowmelt

During January and the start of February 2021 when this thesis was written there were several periods of snow with following freezing temperatures. This meant Sodium Chloride was spread on roads as a deicing salt. Salt content measurements is not originally part of this thesis and the treatment facility is not created to treat/remove salt in any proper degree. Due to the presence of snow and deicing salt during testing period, combined with the Horiba water quality instrument used, which can measure salt content with relative ease, it was decided to include these measurements and see if the facility has any effect on the salt content.

Sodium Chloride in itself, is not considered toxic unless in large enough concentrations to affect cells not accustomed to these concentrations. However, according to Hvitved-Jacobsen et al., (2010) chloride can have some adverse effects when found in snowmelt. It can affect the speciation of heavy metals by transferring them to a more soluble state. This can lead to increased bioavailability of the heavy metals. When released to more stagnant water and lakes, salt can lead to stratification (layering of the water column) and in the worst cases oxygen depletion as there is little mixing (Hvitved-Jacobsen et al., 2010, p. 225)

The accumulation of snow after snowfall has been shown to accumulate particles and pollutants when close to roads. These pollutants accumulate in the snow and are released when the snow melts. Investigations have shown that snowmelt events typically has two times (and sometimes up to six times) the concentrations of runoff pollutants than regular stormwater events. (Hvitved-Jacobsen et al., 2010, p. 131)

2.1.5. First flush

The following section presents the first flush phenomena. This event is defined by a high concentration of pollutants being present at the start of a runoff event, and then flattening out to a lower concentration. (Hvitved-Jacobsen et al., 2010). This event shows there can be a large difference in pollutant loads, and it shows the importance of knowing the variability when choosing a pollutant reduction approach, and when choosing if one is needed at all. The pollutant load at different events such as first flush, high, and low precipitation can vary greatly. It is therefore important to take these into account when deciding if a pollutant reducing step is needed or not (Hvitved-Jacobsen et al., 2010).

In the result section of this thesis pollutant loads at different events will be presented and their variability shown.

By using the equations and definitions presented in the book Urban and Highway Stormwater Pollution (Hvitved-Jacobsen et al., 2010, pp. 44–49) we can calculate the cumulative relative pollutant mass transported and the cumulated relative flow. These values can be used to plot a dimensionless mass versus volume curve. This curve will show us the relative mass transported by one-unit water at each measurement time. If the mass is constant in relation to water volume, we will see a curve that is approximately 45 degrees. Any first flush event will be shown as a steep incline in the start which will steadily flatten out.

Cumulative relative runoff volume:

$$f_{flow} = \frac{\sum_{j=1}^{i} v_j}{\sum_{j=1}^{n} v_j}$$

Equation 2-1 cumulative relative runoff volume

j= 1…i. interval number, i= 1….n. interval number, n= number of samples, v_j= volume of runoff in interval number j (in m^3) (Hvitved-Jacobsen et al., 2010, p. 44)

Cumulative relative pollutant mass transport:

$$f_{mass} = \frac{\sum_{j=1}^{i} c_j v_j}{\sum_{j=1}^{n} c_j v_j}$$

Equation 2-2 cumulative relative pollutant mass transport

C_j =pollutant concertation at interval number j (in mg/l) (Hvitved-Jacobsen et al., 2010, p. 45)

These values can further be plotted against each other to show a mass (M) versus volume (V) curve.

This curve can be described by

$$f_{mass} = (f_{flow})^m$$

Equation 2-3 mass vs volume relationship

Where m is an empirical first flush coefficient. (Hvitved-Jacobsen et al., 2010, p. 46) Using this description of the curve, Hvitved-Jacobsen et al., (2010) concludes a first flush event is present if m<1.

Several other definitions also exist, such as:

If the initial slope is larger than 45° a first flush event is present (Geiger, 1987).

A first flush is present when at least 80% of the mass load is in the first 30% of the runoff volume. (Saget et al., 1996)

The first 20% of the runoff volume contain a significantly higher mass load than 20% of the total mass load. (Deletic, 1998)

The data we use has been measured as NTU using the turbidity meter Horiba multi water quality checker.

In order to present the data as shown above, the readings must be transformed into mg/l suspended solids. This is done with the Correlation study.

The presence of a first flush event is difficult to qualify due to a lack of agreeance in its definition. There are also some that argue this variance in definitions means the event will occur so differently from place to place, that the event cannot be defined as an event at all.

In this paper we assume the event is "possible" and we use the definitions presented by Hvitved-Jacobsen et al., (2010) to see if the event is present or not.

2.2. Why treat

2.2.1. Stormwater in WWT facility

Traditionally, many areas around the world, including Norway, have had made a combined sewer network where municipality's and counties have responsibility for treatment of sewage. A combined sewer network includes sewage and stormwater (SW) (Hvitved-Jacobsen et al., 2010). Today, mostly new areas built in Norway have a separate sewage and stormwater system, but old systems still in place are a problem. Norway has almost 32 000 km of separated sewage pipes and 19 000 km of storm water pipes, But 6 653 km of combined pipes are still in use in 2019 (Statistisk sentralbyrå, 2019).

In many places combined sewer systems are being exchanged in favor for separate systems. In Norway the km of combined systems have been reduced from 7 489 km in 2015 to 6 653 km in 2019 (Statistisk sentralbyrå, 2019).

From Hvitved-Jacobsen et al., (2010) in a separate sewage network, a wastewater treatment (WWT) facility can be dimensioned to handle the current sewage production and an eventual population increase. The inflow to the system is mostly the same and any increase at certain events or times can be planned for. With a combined sewer system any large storm events also need to be taken into consideration. Due to the rarity of extreme rainfall events, the WWT facilities are rarely dimensioned to handle these. The facilities therefore have overflow structures which release the excess sewage and stormwater. The consequence of these overflows is the potential pollution of the receiving water system. (Hvitved-Jacobsen et al., 2010)

From chapter 6 in *Urban and highway stormwater pollution* (Hvitved-Jacobsen et al., 2010), it is shown that the effects of untreated SW and combined sewer overflow on the receiving water body, are much the same, but at different degrees. Pollutants such as sediments and heavy metals will be present in both (see Road runoff characteristics). The overflow will contain much more organic matter, nutrients and pathogens which are an issue when released in large quantities. For a well dimensioned WWT facility these overflow events will be rare. In these cases due to the pollutant load in SW many places it will be less stressing for the water bodies to receive the occasional overflow than the constant SW release (Hvitved-Jacobsen et al., 2010). The receiving water body needs to be considered when choosing to release SW, and in many cases, some form of local treatment should be considered.

When considering the release of pollutants found mainly in wastewater, a separate system is superior, as this should have little to no overflow events. For other parameters such as heavy metals and COD a combined system releases less load overall (Brombach et al., 2005). Separate systems are therefore not always preferred, especially if no further treatment is considered for SW before release. (De Toffol et al., 2007) This shows that for a county/municipality to separate the systems, they first need to evaluate the impact of releasing the SW, and what recipient they are releasing it into. What the recipient can handle needs to be considered and an adequate pollutant reducing measure needs to be put in place.

2.2.2. Outlet into protected stream

Runoff from the examined stretch of fv505 road runs into the middle part of the waterway "Figgjovassdraget".

According to a report by Ledje & Randulff, (2019) Figgjovassdraget is the largest watercourse on Jæren. The middle part is heavily influenced by farming activity from the surrounding area, but it is also becoming more and more influenced by urban runoff as the area becomes more urbanized. The watercourse is ecologically important with nature reserves for birds, important spawning locations for salmon (*Salmo salar)* and the presence of rare river mussels (*Margaritifera margaritifera)*. The Figgjo watercourse is one of the watercourses in Norway that has been given extra protected status to maintain a healthy salmon population. No new activity that could damage the fish population is allowed. (Ledje & Randulff, 2019)

In addition to its healthy fish population, the Figgjo watercourse maintains a large population of freshwater mussels. The species has a status as threatened, but due its high viability and its large population in the Figgjo watercourse, it has an increased protection value (Ledje & Randulff, 2019).

Influences like eutrophication, reduction in host fish (salmon) population, urban runoff and other polluting factors can have a large negative impact on the mussel's population. (Ledje & Randulff, 2019).

The middle section of the watercourse is where the most important areas for anadromous fishes, like salmon, and river mussels is registered. Protecting the section from eutrophication, particles and other pollutions is therefore important. Most of todays planned development and building projects near the Figgjo watercourse are planned around the middle section. It is therefore of increased importance to limit the particles and pollutants released to the watercourse by new development. (Ledje & Randulff, 2019)

The watercourse covers eight different nature reserves and conservation areas (NVE, 2009):

- "Jærstrendene landskapsvernområde"
- "Grudevatn naturreservat"
- "Harvalandsvatnet naturreservat"
- "Øksnedvadtjønn naturreservat"
- "Alvevatnet naturreservat"
- "Heigremyra naturreservat"
- "Lonavatnet naturreservat"
- "Grudevatn dyrefredningsomårde"

Some of these cover specific ecological habitats or flora, while most of them include breeding areas for migratory birds. Most of the watercourse has a common protection status for fish and mussels (NVE, 2009).

The entire Figgjo watercourse is defined as a Ramsar-area. These are areas covered in the Ramsar-convention which is an international cooperation for the protection of wetlands important for species diversity, nesting and overwintering areas for migratory birds. (Ramsar Convention Secretariat, 2016)

From the report by Ledje & Randulff, (2019) it is pointed out that runoff from construction activities and the ensuing developed areas is, and likely will be the largest contributor to pollution in the middle section of the watercourse. (Ledje & Randulff, 2019).

The sedimentation facility presented in this paper is one of the measures implemented and tested to reduce the particle inflow on the watercourse.

2.3. General statistics

The following section covers statistics and statistical methods used in this thesis.

2.3.1. Mean and standard deviation

The mean tells us the average value of our data. To find the mean value of TSS in precipitation events, the sample mean for the event (EMC) can be found, and this is then used as an estimate of the true mean of all events (SMC). Since the sample mean acts as an unbiased estimator of the population mean, the precision of the sample mean depends on the spread of the samples from the sample mean. This is presented as the standard deviation. The standard deviation decreases in proportion to the square root of the sample size. (Moore et al., 2014)

2.3.1.1. EMC, SMC and FWMC.

For urban runoff, where the concentration, intensity and length of runoff events can vary greatly, directly using the mean of all observations can give a skewed image of the average concentrations. EMC, SMC and FWMC can then be used to give a more accurate image of the events. EMC is the event-mean concentration that is measured for one given event for the chosen parameter. SMC is the site-mean concentration and includes the EMC from all measured events. (Hvitved-Jacobsen et al., 2010)

Equation 2-4 Site-mean concentration

$$SMC = \frac{\sum_{j=1}^{n} EMCj}{n}$$

FWMC stands for flow-weighted mean concentration. This includes the mean for all events examined but also includes the volume for each observation. This reduces the weight a high or low flow can have on the measured concentration. (Heidelberg College, 2005; Hvitved-Jacobsen et al., 2010)

Equation 2-5 Flow-weighted mean concentration

$$FWMC = \frac{\sum_{j=1}^{n} EMCj * Vj}{\sum_{j=1}^{n} Vj}$$

2.3.2. Confidence level

To see if the testing method is usable and accurate, one can apply a relevant confidence level to a set of tests and use a t or z value to see how large the expected deviation is. The standard is using a 95% confidence interval. But when a higher accuracy is needed, 99% is usually used or 90% when a high confidence is either not relevant or the margin of error becomes too large. The confidence level tells us how often we can expect to see the result match the true value. (Moore et al., 2014)

If the standard deviation (SD) for a population Is known, the confidence level will follow $N(\mu, \frac{\sigma}{\sqrt{n}})$ if the population is normally distributed. For most research, like the method verifications in this thesis, the "population" mean, or SD is unknown. For these cases a t-test/distribution can be used. (Moore et al., 2014)

2.3.2.1. t-test and z-test

Two commonly used methods are used for finding the confidence interval of a population: A z-test is used when the SD of a population is known, and a t-test is used when the population SD is unknown. In this thesis the t-test is most relevant. The confidence interval is:

Equation 2-6 Confidence interval with unknown population standard deviation

$$\bar{X} \pm t \frac{s}{\sqrt{n}}$$

Where x̄ is the samples mean, t is the value taken from the t-distribution table with n-1 degrees of freedom, s is the sample standard deviation and n is the number of samples. (Moore et al., 2014)

2.3.2.2. Central limit theorem

The central limit theorem tells us that in a population with mean μ and standard deviation σ, a sufficiently large number of samples will be approximately normally distributed. For a sample test, if the sample size is sufficiently large, we can conclude that the sample mean is approximately the population mean. (Moore et al., 2014)

2.3.3. Significance test

A significance test is used to compare the data collected with a hypothesis, usually the null hypothesis. The results are presented as a probability of the hypothesis being correct or rejected. This is decided by the significance level or the alpha value being above or below the chosen confidence level (Moore et al., 2014)

2.3.3.1. Null hypothesis

In a significance test we test to see if we can reject the null hypothesis. This states that the difference in the samples being compared, is due to random variance. By testing to see if we can reject the null hypothesis, we test if the variance is statistically significant. (Moore et al., 2014)

2.3.3.2. P-value, t-value, and Pearson correlation coefficient

The significance level can be expressed as a P-value. This value will tell if the null hypothesis should be rejected or not. By setting a relevant alpha level we can compare it to the p-value, and if the value is below the alpha-value, the null hypothesis can be rejected. (Glen, 2014)

To find the p-value, we can calculate the Pearson correlation coefficient, and then the t-value of the coefficient. Further we use the t-value to find the p-value on a t-distribution table. Usually the p-value is linked to an alpha level of 0.05 so a p-value below 0.05 is considered significant. This alpha level can be chosen on how accurate the data needs to be. (see 2.3.2.) (Glen, 2021)

Pearson correlation can be visualized in the following formula:

Equation 2-7 Pearson correlation coefficient

$$r = \frac{\sum(x-\bar{x})(y-\overline{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}}$$

The two-sided t-value can be calculated by the following formula:

Equation 2-8 two-sided t-value

$$t = \frac{r * \sqrt{n-2}}{\sqrt{1-r^2}}$$

(Glen, 2014, 2021)

As the Pearson correlation coefficient name implies, this method is used when comparing two datasets to see if there is a significant correlation between them.

2.4. Water residence and precipitation

2.4.1. Water residence time

Using the data in the Sedimentation pipes and Precipitation area section of materials and methods it is possible to calculate an approximate residence time of the facility at different precipitations. The precipitation numbers in this thesis are not directly measured at site but rather Precipitation based on metrological reports.

Example 1: an estimated 4,2 mm precipitation over an hour gives us 4,2 $\frac{L/m^2}{hour} *$ $13\ 485\ m^2 (precipitation\ area) = 56\ 637\ L$/h

$\frac{231\ 900\ L(facility\ volume)}{56\ 637\ L/h} = 4{,}1$ hours water residence time. (18.01.2021 measurement)

Example 2: an estimated 2 mm precipitation over an hour gives us 2 $\frac{L/m^2}{hour} * 13\ 485\ m^2 =$ $26\ 970\ L$/h

$\frac{231\ 900\ L}{26\ 970\ L/h} = 8{,}6$ hours water residence time. (21.01.2021 measurement)

These residence time calculations provide an approximation for how long events need to last for a complete volume turnover in the system. Based on the data presented in section 3.1.1 an estimation can be made of the residence time when the facility is at max designed capacity.

An inflow rate of 223,68 l/s over 10 min is given.

$$\frac{231\ 900\ l}{(223{,}68 * 60)\ l/m} = 17{,}28\ min$$

This shows the facility can handle the volume presented in the technical norm, meaning the facility is large enough not just to retain the extreme volume, but also, to a degree, treat it.

2.4.2. «Kommunal teknisk norm»

When designing and building new areas, the contractor is obligated to follow the norms placed by the municipality office. The norm for Rogaland is set in cooperation by all the municipalities. For Sandnes municipality the pipe network, detention and any treatment facilities are dimensioned according to precipitation forecasts based on: expected climate changes, runoff coefficient for the area and chosen IVF values. (Norsk vann, 2017) These variables are presented here to provide a background for what the studied facility is dimensioned for.

The technical norm paper states that for areas smaller than 20 ha manual calculations can be used (Norsk vann, 2017).

Equation 2-9 Technical norm for dimensioning flow

$$Q_{dim} = c * i * cf * A$$

Where c = runoff coefficient, i = precipitation intensity based on the IVF-values for the area, cf= climate factor and A = Area of precipitation.

2.4.2.1. Runoff coefficient

A runoff coefficient is defined as the amount of rainfall or precipitation that becomes runoff. The remaining precipitation is for example permeated through the soil into the groundwater. (Norsk vann, 2017) VA – norm provides a table for determining runoff coefficients.

Table 2-1 runoff coefficients. Source: Kommunaltekniske normer for vann- og avløpsanlegg. Vedlegg 9. (Norsk vann, 2017, p. 2)

Type Areal	**Koeffisient (c)**
Tette flater **(dense surfaces)**	0,85 - 0,95
Bykjerne **(city core)**	0,70 - 0,90
Rekkehus-/ leilighetsområde **(apartment area)**	0,60 - 0,80
Eneboligområde **(housing area)**	0,50 - 0,70
Grusvei/ -plasser **(gravel roads)**	0,70 - 0,80
Industriområde **(industrial area)**	0,70 - 0,90
Plen, park, eng, skog, dyrket mark etc **(park, forest, field etc)**	0,30 - 0,50

2.4.2.2. IVF values

IVF stands for intensity (intensitet), duration (varighet) and frequency (frekvens). These values are for dimensioning precipitation used as an estimate when designing systems for handling of runoff, or when estimating floods. IVF curves show and describe how often it is expected to have an event with a certain intensity and duration in a given area. IVF curves are given by the municipality and used as a standard. (Norsk vann, 2017)

When designing systems to handle urban runoff in Norway, VA-engineers use “box rain” as an estimate of what the system needs to handle. box rain uses a constant precipitation intensity over a set amount of time across the entire precipitation field. The IVF value used for dimensioning is chosen from an IVF-curve that is divided by frequency of these events. Usually systems are designed for the maximum value of a 20-years period, but a system that is designed to last for 60 years might rather use a 40-50 years value. For Sandnes and surrounding municipalities the standard for road runoff treatment facilities is 20 years which is 200 l/s per ha over 10 min. (Norsk vann, 2017)

2.4.3. Precipitation based on metrological reports and SWMM

By using precipitation data provided by “Metrologisk institutt” and from a tip bucket setup close to “Stangelandsåna” an estimate of flow is possible to make using the known area of runoff. When the area of runoff is known and historical precipitation data is available, the SWMM software by the EPA is possible to use to find historical mean runoff volume and more. SWMM is useful to compare the measured runoff volume to the historical runoff data. The historical precipitation data used in this thesis was retrieved from “Norsk Klimaservicesenter” and includes hourly data from January 1st 2018 to December 31st 2020. (Norsk klimaservicesenter, 2021)

2.5. Treatment methods

2.5.1. Closed sedimentation facility

Few dedicated sedimentation tanks for stormwater are built. Mostly detention ponds are used for this type of treatment (Hvitved-Jacobsen et al., 2010). Some places detention tanks for storage of high volumes of stormwater is also used partly for sedimentation, but little information is available on the efficiency of these. There exist some settling tanks for stormwater, but like the facility at fv505, the data found is also on experimental systems (Falco et al., 2020). Settling basins are widely used in wastewater treatment where often flow from combined sewer systems is treated. These settling ponds function as continuous flow reactors while a stormwater settling tank will function more as a combination between continuous flow and batch reactor (Metcalf & Eddy, Inc, 2014). It needs a capacity for settling during low/no flow and during high runoff events. The main issue is creating a system large enough to allow for settling of smaller particles. The size distribution of particles in stormwater is discussed in section 2.1.3 and 4.7. Open/wet ponds are usually easier to dimension for these larger runoff events (Hvitved-Jacobsen et al., 2010). Li et al., (2006) suggest a two-compartment system for treatment of stormwater. This system is meant to be effective in removing small particles.

2.5.2. Open detention pond/wet ponds

Dry detention basins and wet detention ponds are the two most common systems for open ponds. A dry detention basin is mostly used as a retention system that restricts discharge amount. After a rainfall event the water is discharged (and some undergoes evaporation and infiltration) during this time some settling will also take place, thus reducing the TSS of the effluent (Hvitved-Jacobsen et al., 2010). A wet pond is designed with a permanent water level. This also works as a hydraulic retention system, but with long enough water residence time that sufficient particle settling occurs. A wet pond is usually divided into two sections: one forebay for settling heavy particles like sand, and the main pond where fine sedimentation occurs. A wet pond is often combined with specific vegetation that is known to be effective in uptake of pollutants or nutrients. This means a wet pond can be designed to also have recreational value in an area, attracting other plants and animals. (H Paus et al., 2013; Hvitved-Jacobsen et al., 2010)

A wet pond will have a permanent water volume and a storage volume. The outlet of the pond will be at the bottom of the storage height, often with a limiting outlet pipe. The water is then slowly released, allowing most particles to settle, and a permanent water volume will allow small particles still present to settle during dry periods. (Hvitved-Jacobsen et al., 2010)

2.5.3. Gully pots

Information on the efficiency and setup of gully pots is collected mainly from 4 sources: (Butler & Karunaratne, 1995; Deletic et al., 2000; Hvitved-Jacobsen et al., 2010; Rietveld et al., 2020)

Gully pots are usually formed as collection basins to collect sediments at points along the runoff pipes and/or at the outlet. Gully pots are designed to catch heavy particles before they reach a recipient water or second treatment step. Observations have shown that gully pots have a high efficiency in screening large particles (>90% for 500 µm) and with steep drop for particles below 200 µm (Butler & Karunaratne, 1995). This paper by Butler and Karunaratne also estimates that silts (<60 µm) will not exceed 25% removal efficiency unless at very low flows. As other papers show (Li et al., 2006) most particles present in stormwater runoff are below 10 µm. The gully pot is therefore designed to remove large particles that are present during first flush events and to a smaller degree remove smaller particles during low flow. The efficiency of the gully pot will vary greatly depending on the particle size distribution (PSD) and rate of inflow (Hvitved-Jacobsen et al., 2010).

3. Materials and methods

3.1. Fv.505 sedimentation facility

3.1.1. Dimensions and setup

The facility has been dimensioned to handle a runoff amount of 223,68 l/s for 10 min (IVF values). this is based on the municipality technical norm with a runoff coefficient of 1,0 (2.4.2.1) and a climate factor of 1,2 (P. Møller-Pedersen, personal communication, May 10, 2021). In this, any possible delays in the system have not been included.

Due to the change from state responsibility of the road networks to county just in the period this area was developed, further information from the Norwegian Public Roads Administration on the project is hard to find.

The facility is comprised of 3 main parts. A gully pot at the start, three sedimentation pipes and a gully pot/retention basin at the end. The main inlet into the facility gully pot is designated as P1. The outlet from the gully pot/inlet to the pipes is designated as P2 with each pipe numbered 1 to 3 (i.e. P2-1, P2-2 and P2-3) The last sampling site we focus on is the outlet from the pipes designated as P5-1, P5-2 and P5-3 (L. Møller-Pedersen, personal communication, February 1, 2021).

3.1.1.1. Gully pots

The start and end of the facility contains a 2400 mm in diameter gully pot. The one at the start receives the inflow from a 500 mm diameter pipe which is placed 2300 mm from the bottom of the gully pot. The three inflows to the pipes are placed 50 mm lower at 2250 mm from the bottom. These pipe into the sedimentation pipes 2050 mm from the bottom of the pipes (L. Møller-Pedersen, personal communication, February 1, 2021).

The gully pot at the end of the sedimentation pipes also measures 2400 mm in diameter with the outgoing pipe 520 mm from the bottom. This pot is made to act more as detention basin than a sedimentation basin (L. Møller-Pedersen, personal communication, February 1, 2021).

3.1.1.2. *Sedimentation pipes*

The sedimentation facility is comprised of 3 pipes, each 27 m long. the pipes have a diameter of 2400 mm with the outlets being 1350 mm above the bottom and the inlet 2050 mm above the bottom (L. Møller-Pedersen, personal communication, February 1, 2021) (Azrague & Sivertsen, 2019).

Volume of the sedimentation area of each pipe is the calculated using formula for half pipe:

Equation 3-1 Volume of a half-pipe

$$V = \frac{1}{2}\pi r^2 L$$

Equation 3-2 sedimentation facility volume

$V = \frac{1}{2}\pi 1{,}35\ m^2 * 27\ m = 77{,}3\ M^3$ = 77 300 L. For all three pipes: V = 231 900 L

This calculation uses the outlet height as a radius (since this is the water level) while the actual radius is 1,2 m. The curvature of the pipe between 1,2 and 1,35 m height will therefore lead to a small overestimation in volume.

3.1.1.3. *Dividing walls*

All three sedimentation pipes contain one set of walls each. These walls are in a set of two where the lower wall is 1367 mm tall and the upper wall is 1197 mm tall. The lower wall is mounted to the bottom of the pipe and the upper wall at the top. These walls are placed 1300 mm from each other. With the top wall closest to the inlet this creates an overlap of 164 mm.

Each set of walls is placed differently. In pipe 1 the pipe is divided in half. In the middle the pipe is divided in 1/3 and 2/3 (from inlet). In the third pipe the pipe is divided to 1/4 and 3/4 (from inlet).

3.1.2. Precipitation area

The precipitation field for the sedimentation facility is a ca 1,35 ha (13485 sqm) area designated as “godsterminal” west. This area also includes a detention basin for large amounts of precipitation, but this facility is not designed to have any pollutant reducing effect. The precipitation area includes a stretch of road and a bridge. The facility receives its runoff from 4 storm drains connected to 4 gully pots with a circumference of 1000 mm and a sludge height of 1000 mm. (P. Møller-Pedersen, personal communication, May 10, 2021)

The gully pots are designed and placed so they remove the heaviest and coarsest sediments. Further studies and comparisons to the pollutant removing effect of gully pots are presented in the results section on Gully pots. These gully pots are placed along the road, so the runoff is first treated in these before entering the treatment facility. As previously mentioned, the facility also includes a gully pot right before the pipes.

3.2. Sedimentation pond

3.2.1. Dimensions and setup

On a stretch of the same road further east an open sedimentation pond is used for treatment. Based on available information the sedimentation pond by fv505 is made for a volume of 200 m^3 and a surface area of 430 m^2. The pond is divided in several thresholds to distribute the runoff evenly across the pond. The pond is estimated to be 1,5 m deep at normal precipitation. At high precipitations the depth will be higher, and the pool is made to function as a detention pond. Areas of the pond where the depth is normally below 0,7 m there is planted appropriate flora that can assist in removal of nutrients and pollutants. The outlets from the pond are below the storage volume to hinder floating debris and sludge to exit the pond. (L. Møller-Pedersen, personal communication, February 1, 2021)

In addition to the gully pots along the runoff channels leading to the sedimentation pond, there is also a gully pot right before the pond to catch the coarsest particles.

3.2.2. Precipitation area

The precipitation area for the sedimentation pond is just east of the “godsterminal” vest area and is designated as “godsterminal” east. This pond receives runoff from at least seven storm drains (again here there is some uncertainty due to lack of available documentation) and ten gully pots. The area includes runoff from the east side of the bridge over the freight terminal and a stretch of road. Based on the available plans and the pond being dimensioned for 320 l/s (standard from ”«Kommunal teknisk norm” sets dimensioning to 200 l/s per ha) we can approximate that the precipitation area is ca 1,6 ha (16 000 kvm) (L. Møller-Pedersen, personal communication, February 1, 2021)

3.3. Sampling

3.3.1. Turbidity and TSS verification and correlation

For the verification and correlation test, a 10-liter sample was collected at the inlet of the middle pipe (pipe 2) of the sedimentation facility at fv.505 on the 18.01.2021. This sample was collected close to the end of the observed event that day. Reduced access to the university laboratory due to Covid-19 restrictions, led the sample to be stored for 24 days before testing. The sample was stored dark between approximately 1-10 °C.

3.3.2. Turbidity exploratory testing

Exploratory testing was done using the Horiba instrument. All sampling except one was done in-situ. This one set of samples (22.04) was collected in a container and tested the next day.

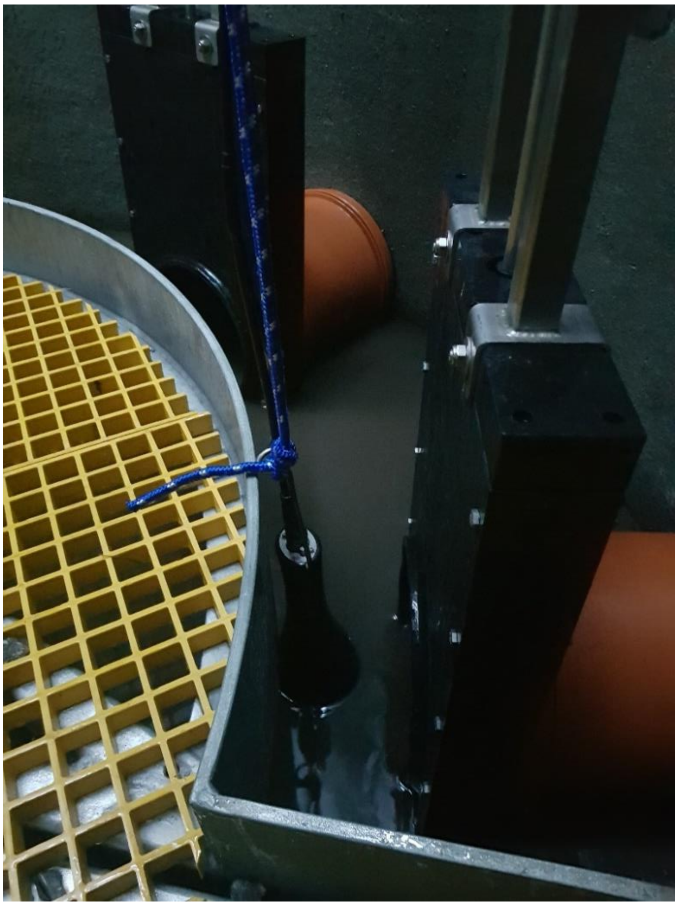

Figure 3-1 Horiba water quality measurer probe measuring flow into pipe 3 (P2-3) (photographed by author 2021)

3.3.3. Particle size analysis

Particle size was analyzed at the lab at UiS and samples were therefore collected in storage containers from the preselected points P1, P2-2 and P5-2. These containers were transported to UiS and analysis was performed within 2-3 days. The samples were analyzed using a Beckman Coulter Multisizer 4e Coulter Counter. The instrument was set up to analyze the size distribution of the first 2000 particles passed through the aperture.

3.3.4. Horiba multi water quality checker

The instrument used for most sampling is an in-situ field instrument that was placed in the water column and set to collect data on a set timer.

3.3.4.1. Turbidity

The instrument uses a tungsten lamp as a light source and has a detector 90° of the source that detects scattered light. The turbidity is presented as how much transmitted light is scattered and detected. The instrument complies with EPA method 180.1 (HORIBA Ltd., 2009).

3.3.4.2. Conductivity/TDS/Salinity

The conductivity is measured using two voltage-detecting electrodes and two voltage-applying electrodes. These detect and apply AC voltage. The conductivity is reported as SI units. Since conductivity changes with temperature, The instrument automatically converts the value to conductivity at 25 °C using a coefficient of 2%/°C. (HORIBA Ltd., 2009)

Total dissolved solids comprise some of the substances in the solution that can be detected using conductivity. The TDS is estimated from conductivity by:

$$TDS\ (g/L) = L\ (S/m) * K * 10$$

Equation 3-3 TDS estimation from conductivity (HORIBA Ltd., 2009)

Where K is a TDS coefficient.

At certain temperatures the relationship between salinity and conductivity can be estimated. By measuring the temperature and the conductivity the instrument can then calculate the salinity of the sample. This is displayed as NaCl concentration, even if the constituent is for example HCl (HORIBA Ltd., 2009).

3.4. Verification and correlation method

To use turbidity as a measurement for the mass of particles present in a sample, a correlation study is required to see the ratio of light absorbance to mass of suspended particles. To show this correlation several dilutions of the same sample was tested using turbidity and TSS standard methods (American Public Health Association, 2017; Standards methods committee, 1997). To investigate if the correlation is correct, a statistical verification is made of the TSS and turbidity measuring methods. For both verification tests, 30 smaller samples were taken and tested from the same collection jug. This sample was collected from the inlet of the fv.505 treatment facility on 18.01.2021.

3.4.1. Turbidity testing at lab

Turbidity test was performed on a Horiba U-50 multi-parameter water quality checker. The instrument was calibrated according to the procedure in the instrument manual (HORIBA Ltd., 2009)

3.4.2. TSS testing at lab

For measuring the total mass of suspended solids in a sample, standards method 2540 D was used. (Standards methods committee, 1997). A vacuum filtration system using flowing tap water for suction was used with 47 mm diameter GF/C filters with a pore size of 1.0 μm. following the standards method, each filter was dried at 105 °C for one hour, weighed, sample filtered through, dried at 105 °C for another hour before they were weighed again. 30 filters were used with 200 ml sample water each.

For turbidity and TSS validation, the standard deviation was calculated using the STDEV.S command in excel. The standard error was found using the sample standard deviation and sample size, and this was used to calculate a 95% confidence interval using a t-value standard distribution table.

3.4.3. Correlation study

A 500 ml sample was taken from the collection jug into one 500 ml glass bottle. Further two 250 ml samples were put into two glass bottles and filled with 250 ml tap water. These were further divided in two and filled again. This was done until there were 8 dilutions from 1:1 to 1:128.

These samples were tested for turbidity and the same sample was then used for TSS testing. By reusing the samples any error with the measuring of sample amount or tap water amount is not relevant. The aim of the test is to measure the correlation of TSS and turbidity in a specific sample. The exact dilution is not important.

The Pearson r-correlation coefficient was found using the PEARSON command in excel and the t-value was found using the equation:

$$\frac{r * \sqrt{DF}}{\sqrt{1 - r^2}}$$

Equation 3-4 t-value using the pearson correlation coefficient

Where r is the Pearson correlation coefficient and DF are degrees of freedom. From the T-value the p-value can be found using the TDIST command in excel.

3.5. Particle size analyses – Coulter counter

A Beckman Multisizer 4e coulter counter was used for examination of the particle size distribution of 2 representative events. The main inlet before the facility gully pot was examined (P1) in addition to the inlet to the middle pipe (P2-2) and the outlet from the middle pipe (P5-2). Some samples were first run on an aperture size of 1000 µm. This created a distribution of particles from 100 µm to 600 µm. When each sampling location showed all particles were below 100 µm the aperture was changed to 100 µm. This provides a distribution for particles between 2 µm and 60 µm. This aperture was used for both event sets.

3.6. Analytical and statistical methods

For analysis of turbidity/TSS data, the method for determining concentration by EMC and SMC was retrieved from Hvitved-Jacobsen et al.,(2010). The method for determining FWMC was retrieved from Heidelberg College, (2005) and Hvitved-Jacobsen et al., (2010). Graphical presentations and tables were created in Microsoft excel.

For calculations and evaluation of data, Excel and its integrated formulas was used. For t-tests in exploratory testing between the three pipes, the “Analysis Toolpak” add-in for excel was added and used. The t-test was chosen as a two-sample assuming unequal variances.

3.7. Precipitation reporting

A precipitation measurer set up at the test facility was meant to be used to estimate flow into the system. This would give millimeters precipitation per square meter per minute. With an accuracy of 0,1 mm. Due to a software issue with the recording device, all data for the test period was lost. Due to this, two alternative precipitation measurers were used. The first one at Stangelandsåna was set up non-ideally on a roof with little wind cover. This measurer was also 4,2 km north of the facility. In addition, metrological institute's measurements from Rovik was used as a comparison. The measurement site at Rovik is 7,2 km northeast of the test facility.

Due to this distance from the facility, and the unknown retention time in the pipes, each event includes the previous hour of precipitation. This is then divided into precipitation per minute. For example: The event is one hour long and reports 3 mm precipitation. The previous hour reports 2 mm. 5 mm is then divided over 120 minutes giving us an average precipitation of 0,042 mm precipitation per minute.

4. Results

4.1. TSS and turbidity correlation

4.1.1. TSS verification

A 200 ml sample was taken from the container and filtered. This was done 30 times to find the mass given below.

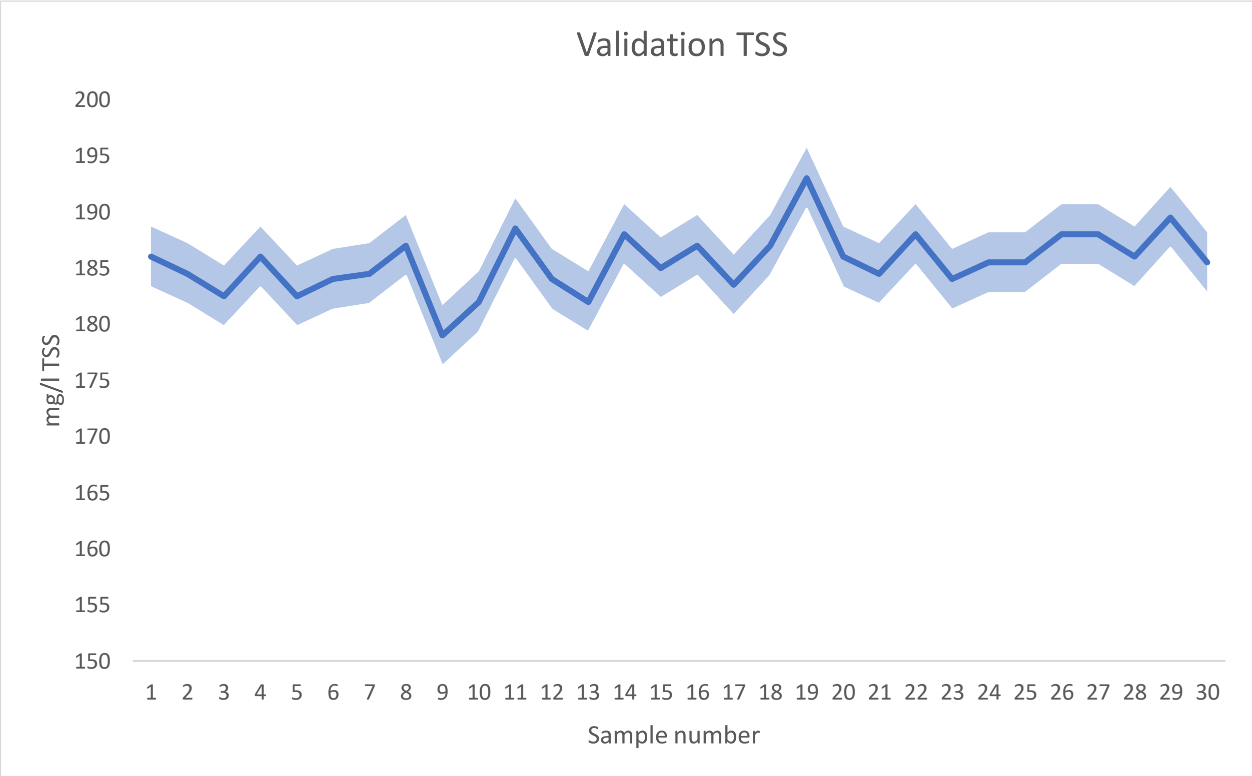

Figure 4-1 TSS (mg/l) from 18.01.2021 inlet sample with standard deviation as error field.

From this data; standard deviation, standard error, and a 95% confidence interval was found.

Table 4-1 Values calculated from TSS validation samples (mg/l)

Mean value TSS	Standard deviation TSS	Standard error	95% confidence interval
185,55	2,71	0,49	0,97

To verify if this deviation is acceptable, the example deviation given by the Standard method 2540D is used as a comparison (Standards methods committee, 1997). They give a deviation of 2,8 mg/l from 50 duplicate samples compared to our deviation of 2,71 mg/l. Several examples of deviations at different concentrations are also given, the most similar concentration to ours show a deviation of 24 mg/l (10%) at a mean concentration of 242 mg/l. These were done on 10 samples.

The confidence interval calculated at 95% shows a deviation of 0,5% and lies between 184,58 and 186,52 mg/l.

4.1.2. Turbidity verification

The samples for turbidity validation was taken from the same container as TSS testing. The instrument reports the values as nephelometric turbidity units (NTU).

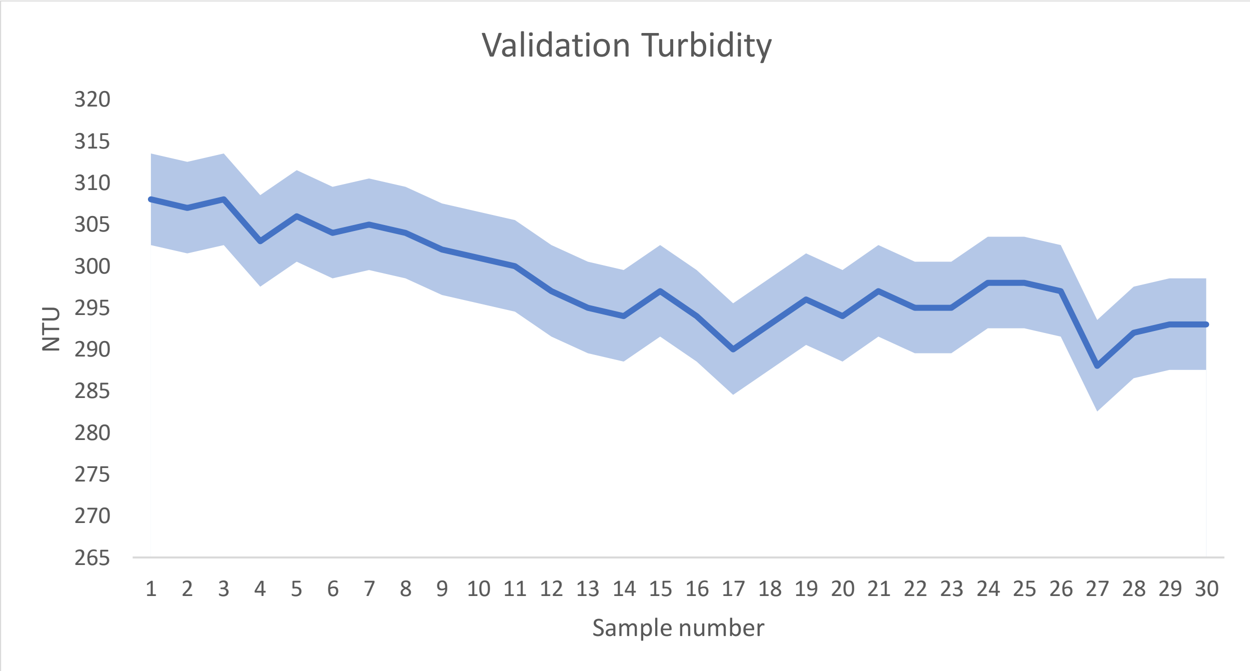

Figure 4-2 Turbidity (NTU) from 18.01.2021 inlet sample with standard deviation as error field.

From this data standard deviation, Standard error, and a 95% confidence interval was found.

Table 4-2 Values calculated from turbidity validation samples (NTU)

Mean value turbidity	Standard deviation turbidity	Standard error	95% confidence interval
298,13	5,50	1,00	1,97

The standards method 2130 (American Public Health Association, 2017) and other procedure sheets such as the Hach methods sheet 8195 (Hach company, 1999) both show the following result report sheet:

Table 4-3 Turbidity reporting. (American Public Health Association, 2017)

NTU	Report to nearest:
0,0 – 1,0	0,05
1 – 10	0,1
10 - 40	1
40 - 100	5
100 - 400	10
400 - 1000	50
>1000	100

This is used due to uncertainties shown in turbidity measurements at larger concentrations.

Using this reporting the following values can be calculated:

Table 4-4 values calculated from turbidity validation samples and reported according to table 4-3 (NTU)

Mean value turbidity	Standard deviation turbidity	Standard error	95% confidence interval
300	6,8	1,2	2,4

An example of a reported standard deviation was found in the Hach method 8195 sheet. This shows a standard deviation 2,31% from a sample containing 26 NTU. Our deviation from Table 4-4 shows a standard deviation of 2,27%. It is important to note that the compared test contained 26 NTU in relation to our mean of 300 NTU.

With a 95% confidence interval we have a deviation of 0,82% from the mean with a value between 297,6 NTU and 302,4 NTU.

4.1.3. Correlation

Both the TSS test method and turbidity method are seen as usable methods from the data collected. And they can further be used to show correlation between the methods so one can be used to estimate the other.

Samples from the collection jug were taken and increasingly diluted. These dilutions were first turbidity measured, then TSS. The dilutions tested were: 1:1, 1:2, 1:4, 1:8, 1:16, 1:32, 1:64 and 1:128.

Figure 4-3 shows the correlation between these TSS and turbidity measurements. The Pearson correlation coefficient (r) was calculated using the PEARSON command in excel. The t-value and p-value (using the excel command TDIST) was also calculated and is presented in Table 4-5.

Table 4-5 calculated correlation values for NTU vs TSS correlation test

Pearson correlation coefficient (r)	t-value	p-value	R^2
0,997867585 ≈ 1	30,58	$6{,}81 \cdot 10^{-6}$	0,9957 ≈ 1

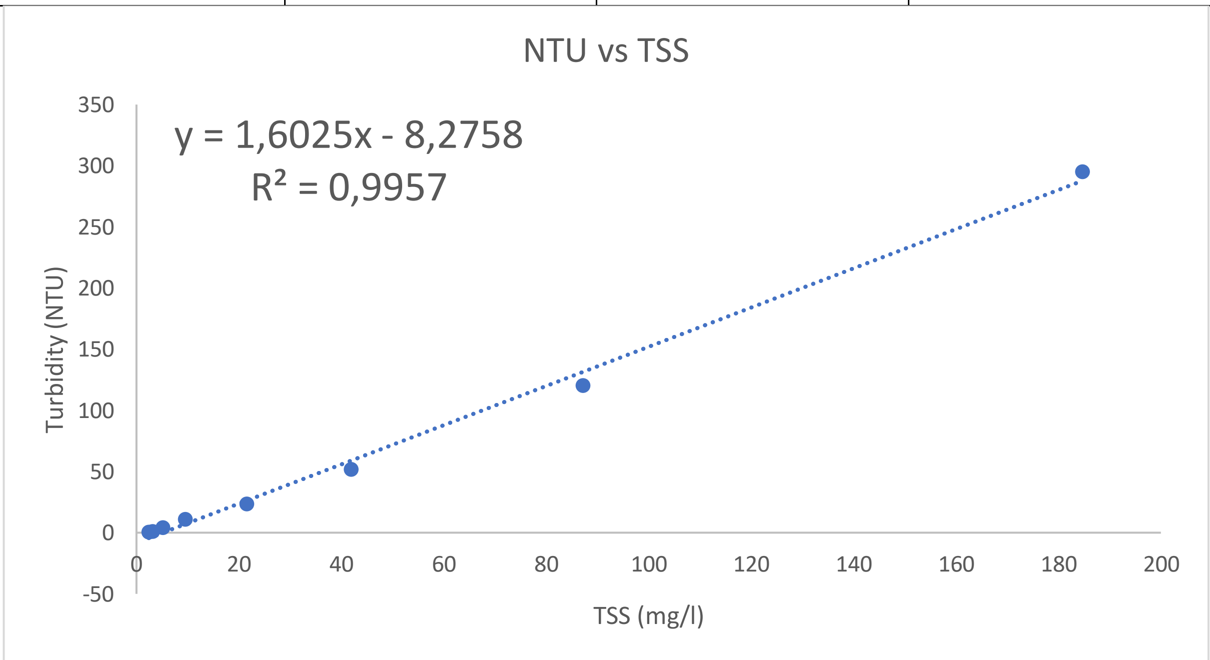

Figure 4-3 Correlation plot between TSS and turbidity on increasing dilutions.

The graph shows a strong correlation between the methods (r ≈ 1) and with little spread (R^2 ≈ 1)

As presented in section 2.3.3.1, the null hypothesis assumes that there is no relationship between the data obtained and the variable examined. The p-value assumes the null hypothesis is true and provides a probability that the data obtained is possible if the null hypothesis is true. The smaller the p-value is, the larger the evidence against the null hypothesis. The common limit for rejecting the null hypothesis is a p-value below 0.05 or 0.01 if strong evidence is required. This translates to the null hypothesis being true in 5% and 1% of cases respectively. (Moore et al., 2014)

Our data shows a p-value of $6{,}81 \cdot 10^{-6}$ which is ≈ 0,000007% of cases where the null hypothesis could be true. A value well below the limits for rejecting the null hypothesis.

It is critical to remind that the TSS measurement done in the lab for the correlation study was performed using a 1 µm filter. Any particles below 1 µm are therefore not considered.

4.2. First flush results

The measurement made on the 18.01.2021 was made between 10.14 and 11.54. From 10 to 11 am the reported precipitation by Yr was 4.2 mm. This precipitation is used as an estimate for the flow to the facility. The amount is calculated using the given runoff area of 13485 m^2.

Table 4-6 Precipitation history from 18.01.2021 for Rovik measurement station - Sandnes. (Metrologisk institutt, 2021)

Mandag 18. januar

Tid	Vær	Min. temp.	Maks temp.	Målt temp.	Nedbør mm	Snødybde cm	Vind m/s	Kraftigste vindkast m/s	Luftfuktighet
01	–	–	–	2,4°	0,0	–	–	–	–
02	–	–	–	2,4°	0,1	–	–	–	–
03	–	–	–	2,5°	0,1	–	–	–	–
04	–	–	–	2,5°	0,0	–	–	–	–
05	–	–	–	2,3°	0,0	–	–	–	–
06	–	–	–	3,0°	0,0	–	–	–	–
07	–	–	–	3,5°	0,0	–	–	–	–
08	–	–	–	3,7°	0,0	–	–	–	–
09	–	–	–	3,0°	0,7	–	–	–	–
10	–	–	–	2,0°	4,2	–	–	–	–
11	–	–	–	2,5°	0,8	–	–	–	–
12	–	–	–	3,1°	0,0	–	–	–	–
13	–	–	–	2,9°	0,3	–	–	–	–
14	–	–	–	3,0°	0,0	–	–	–	–
15	–	–	–	3,1°	0,2	–	–	–	–
16	–	–	–	2,3°	0,4	–	–	–	–
17	–	–	–	2,5°	0,0	–	–	–	–
18	–	–	–	2,1°	0,0	–	–	–	–
19	–	–	–	2,4°	0,5	–	–	–	–
20	–	–	–	2,1°	0,1	–	–	–	–

over an hour the precipitation gives us $4{,}2\ \frac{L/m^2}{hour} * 13485\ m^2 = 56\ 637\ L/$h

we divide this by 60 since the instrument was set to make a measurement every minute:
$\frac{56637\ l/h}{60} = 944\ l/m$

our instrument was set up in front of the inlet to one of the 3 pipes: $\frac{944\ l/m}{3} = 315\frac{l}{min} = 0{,}315\ m^3/min$

We further use this estimation as an average input flow since a continuous flow measurement was not available. Another rainfall measurer was available at Stangelandsåna but the timestamps for precipitation in this measurer did not match with when flow was observed at the test facility for the first flush event.

In accordance to the equations presented in the theory section on First flush**,** a mass (M) versus volume (V) curve is created. This curve is made using NTU data for the inlet on 18.01.2021 and a flow estimation explained above. The NTU data is transformed to mg/l TSS using the correlation study presented in the Correlation results section**.**

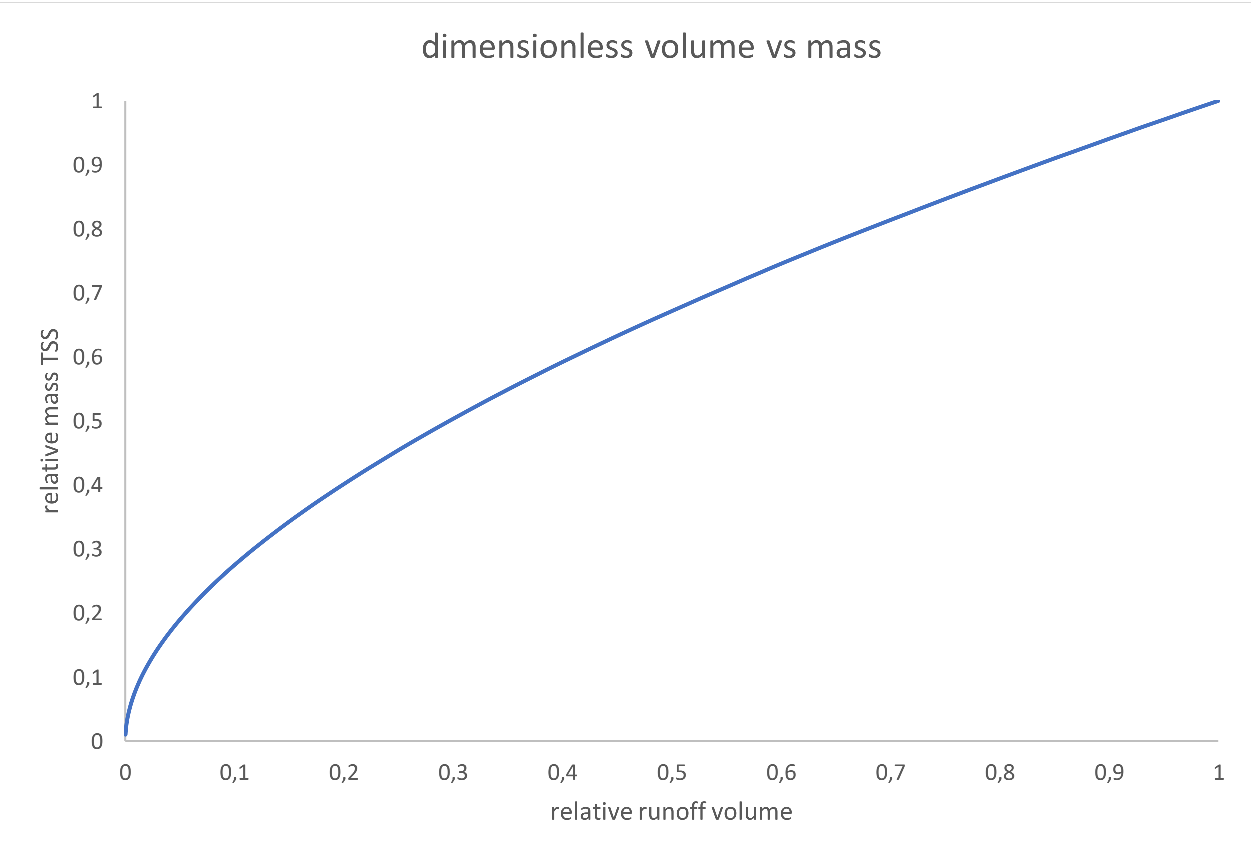

Figure 4-4 Dimensionless Mass(M)Volume(V) curve from fv.505 inlet data 18.01.2021

According (Hvitved-Jacobsen et al., 2010), a first flush event is present if m in Equation 2-3 is <1.

For Figure 4-4 $m = 0{,}98$. This is below 1, but only barely. This is found using the CORREL command in excel.

The second definition presented by Hvitved-Jacobsen et al., (2010) states a first flush event is present if the initial slope of the M(V) curve is larger than 45° (Geiger, 1987). Figure 4-5 presents the initial slope of our data on 18.01.2021 vs a 45° line. The figure shows the initial slope is larger than 45°. This line is based on the initial 20 measurements.

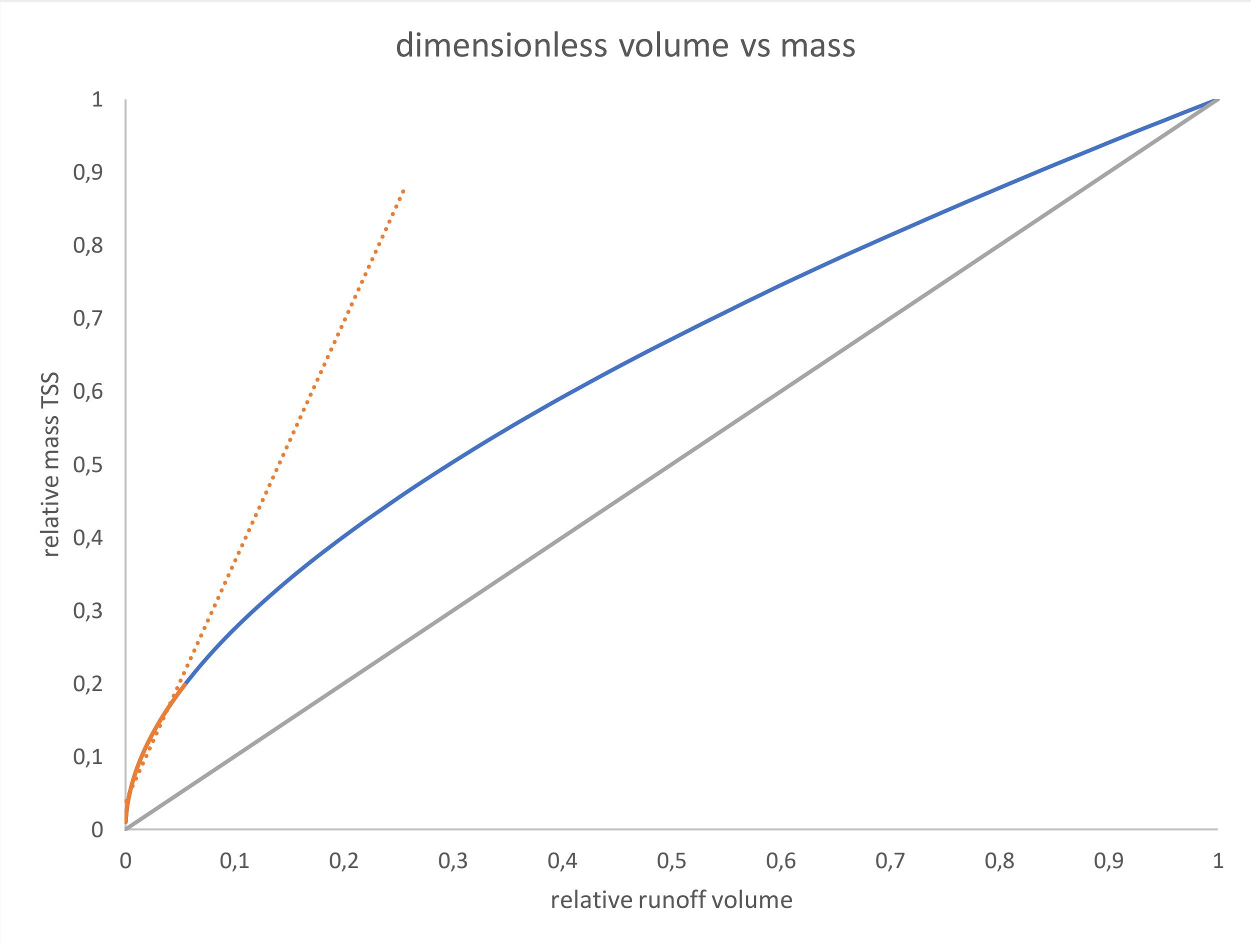

Figure 4-5 Dimensionless M(V) curve depicting initial slope of the curve against a 45° line.

The third definition states that a first flush is present when 80% of the total mass is present in the first 30% of the volume (Saget et al., 1996). Since our volume is based on precipitation data and the flow is set to be even across the event, The first 30% of mass measurements can be divided by the total mass to give us the percentage of mass in the first 30% of volume.

$$\frac{11021{,}08\frac{mg}{l}\,(mass\ in\ first\ 30\%)}{28398{,}04\frac{mg}{l}\,(total\ mass)} = 0{,}39 = 39\%$$

The first 30% of volume runoff contains 39% of the total mass measured.

The fourth definition states the first 20% of the runoff volume should contain a significantly higher mass load than 20% of the total mass load (Deletic, 1998).

The mass of the first 20% volume is found the same way as for the third definition.

$$mass\ first\ 20\%\text{: } 7774{,}43\ mg/l$$

$$mass\ 20\%\ of\ total\text{: } 28398{,}04\frac{mg}{l} * 0{,}2 = 5679{,}6\frac{mg}{l}$$

$$\frac{5679{,}6\frac{mg}{l}}{7774{,}43\frac{mg}{l}} = 0{,}73 = 73\%$$

The first 20% of mass contains 27% more mass than the total average.

Another suspected first flush event was the night of 15.02.2021. This event was measured the same way as 18.01.2021 with exception of the measurements being made over 13 hours and with a measurement made every 6 minutes. This allowed us to also see the decrease in turbidity in addition to increase.

Until 4 am no precipitation is reported, and the turbidimeter shows 0 NTU. Due to varying hourly reported precipitation, and an unknown pipe detention time, a mean l/h is found in the measurement period. (Metrologisk institutt, 2021) from 4 am to 12 am, this is 2 mm.

$2\ \frac{L/m^2}{hour} * 13485\ m^2 = 26\ 970\ L/\text{h}$

we divide this by 10 since the instrument was set to make a measurement every six minutes: $\frac{26970\ l/h}{10} = 2697\frac{l}{6\ min} = (450\ l/min)$

our instrument was set up in front of the inlet to one of the 3 pipes: $\frac{2697\ l/6\ min}{3} =$

$899\frac{l}{6\ min} = 0{,}9\ m^3/6\ min$

Figure 4-6 includes the data from when the first turbidity above 0 was measured during the event. Figure 4-7 shows from when there was a clear increase in the turbidity. Figure 4-6 starts at 04.10 am and Figure 4-7 at 06.22 am.

first definition from Figure 4-6: $m = 0{,}92$

Second definition is presented graphically in Figure 4-6.

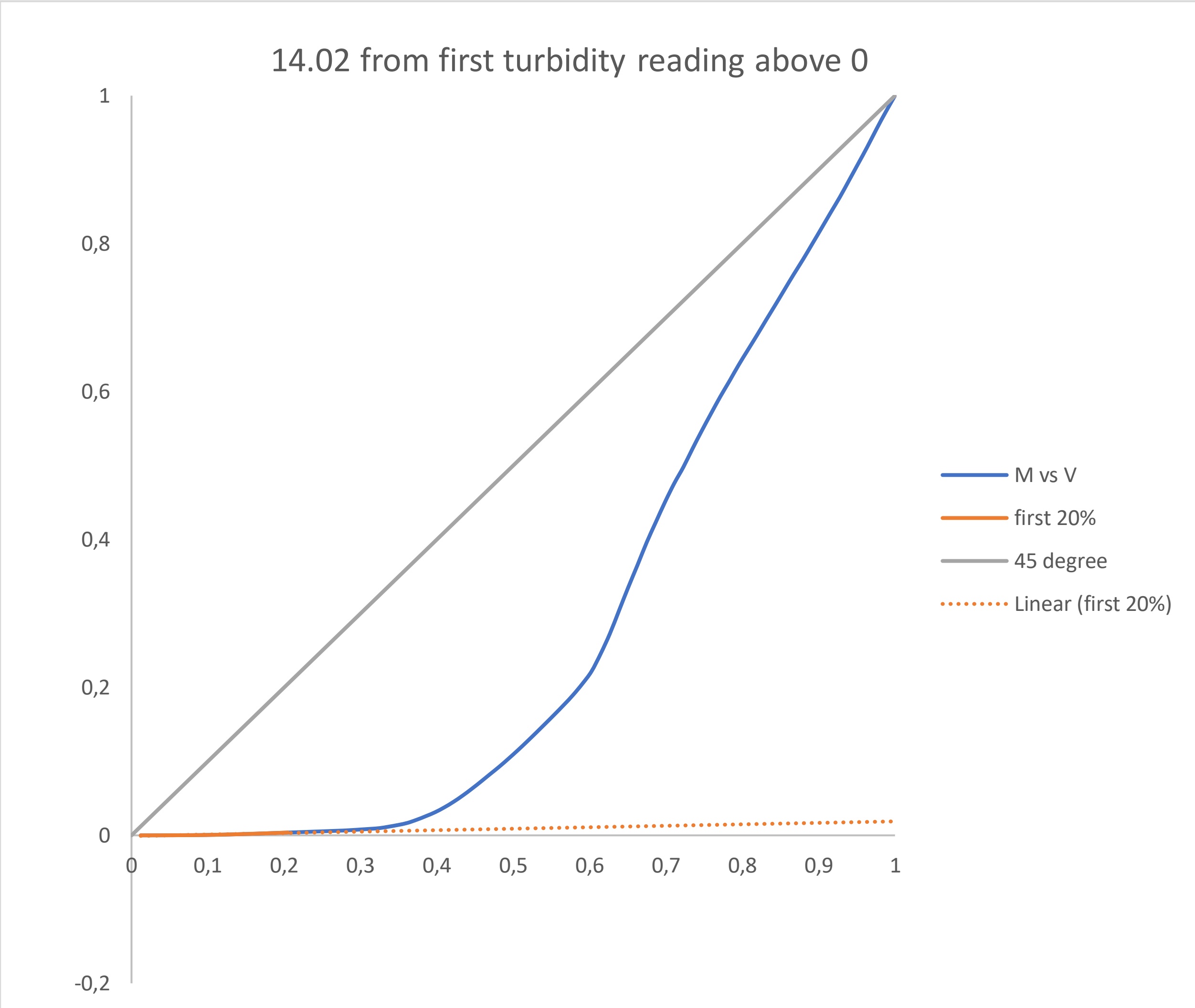

Figure 4-6 Dimensionless M(V) curve from inlet 14.02. depicting curve against a 45-degree line.

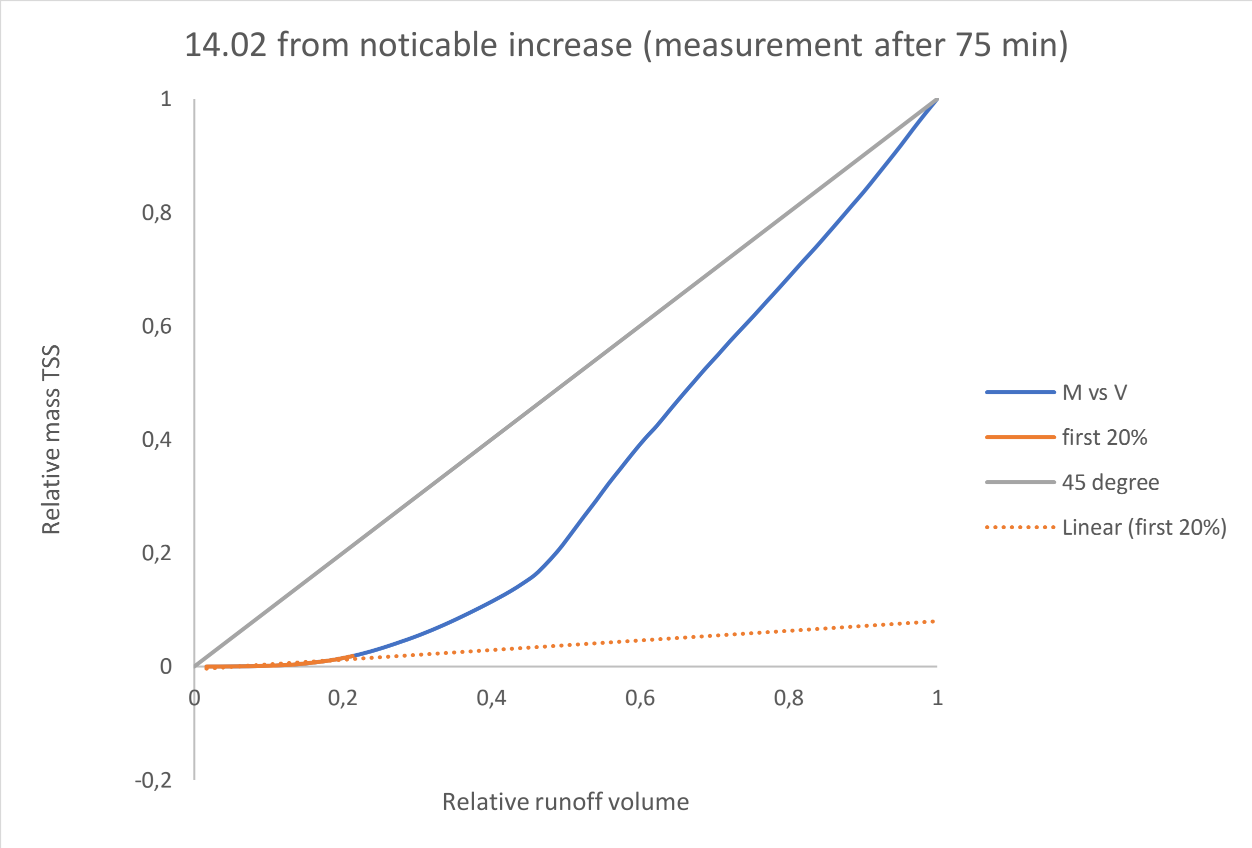

Figure 4-7 Dimensionless M(V) curve from inlet 14.02. depicting curve against a 45-degree line.

third definition from Figure 4-6:

$$\frac{379{,}57\frac{mg}{l}\,(mass\ in\ first\ 30\%)}{557006{,}17\frac{mg}{l}\,(total\ mass)} = 0{,}00068 = 0{,}07\%$$

The first 30% of volume runoff contains 0,07% of the total mass measured.

fourth definition from Figure 4-6:

$$mass\ first\ 20\%\text{: } 248{,}29\ mg/l$$

$$mass\ 20\%\ of\ total\text{: } 557006{,}17\frac{mg}{l} * 0{,}2 = 111\ 401{,}23\frac{mg}{l}$$

$$\frac{111\ 401{,}23\frac{mg}{l}}{248{,}29\frac{mg}{l}} = 448{,}67 = 44\ 867\%$$

20% of the total mass is 44 867% higher than the mass in the first 20% of the flush.

first definition from Figure 4-7: $m = 0{,}97$

second definition is presented graphically in figure 4-7.

third definition from Figure 4-7:

$$\frac{2516{,}16\frac{mg}{l}\,(mass\ in\ first\ 30\%)}{557006{,}17\frac{mg}{l}\,(total\ mass)} = 0{,}005 = 0{,}45\%$$

The first 30% of volume runoff contains 0,45% of the total mass measured.

fourth definition from Figure 4-7:

$$mass\ first\ 20\%\colon 1134{,}78\ mg/l$$

$$mass\ 20\%\ of\ total\colon 557006{,}17\frac{mg}{l} * 0{,}2 = 111\ 401{,}23\frac{mg}{l}$$

$$\frac{111\ 401{,}23\frac{mg}{l}}{1134{,}78\frac{mg}{l}} = 98{,}17 = 9\ 817\%$$

20% of the total mass is 9 817% higher than the mass in the first 20% of the flush.

4.3. Fv.505 pilot facility

4.3.1. Inlet

The suspended solids removal rate of the sedimentation facility has been measured using turbidity measurements. There are many ways to visualize the data and determine the efficiency of the facility. In this thesis, mainly the mean concentration for an event (EMC) is used when presenting the turbidity throughout an event. This is done since the length of each event varies and the measurement period varies. Giving each measurement the same weight could therefore skew the results in favor of the longer events. To examine this, the total median is also examined. Sections where all measurements are used (such as histograms) it is noted that these results use all measurements.

The data is presented in several ways to show the variation in determining efficiency. The mean of each event and the site-mean concentration (SMC) is presented for both inlet and outlet. Further, the flow-weighted mean concentration is also calculated for inlet and outlet. This uses the flow estimates from both Stangelandsåna and Rovik (Metrologisk institutt,

2021) to generate a concentration that takes any high or low flow into account. This way, any dilution due to higher precipitation, or up-concentration due to low precipitation, is considered.

The extreme observations from the inlet and outlet is also presented, in addition to total median and histograms of all measurements. For inlet, measurements were also made on 20.02.2021 but a review of the data collected saw that the instrument was either placed wrong or there were no flow present. This data is therefore not included.

It is important to note the validation study done of the measurement instrument showed a standard deviation of 2.28%.

4.3.1.1. Flow estimation

Flow estimation was made by collecting precipitation data from Stangelandsåna and Rovik, taking the average precipitation for the measurement period then dividing it to estimate the amount flowed between each measurement. Due to the distance of the measurers to facility and the use of precipitation data, the rainfall the hour before measurement start is also included in the average for the event. The extra 60 min is included when the volume is divided over the measurement period.

Table 4-7 Precipitation data inlet measurement periods gathered from YR.no (Metrologisk institutt, 2021)

characteristics	18.01	21.01	15.feb	18.02	19.02	23-24.02	24.02	09.05
Precipitation per hour (mm)	0,7-4,2	0-2	0-0,8	0-0,9	1,2-1,5	0-3,6	0,1-0,4	0,4-1,9
Precipitation average (mm/h)	1,9	1,7	0,21	0,65	1,35	1,59	0,25	1,225
Measurement time (hours)	1,67	0,55	5,9	0,47	0,25	14,4	0,33	3,25
Average return period (2018-2021)	33 days	22 days	7 days	7 days	15 days	18 days	7 days	15 days

Table 4-7 presents the precipitation for the measurement periods and the length of these events. It also includes the rarity of the events compared to events at Rovik from 2018 to 2021. An event in this case has at least 0.2 mm precipitation and requires a separation time of minimum 6 hours. This was found using a statistical analysis provided by the SWMM program.

4.3.1.1.1. SWMM

Using the known precipitation area size and historical precipitation data from Rovik, The SWMM program was used to create a simple runoff model. (used map providing overview of pipes, and infiltration sites not available to view due to copyright (L. Møller-Pedersen, personal communication, February 1, 2021)) The program was used to perform a statistical analysis of average runoff volume to compare to our estimated volume.

Table 4-8 Statistical inflow report from SWMM

Object	System
Variable	Total Inflow (CMS)
Event Period	Variable
Event Statistic	Mean (CMS)
Event Threshold	Total Inflow > 0.0010 (CMS)
Event Threshold	Event Volume > 0.0010 (m3)
Event Threshold	Separation Time >= 6.0 (hr)
Period of Record	01/01/2018 to 01/01/2021
Number of Events	497
Event Frequency*	0.138
Minimum Value	0.001
Maximum Value	0.016
Mean Value	**0.003**
Std. Deviation	0.002
Skewness Coeff	2.658

*Fraction of all reporting periods belonging to an event.

Table 4-9 Estimated cubic meter per second flow per event

date	CM/S SÅ	CM/S YR
18.01	0,004	0,008
21.01	0,002	0,004
15.02	0,0001	0,0007
18.02	0,0013	0,0010
19.02	0,006	0,006
23-24.02	0,005	0,006
24.02	0,0008	0,0008
09.05	unavailable	0,0011
	Average CMS SÅ	Average CMS YR
	0,002712	**0,003848**

(SÅ refers to Stangelandsåna and YR to Rovik)

The average flow for our events shows 0,0027 CM/s and 0,0038 CM/s compared to the 0,003 CM/s average for events in 2018-2021.

4.3.1.2. Turbidity

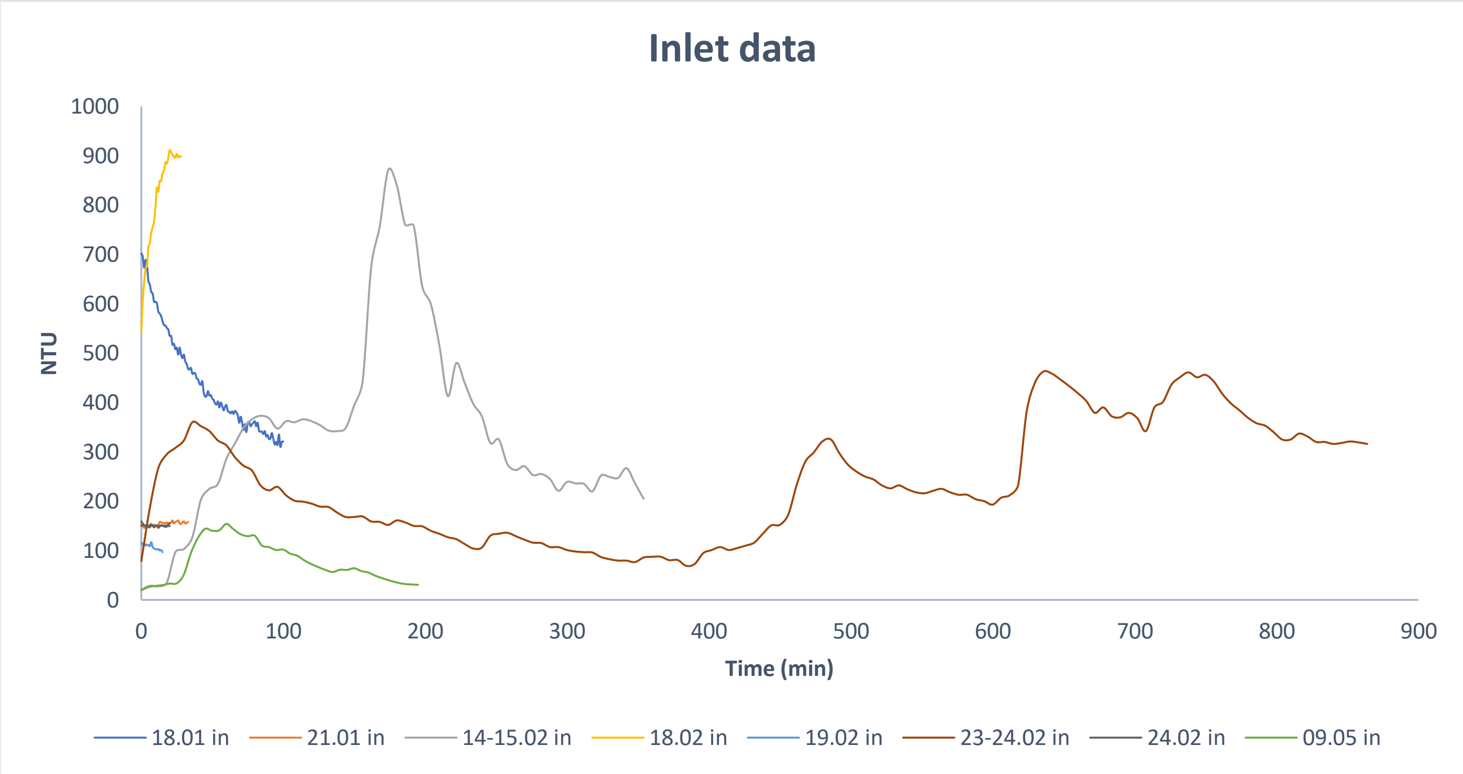

Figure 4-8 graphical representation all inlet events

On 18.01 and 18.02 the measurements included snow melting and significant periods before with little rainfall.

There was originally sampled 9 events for inlet. 20.02.2021 was chosen to be removed as it showed an unexpected low turbidity. It is believed the sampling either happened before adequate flow was present, or the instrument was placed wrong.

From the Correlation study performed, a correlation between NTU on the instrument and mg/l TSS was found to be:

Equation 4-1 Conversion rate NTU - mg/l

$$x\frac{mg}{l} = (y\ NTU + 8{,}2758)/1{,}6025$$

Table 4-10 All inlet measurements. Divided by each event. Mean and median reported according to standard

characteristics	18.01	21.01	15.feb	18.02	19.02	23-24.02	24.02	09.05
extreme (NTU)	702	161	871	911	117	461	159	154
mean (NTU)	450	150	340	800	110	240	150	75
Turbidity (NTU)	310-702	146-161	20,7-871	524-911	96,6-117	69-461	146-159	18,1
median (NTU)	400	160	320	850	110	220	150	60
SD for mean (NTU)	104,94	4,10	191,69	105,01	6,22	115,53	3,09	41,27

Using the conversion rate, we can convert the NTU results to mg/l TSS.

Table 4-11 Inlet measurements. Divided by each event. mg/l TSS

characteristics	18.01	21.01	15.02	18.02	19.02	23-24.02	24.02	09.05
extreme (mg/l)	443,2	105,6	548,7	573,7	78,2	292,8	104,4	101,3
mean (mg/l)	286,0	98,8	217,3	504,4	73,8	154,9	98,8	52,0
Turbidity (mg/l)	198,6-443,2	96,3-105,6	18,1-548,7	332,2-573,7	65,4-78,2	48,2-292,8	96,3-104,4	17,3-101,3
median (mg/l)	254,8	105,0	204,9	535,6	73,8	142,4	98,8	42,6
SD (mg/l)	70,6	below 4	124,8	70,7	below 6	77,3	below 3	30,9

(The conversion rate becomes inaccurate for values below 8,3, these values are therefore reported as: below y NTU.)

The mean of the extreme measurements was found. In addition, SMC from EMCs was found. The median value from all samples is calculated and presented as an alternative to the SMC. Reasoning for this is presented in Discussion. Also, as a comparison to the SMC, the flow-weighted mean concentration is found (FWMC). This considers the estimated flow during the events.

Table 4-12 extreme, SMC, SD, total median and FWMC for test facility inlet

mean of extremes (NTU)	mean of means (SMC) (NTU)	standard deviation (NTU)	median of all samples (NTU)	FWMC SÅ (NTU)	FWMC YR (NTU)
442	289,375	244,1365	267	256,3591	258,9634
mg/l extreme	mg/l mean (SMC)	mg/l SD	median of all samples (mg/l)	FWMC SÅ (mg/L)	FWMC YR (mg/l)
280,9833385	185,7415	157,5116	171,779	165,1388	166,7639

4.3.1.3. Outlet

For outlet there was made 5 event measurements. As will be covered in discussion, these measurements were not seen as necessary to take at the same time, or exactly after inlet measurements due to the detention time in the system.

4.3.1.3.1. Flow

A flow estimation was also made for the outlet from precipitation data during the measurement period.

Table 4-13 Precipitation data outlet measurement periods gathered from YR.no (Metrologisk institutt, 2021)

characteristics	18.01	21.01	18-19.02	20.02	24.02
precipitation per hour (mm)	0,0-0,8	0,1-2,0	0,0-3,2	0,6-2,1	0,1-2,0
precipitation average (mm/h)	0,37	0,6	0,61	1,57	1,1
measurement time (hours)	1,2	0,5	13,17	12,33	6,33
return period (2018-2021)	7 days	7 days	7 days	18 days	11 days

Table 4-14 Estimated cubic meter per second flow per event on outlet

CM/s SÅ	CM/s YR
0,00000	0,00117
0,00175	0,00300
0,00156	0,00175
0,00539	0,00587
0,00398	0,00444
Average CM/s SÅ	Average CM/s YR
0,00254	0,00325

Table 4-14 shows an average of ca 0,0025/ 0,0033 cubic meter per second for outlet measurements compared to the 2018-2021 average of 0,003 cubic meter/s.

4.3.1.3.2. Turbidity

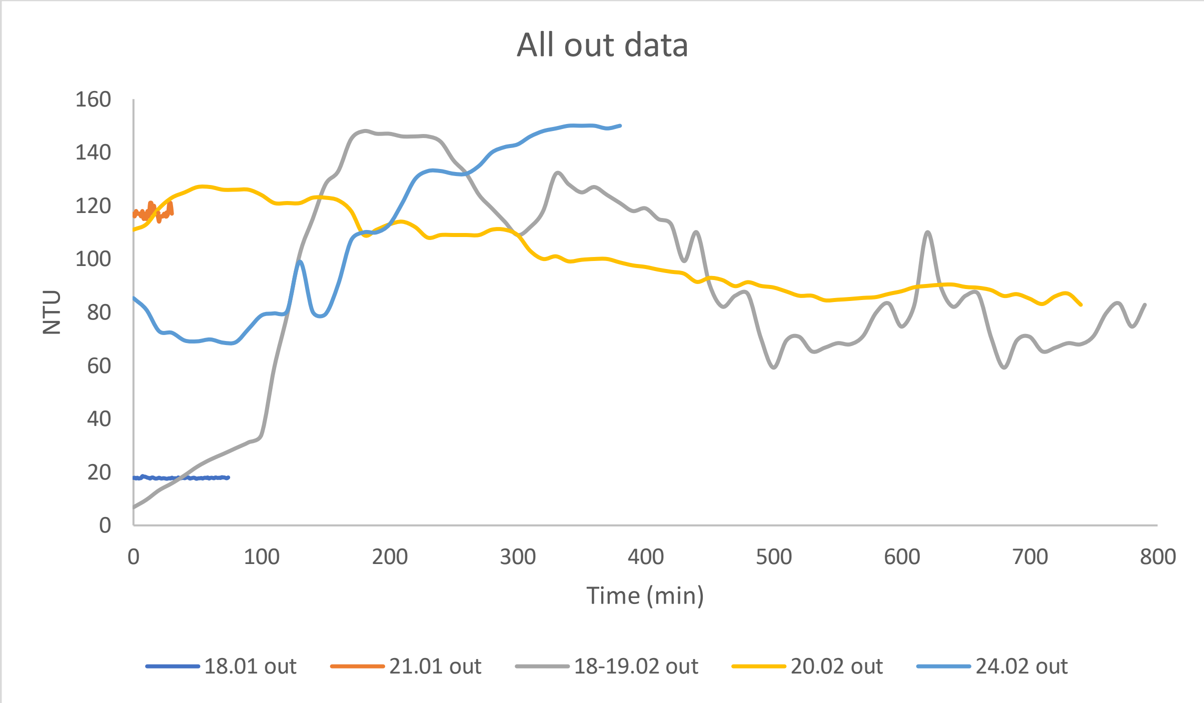

Figure 4-9 Graphical representation of out data. Divided by events

Figure 4-9 and Figure 4-10 shows all outlet samples. A representation without 18.01 and with a later measurement on 18-19.02 was included since on both these dates measurements were started on the first flow after longer dry periods. On 18.01 the previous significant rainfall event was 27.12.2020. On 18.02 the previous significant rainfall was 22.01/23.01. A separate representation was included since the flow from the outlet on these days would have been in the system for quite a while, and not necessarily be representative.

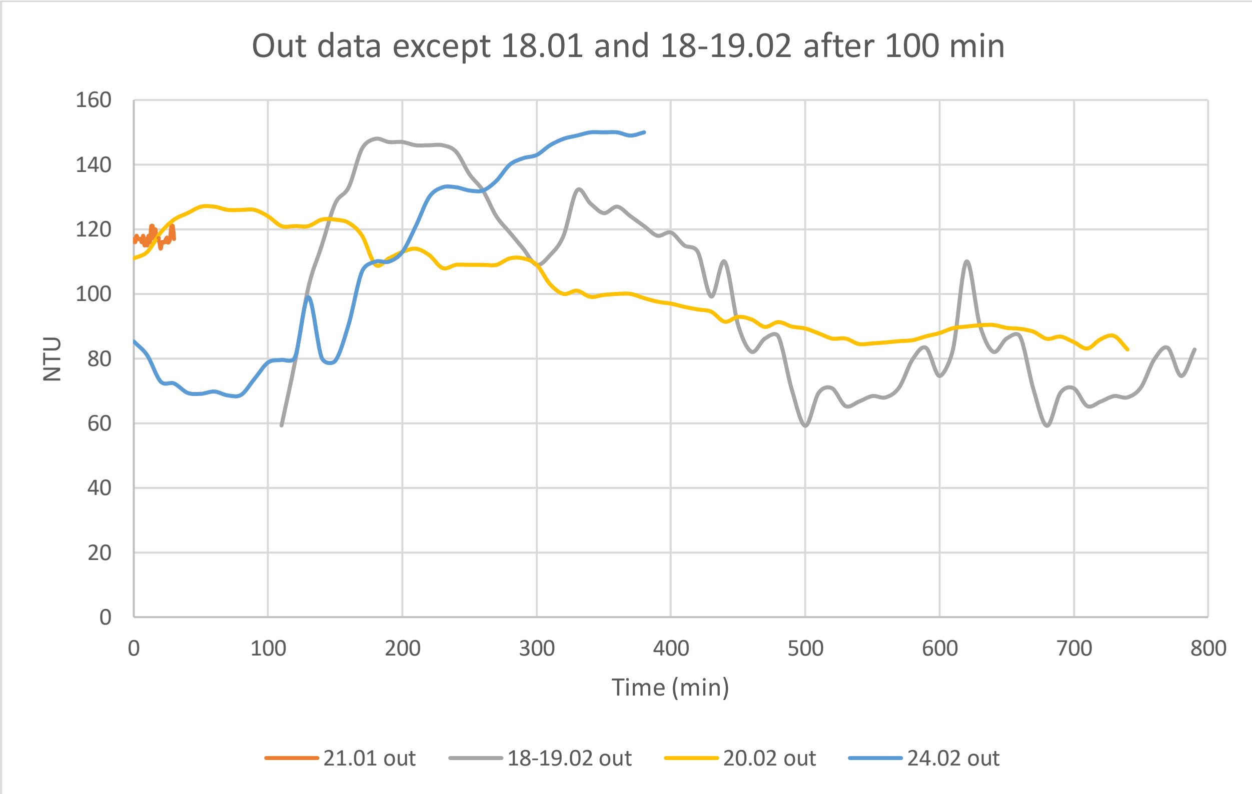

Figure 4-10 Graphical representation of out data without 18.01 and 18/19.02 after 100m min

Table 4-15 All outlet measurements. Divided by each event. Mean and median reported to standard.

characteristics	18.01	21.01	18-19.02	20.02	24.02
extreme (NTU)	18,5	121	148	127	150
mean (NTU)	18	120	90	100	110
Turbidity (NTU)	17,6-18,5	114-121	6,8-148	82,8-127	68,6-150
median (NTU)	18	120	80	100	110
SD of mean (NTU)	0,19	1,83	37,85	14,33	31,37

The NTU readings are then converted to mg/l TSS in the same way as for the inlet.

Table 4-16 All outlet readings. Divided by each event. mg/l TSS

characteristics	18.01	21.01	18-19.02	20.02	24.02
extreme (mg/l)	16,7	80,7	97,5	84,4	98,8
mean (mg/l)	16,4	80,0	61,3	67,6	73,8
Turbidity (mg/l)	16,1-16,7	76,3-80,7	<6,8-97,1	56,8-84,4	48,0-98,8
median (mg/l)	16,4	80,0	55,1	67,6	73,8
SD (mg/l)	Below 1	below 2	28,8	14,1	24,7

Table 4-17 extreme, SMC, SD, median and FWMC for test facility outlet

mean of extremes (NTU)	mean of means (SMC) NTU)	standard deviation (NTU)	median of all samples (NTU)	FWMC SÅ (NTU)	FWMC YR (NTU)
112,9	87,6	40,16006	87,4	101,3416309	100,5267
mg/l extreme	mg/l mean (SMC)	mg/l SD	median of all samples (mg/l)	FWMC SÅ (mg/L)	FWMC YR (mg/l)
75,61672	59,8289	30,22518	59,70409	68,40401305	67,8955

Table 4-18 extreme, SMC, SD, median and FWMC for test facility outlet without 18.01 and 18-19.02 after 100 min

mean of extremes (NTU)	mean of means (SMC) (NTU)	standard deviation (NTU)	median of all samples (NTU)	FWMC SÅ (NTU)	FWMC YR (NTU)
136,5	107,5	8,206306	109	103,2825345	103,2582
mg/l extreme	mg/l mean (SMC)	mg/l SD	median of all samples (mg/l)	FWMC SÅ (mg/L)	FWMC YR (mg/l)
90,34371	72,2470	10,28525	73,18303	69,61518534	69,60002

4.3.2. Comparison

Table 4-19 Inlet and outlet SMC, SD, extremes, total median and FWMC fv505 facility

Graph IN	**SMC (mg/l)**	**Standard Deviation SMC (mg/l)**	**Mean of extremes (mg/l)**	**Median (mg/l)**	**FWMC (mg/l) SÅ**	**FWMC (mg/l) YR**
All readings	185,7415	157,51	280,98	171,78	165,14	166,76
Graph OUT	**SMC (mg/l)**	**Standard Deviation SMC (mg/l)**	**Mean of extremes (mg/l)**	**Median (mg/l)**	**FWMC (mg/l) SÅ**	**FWMC (mg/l) YR**
All readings	59,8289	30,23	75,62	59,7	68,40	67,90
Without 18.01 and 19.02 after 100min	72,2470	10,29	90,34	73,18	69,62	69,60

Table 4-20 Removal efficiency fv505 facility

Removal efficiency	**SMC**	**Mean of extremes**	**Median**	**FWMC SÅ**	**FWMC YR**
From all to all	68 %	73 %	65 %	59 %	59 %
From all to without 18.01 and 19.02 after 100min	61 %	68 %	57 %	58 %	58 %

Table 4-20 shows the removal efficiency of the sedimentation facility at fv505. The removal efficiency does not include the gully pot before the sedimentation pipes. The given removal efficiency is only for the sedimentation pipes. The median value represented is the median value of all readings taken.

4.3.2.1.1. Histograms

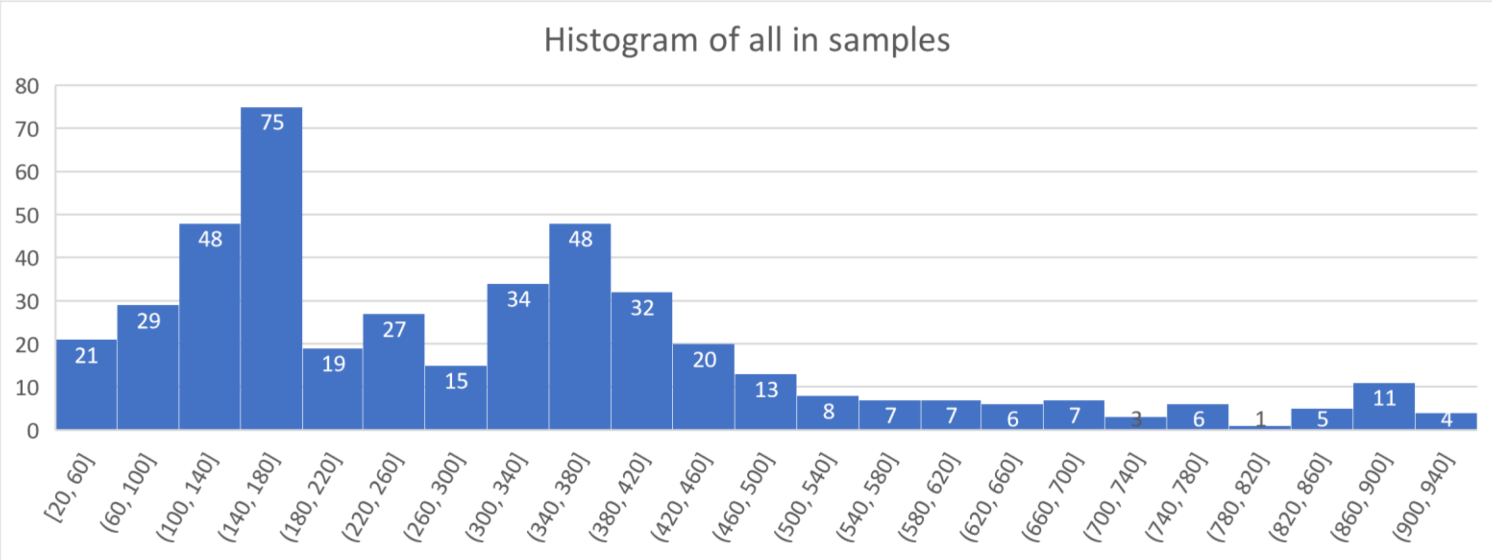

Figure 4-11 Histogram showing NTU value of all IN samples

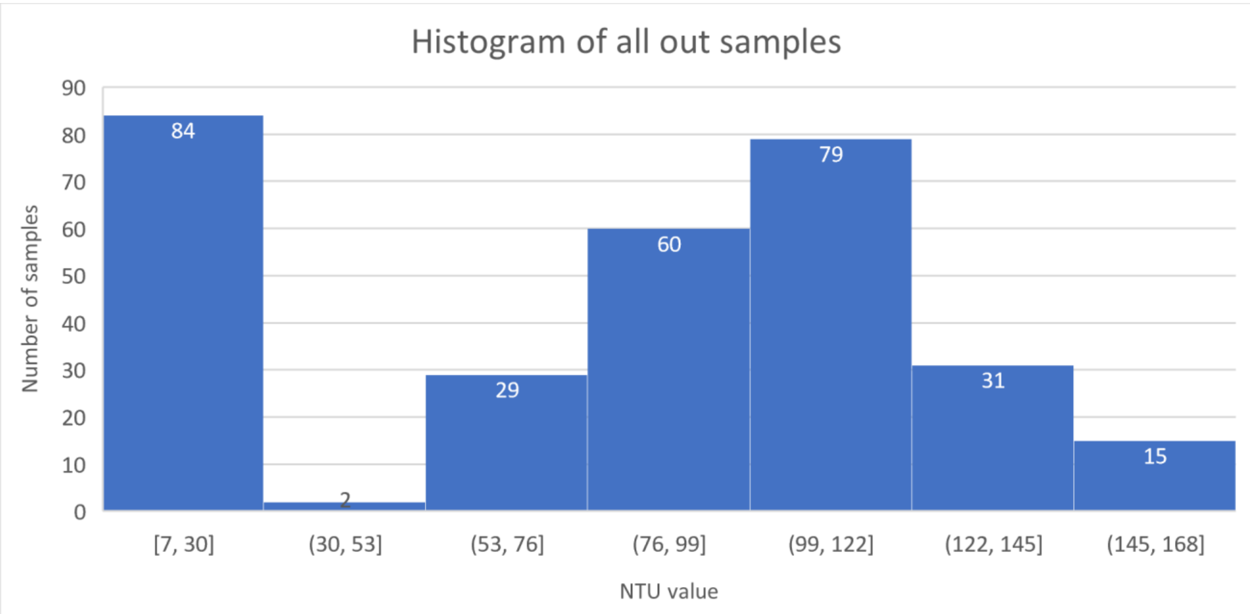

Figure 4-12 Histogram showing NTU value of all OUT samples

Figure 4-11 and Figure 4-12, although they differ in number of samples, demonstrates the large variance in concentration in the inlet, where samples vary all the way from 21 to 940, compared to the outlet, where it varies from 7 to 168 NTU. It also demonstrates where the peak values are present. In the inlet, number of samples are highest around 140-180 NTU and 340-380 NTU. In the outlet, the highest number of samples lie around 7-30 NTU and 99-122 NTU.

As we see in the histograms, the sedimentation facility also functions as a retention basin to even out the concentration of the runoff. This means the recipient avoids any flushes of high concentration.

4.3.3. Conductivity

From conductivity measurement, the instrument used will calculate salinity and total dissolved solids (TDS). Following is an overview of conductivity, TDS and, including any reduction from inlet to outlet.

Table 4-21 Conductivity, TDS, and salinity data

Characteristics	SMC	median	extreme
IN Conductivity(mS/cm)	4,90	0,36	20,48
IN TDS (g/L)	3,05	0,23	12,64
IN Salinity (ppt)	2,66	0,20	11,44
OUT Conductivity (mS/cm)	2,80	3,22	6,17
OUT TDS (g/L)	1,78	2,06	3,89
OUT Salinity (ppt)	1,43	1,60	3,20

Table 4-22 Percentage reduction from inlet to outlet of conductivity, TDS and salinity

Reduction percentage	SMC	median	extreme
Conductivity	43 %	-806 %	70 %
TDS	42 %	-792 %	69 %
Salinity	46 %	-700 %	72 %

Table 4-23 shows the event-mean concentration for each parameter presented in Table 4-21 and Table 4-22. This is included to show the variance in values between events.

Table 4-23 EMC of conductivity, TDS and salinity for all events

EMC IN	Conductivity (mS/cm)	TDS (g/L)	Salinity (ppt)
18.01	7,44	4,69	3,83
21.01	0,24	0,15	0,10
14-15.02	20,48	12,64	11,44
18.02	5,52	3,48	2,82
19.02	0,35	0,23	0,20
23-24.02	0,17	0,11	0,11
24.02	0,13	0,09	0,10
EMC OUT			
18.01	5,99	3,77	3,13
21.01	2,17	1,39	1,10
18.-19.02	3,26	2,09	1,63
20.02	2,01	1,28	0,98
24.02	0,60	0,38	0,29

4.3.4. pH

pH measurements were taken for each event and the SMC, median and extreme values were found. Any reduction in pH was also calculated.

Table 4-24 pH SMC and median values and reduction percentage from inlet to outlet

Characteristics	SMC	median
IN pH	8,27	8,16
OUT pH	8,44	8,75
reduction percentage	**SMC**	**median**
pH	-2 %	-7 %

No significant difference is observed in pH between inlet and outlet.

4.4. Open wet pond

An open wet-pond sedimentation facility also connected to fv505 was intended to be used as a comparison of treatment efficiency. Due to an issue with the measuring instrument where it was unavailable for 1,5 months, and no access to the inlet during high flow, no usable measurements were taken from the site. From Hvitved-Jacobsen et al., (2010) an example of the average removal efficiency of a wet pond is presented. This pond has a specific surface area of 240 $m^2 ha^{-1}$, an average depth of 1,2 m and a detention capacity of 30 mm precipitation. This example gives a removal efficiency of 84% on TSS. Other investigations on wet ponds under similar rain events have shown that ponds with a specific area larger than 250 $m^2 ha^{-1}$ have not shown a higher removal efficiency than 84% for TSS. (Hvitved-Jacobsen et al., 2010)

The fv505 wet pond with its 430 m^2 surface area and catchment area of 1,6 ha (3.2.2) gives us a specific surface area of 269 $m^2 ha^{-1}$. From Hvitved et al. (2010) we know that the facility is unlikely to have a removal efficiency higher than 84%. This is therefore assumed for wet ponds of this size. This is also likely when viewing the expected removal efficiency from "Statens Vegvesen", (2018) which is 80% TSS removal.

4.5. Gully pot

The treatment facility includes a gully pot before the sedimentation pipes. The samples were taken after the gully pot to focus on and properly examine the efficiency of the sedimentation pipes. There exist a lot of literature on the size removal of gully pots. One source (Butler & Karunaratne, 1995) shows the sedimentation efficiency of different particle sizes. It shows removal efficiency increases with size and nearing 100% for particles around 500 µm. the smallest size measured in the paper was 63-100 µm. They show the smallest removal efficiency in this size, with a removal of 15%. other sources report a fine granular removal of up to 48,3% (Deletic et al., 2000) in analyzed gully pots.

The gully pot before the sedimentation facility is significantly wider and deeper than normal gully pots. The depth of the pot will determine at what bed level the rate of accumulation starts to decrease. A deeper pot will mean a larger amount can sediment before efficiency is affected. The depth of the pot is not found to influence sedimentation efficiency below the bed level depth. The flow patterns are therefore expected to be similar regardless of gully pot depth as long as the gully pot is regularly emptied (Rietveld et al., 2020). Butler & Karunaratne (1995) also determined that little to no re-suspension of solids is present as long as the sediment bed height is below intended design height. The total TSS removal of a gully pot is hard to determine. It is extremely dependent on flow rate and the size of the particles. As presented in section 2.5.3, gully pots have a high removal efficiency of particles above 200 µm and decreases dramatically the smaller the particles are.

4.6. Exploratory testing

Three exploratory tests were performed in addition to the main efficiency analysis. The first part explores the hypothesis that there is a short-circuit from the main inlet to the middle pipe inlet, thus significantly increasing the TSS load compared to the other pipes. The second exploration looks at what effect the differing wall setups can have on TSS and TDS removal.

The left pipe (pipe 1) had to be closed due maintenance so there are 4 events sampled for exploratory testing on this, and 6 events sampled for right pipe (pipe 3) and middle (pipe 2).

The third exploratory sampling was to examine the particle size fractions present at inlet and outlet. This can then be used to examine the efficiency in removing small particles which in turn reflects the facilities ability in removing heavy metals.

4.6.1. Short circuit from main inlet to middle pipe

We assume the null hypothesis, where there is no statistical difference between the samples taken from the different inlet pipes. 3 samples are taken from each inlet pipe at the time of testing. 3 are taken so to reduce the stochastic variable in the sampling. The mean of these 3 is used. Due to sampling only being available when there is precipitation and flow into the system, the number of samples available is limited. Due to this a t-test is performed to test the hypothesis, as opposed to a randomization-based testing. Further the p-value is found to reject or accept the null hypothesis.

Since the pipes are compared between each other, and not between precipitation events, the variance between events needs to be eliminated. This is done by presenting the data as a percentage from the value of the middle pipe at the sample time. The middle pipe has therefore always the value 1.

Two “two-sample t-test” are performed. One comparing left and middle, and one comparing right and middle. The tests are performed with a significance level of 0,05 and 0,1. A t-test assuming unequal variances is used due to the natural variances in stormwater measurements.

Table 4-25 turbidity t-test for left inlet (P2-1) compared to middle inlet (P2-2)

t-Test: Two-Sample Assuming Unequal Variances		
	left (P2-1)	*middle (P2-2)*
Mean	1,0199405	1
Variance	0,0075996	0
Observations	4	4
Hypothesized Mean Difference	0	
df	3	
t Stat	0,4574791	
P(T<=t) one-tail	0,3392122	
t Critical one-tail	2,3533634	
P(T<=t) two-tail	0,6784243	
t Critical two-tail	3,1824463	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	FALSE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Table 4-26 turbidity t-test for right inlet (P2-3) compared to middle inlet (P2-2)

t-Test: Two-Sample Assuming Unequal Variances		
	right (P2-3)	*middle (P2-2)*
Mean	0,936904762	1
Variance	0,00960034	0
Observations	6	6
Hypothesized Mean Difference	0	
df	5	
t Stat	-1,577353009	
P(T<=t) one-tail	0,087770742	
t Critical one-tail	2,015048373	
P(T<=t) two-tail	0,175541485	
t Critical two-tail	2,570581836	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	TRUE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

One possibly statistically significant result was found. For a one tailed comparison with an alpha value of 0,1 the t-test states the null hypothesis can be rejected for the comparison between P2-3 and P2-2.

4.6.1. Wall setup effects

Parallel samples from the outlet pipes were taken and t-tests were also performed on these. These were also performed as a percentage difference from the middle pipe.

t-tests were performed for turbidity, total dissolved solids, and salinity.

Table 4-27 turbidity t-test for left outlet (P5-1) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances Turbidity		
	LEFT (P5-1)	*MIDDLE (P5-2)*
Mean	0,8330514	1
Variance	0,1724314	0
Observations	4	4
Hypothesized Mean Difference	0	
df	3	
t Stat	-0,80409	
P(T<=t) one-tail	0,2400802	
t Critical one-tail	2,3533634	
P(T<=t) two-tail	0,4801604	
t Critical two-tail	3,1824463	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	FALSE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Table 4-28 turbidity t-test for right outlet (P5-3) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances Turbidity		
	RIGHT (P5-3)	*MIDDLE (P5-2)*
Mean	0,989379699	1
Variance	0,450591114	0
Observations	6	6
Hypothesized Mean Difference	0	
df	5	
t Stat	-0,03875441	
P(T<=t) one-tail	0,485292984	
t Critical one-tail	2,015048373	
P(T<=t) two-tail	0,970585968	
t Critical two-tail	2,570581836	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	FALSE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Following are the t-tests done for TDS on the same sample set.

Table 4-29 TDS t-test for left outlet (P5-1) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances TDS		
	LEFT (P5-1)	*MIDDLE (P5-2)*
Mean	1,330157377	1
Variance	0,087501639	0
Observations	4	4
Hypothesized Mean Difference	0	
df	3	
t Stat	2,232250387	
P(T<=t) one-tail	0,055881319	
t Critical one-tail	2,353363435	
P(T<=t) two-tail	0,111762638	
t Critical two-tail	3,182446305	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	TRUE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Table 4-30 TDS t-test for right outlet (P5-3) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances TDS		
	RIGHT (P5-3)	*MIDDLE (P5-2)*
Mean	2,838408858	1
Variance	6,692925497	0
Observations	6	6
Hypothesized Mean Difference	0	
df	5	
t Stat	1,740643104	
P(T<=t) one-tail	0,071113522	
t Critical one-tail	2,015048373	
P(T<=t) two-tail	0,142227044	
t Critical two-tail	2,570581836	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	TRUE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Following is the salinity t-tests for the same set of samples as turbidity and TDS outlet t-tests.

Table 4-31 Salinity t-test for left outlet (P5-1) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances Salinity		
	LEFT (P5-1)	*MIDDLE (P5-2)*
Mean	1,489583333	1
Variance	0,139322917	0
Observations	4	4
Hypothesized Mean Difference	0	
df	3	
t Stat	2,623284189	
P(T<=t) one-tail	0,039389268	
t Critical one-tail	2,353363435	
P(T<=t) two-tail	0,078778535	
t Critical two-tail	3,182446305	
reject null hypothesis one-tail	TRUE	95 %
reject null hypothesis one-tail	TRUE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

Table 4-32 Salinity t-test for right outlet (P5-3) compared to middle outlet (P5-2)

t-Test: Two-Sample Assuming Unequal Variances Salinity		
	RIGHT (P5-3)	*MIDDLE (P5-2)*
Mean	3,18125	1
Variance	10,48655382	0
Observations	6	6
Hypothesized Mean Difference	0	
df	5	
t Stat	1,649926791	
P(T<=t) one-tail	0,079935425	
t Critical one-tail	2,015048373	
P(T<=t) two-tail	0,159870851	
t Critical two-tail	2,570581836	
reject null hypothesis one-tail	FALSE	95 %
reject null hypothesis one-tail	TRUE	90 %
reject null hypothesis two-tail	FALSE	95 %
reject null hypothesis two-tail	FALSE	90 %

On the outlet, no significant difference is found in turbidity testing. For conductivity, TDS, and salinity one tailed significant correlations are found. some for only 0.1 alpha value, and some for both 0.05 and 0.1. It is important to remember the instrument measures conductivity and estimates TDS and salinity from this measurement.

4.7. Size fractions

To examine the size fractions of the road runoff, two representative samples were taken and analyzed. 21.04 had an average precipitation of 0.5 mm/h when sampling while 09.05 had an average of 1,3 mm/h. This places them as a low representation and a medium representation of event flow.

Table 4-33 Size fractions for 21.04 and 09.05

Date	21.apr			09.may		
Section	P1	P2-2	P5-2	P1	P2-2	P5-2
Mean (µm)	3.179	3.107	3.144	3.570	4.125	2.912
Median (µm)	2.657	2.633	2.415	2.874	3.273	2.448
S.D (µm)	1.525	1.695	2.358	2.045	2.569	1.669
D10 (µm)	2.097	2.098	2.069	2.115	2.164	2.077
D50 (µm)	2.657	2.633	2.415	2.874	3.273	2.448
D90 (µm)	4.873	4.466	4.701	5.807	7.064	4.052

Most values show a similar size when comparing dates, but also when comparing sections of the facility. The most notable difference is a small reduction in size for P5-2 on 09.05 when comparing to P1 and P2-2. All values found are below 10 µm. Each sample was run until 2000 particles had passed and been measured. The time for each sample was observed, but the machine did not log it. P1 and P2 samples were observed to take around 1-3 seconds while P5 samples usually took between 20 and 30 seconds for the same sample amount.

5. Discussion

In this section the use of precipitation data as flow estimation is discussed and how this data affects first flush calculations. Further the TSS treatment efficiency of the facility is looked at, and it is discussed why there are several different ways of estimating the concentration. The exploratory tests on inlet and outlet are reviewed. Quality assurance points of data is looked at to review the data collection method and analysis. Lastly, as the facility is a pilot and test facility, what further test that should be conducted are presented.

5.1. Flow estimation

In this paper, waterflow into the system is estimated from precipitation data. When data is needed for flow at a specific measurement, such as for the creation of M(V) curves for first flush, the flow is estimated from the reported precipitation over the measurement period. Originally, precipitation data from a tip-bucket system next to the test-facility was to be used, but due to an issue with the recording device, all data for January and February was corrupt or missing. Precipitation data therefore had to be collected from the official metrological institute’s instruments in the area and a device setup another place in Sandnes. The first instrument was at Rovik, 7,2 km northeast of the test facility while the other was at Stangelandsåna, 4,2 km northwest. These were used comparatively to estimate the precipitation at the test facility.

Water detention time in the pipes was seen as a concern when using precipitation data instead of flow measurements. From the data on the inlet on 14-15 February, it seems there is little detention in the pipes. Here the inflow starts at 0 NTU (due to a 4-week dry period) and suspended solids are starting to be detectable from around 4.10 am. From precipitation history that day, 0.3 mm is reported from 4-5 am. Although, when precipitation data from an instrument at Stangelandsåna was compared to when the turbidity started to rise, little to no precipitation was measured. This could be due to the distance or setup of the instrument.

Due to the differences between measuring sites, and the unknown detention times in the pipes, when reporting flow for these long measurement periods a mean value is used that includes the hour before measurement starts. From the precipitation data on 15.02.2021 (Metrologisk institutt, 2021), there is no reported precipitation between 8 am and 9 am, but there was still observed flow carrying suspended solids to the system. No precipitation is reported after 11 am, but there is measured suspended solids flowing to the system. This way of reporting using a mean value and the hour before is necessary due to the lack of any direct flow measurement equipment when these measurements were made. The use of a mean value is a common way of estimating flow in runoff. Using precipitation with a constant intensity over time is used by Norwegian VA-engineers when dimensioning detention basins, sedimentation facilities etc. This is known as “box rain”.

To see if the events measured were comparable to earlier events, the SWMM program was used to find the average cubic meter per second flow of events between 2018 and 2021. They show an average of 0,003 CMS and our events show an average of 0,0027 for SÅ and 0,0038 for YR on the inlet. The events measured are therefore seen as valid examples of events in the area.

5.1.1. Detention time

The original idea when choosing this thesis was to perform comparable sampling on outlet and inlet at the same time. This proved to be difficult as the university only had one field turbidimeter available. It was further decided to continue with only the one instrument due to the dimensions of the facility. It would require a very large event to overcome the detention capacity of the facility. The mixing in the facility will therefore mean any extreme measurements on inlet will be easily mixed. It was therefore decided that inlet and outlet could be measured at different times. Some of the measurements were taken during the same event. On these events the instrument was moved from one end to the other when the readings had been stable for a while and an adequate mean and median could be concluded for that event.

Due to the detention time in the facility, the varying nature of the flow rate during events and the mixing present in the system, it was concluded that sometimes the particles from one specific event might be in the facility for weeks and be completely mixed with earlier and later events. Linking a specific outflow concentration to an inlet concentration is therefore near impossible. Several events are necessary and total efficiency of the facility needs to be found. An extra instrument on the outlet would have been to prefer, but only to provide more data points overall.

5.2. First flush

Originally, first flush calculations were not planned to be included in the thesis due to the lack of proper flow measurements. After the first measurement was taken, which included some snowmelt and runoff after a long dry period, there was observed a clear increase in turbidity during the event. As shown in the first flush calculations, there are many different definitions of a first flush. Some are simple and straightforward, stating it requires an increase steeper than 45 degrees on a mass-volume curve, while other requires a certain amount of mass present in the early volume. Since first flush calculations were not originally planned no flow meter was set up and flow needed to be estimated using reported precipitation.

There is an issue with using precipitation data since an average flow must be used. Some graphs were attempted to be made using minute for minute precipitation data, but there were to large discrepancies. Likely due to distance from test facility to precipitation measurer, and from detention time in runoff pipes.

Definitions for first flush events are varying, visual examination of graphs shows clearly a "bubble" of particles early in events when there has been dry periods/snowmelt. Even on events where some calculations suggest there is no first flush present. This shows that proper flow measurements are necessary. These are however chosen to be included to demonstrate the methods for determining first flush, and the variation on definitions. Calculations relying heavily on flow measurements does not conclude there is a first flush on the chosen events. However, the definitions that do not rely too heavily on exact flow measurements show there is a likely first flush. The m-value on both events is below 1 and the first event has a M(V) curve that starts steeper than 45 degrees. This combined with the overall increase and decrease on the turbidity graphs; the presence of a first flush is highly likely.

5.3. Is the treatment sufficient

Deciding if a runoff site requires purification measures or not is determined by the annual average daily traffic (AADT) and the vulnerability of the recipient. The vulnerability is determined based on the Norwegian water directive and nature diversity act. From this it is determined if a site requires no cleaning, step 1 cleaning, or step 1 +2 cleaning. Step one includes sedimentation of particles and step 2 includes the removal of diluted pollutants. The examined facility at fv505 has a combination of recipient vulnerability and AADT that requires it to have a step 1 cleaning. For step 1 cleaning a TSS removal efficiency of minimum 80% should be accomplished (Åstebøl & Dalen, 2020; Statens Vegvesen, 2018). As shown in the results there are several ways to determine the removal efficiency. The simplest (and likely most accurate) method is with mean and median percentage reduction. We have also calculated the extreme values reduction to show the difference in short, but high concentrations in the facility (Table 4-20). This is also demonstrated using histograms (

Figure 4-11 and Figure 4-12 shows the value of all readings. These together demonstrate the significant reduction in high concentrations and first flush. The estimated TSS removal efficiency, using SMC, of the facility is 68%. This is below the set 80% for step one cleaning but it is important to note the 80% includes all steps, including the sedimentation in gully pots both before the facility and individual gully pots along the catchment (Statens Vegvesen, 2018).

Measuring individual gully pots during an event would require several instruments placed at both the inlet and outlet of the gully pots including the measurements made at the sedimentation facility. Since the focus for this thesis was the sedimentation facility, instrumentation of the gully pots was viewed as unnecessary. In hindsight this would have given a much clearer overview of the total removal from runoff to recipient. Another reason gully pots were not included is they are extremely varying in measurements. Sources cited in the result section 4.5 on gully pots show that they can have a removal rate from 15% to 100% depending on flow and particle size. With the limited time for this thesis it was thought that including gully pots would require significantly more event readings to get a representative removal rate. By only focusing on the sedimentation pipes it is possible to offer a more conclusive number on the removal rate.

To examine if the facility fulfills the removal rate expected by the county, the gully pots must be included. If we assume the minimum removal rate found in sources (Butler & Karunaratne, 1995) of 15% have occurred, we get a TSS removal rate of 82,2% when applied to the SMC.

5.3.1. Mean vs median vs flow weighted mean

Since urban runoff is so varied due to the size and length of events and dry periods, determining a common value is difficult. The different methods have their advantage and disadvantage. A mean value will give an average of all samples, but it will be heavily influenced by high or low values which might not be representative. A first flush event can have a large impact on the value. A good replacement is a median value. This will give each measurement equal weight, meaning first flush events need to be long to have any significant impact. The median value however has its flaws as well. In the setting of urban runoff, some events might be short while others might be much longer. A long event with low turbidity will then skew the median since it contains more measurements. To attempt to put equal weight on each event, event mean concentrations (EMC) and site mean concentrations (SMC) can be used.

5.3.1.1. SMC, EMC and FWMC

An SMC will include each EMC and weigh them equally. Several EMCs are needed, and the length of the events are not relevant. This system is better to reduce the impact a non-representative event can have on measurements than a pure mean value will, but the number of events will have a large impact. If there are too few events, the method will not be able to reduce the non-representative event impact. Hvitved-Jacobsen et al., (2010) recommends a minimum of 10-15 events to have a representative sample set, but they underline that this is a "pragmatically" recommended value due to the uncertainty and variation in determining SMCs (Hvitved-Jacobsen et al., 2010, p. 60). A study with limited events might therefore benefit from using a median value, but then it is important that all events have been measured with close to the same time intervals for the duration of the event and preferably be close in length as well. In this thesis both SMC and median values have been calculated. The SMC value of 289 NTU and the median of 267 NTU shows that the SMC value have been somewhat influenced by high concentration events, but the similarity is close enough that both values are usable and appliable in this thesis.

A flow weighted mean concentration (FWMC) can be further used to take volume into account. FWMC is properly used with accurate flow measurements. In this thesis FWMC has been calculated using precipitation data from two different sites. Both were used so they could verify each other. A large difference in FWMC would mean one or both are not representative for the test site. The inlet value shows 256 NTU for Stangelandsåna (SÅ) and 259 NTU for Sandnes-Rovik (YR). calculations on outlet shows approximately 103 NTU for both SÅ and YR. This demonstrates that the distance and measurement method between the sites does not have a significant impact on data collected.

Comparing FWMC and SMC we have 256/259 NTU and 289 NTU respectively for inlet. For outlet we have 103 NTU and 107,5 NTU respectively for FWMC and SMC. For the inlet there is a small difference where FWMC<SMC, this demonstrates that concentration sampling from this site can be influenced by events with low volumes and high EMC. Having this in mind is important, but in practice, SMC is still often the best estimate (Hvitved-Jacobsen et al., 2010). Low NTU values can be expected from large volumes due to dilution, but high values are also to be expected due to sediment erosion in the system or on the road. FWMC can therefore have a large variation depending on the site, length of dry period and snowmelt (Hvitved-Jacobsen et al., 2010).

The low difference in NTU on the outlet is believed to be due to mixing in the facility and a narrow outlet. The facility is designed to retain water at large flow and rather release it at an even flow through a narrow outlet. High flow into the system will therefore not necessarily mean there is a large flow out of the system.

5.3.2. Theory: short-circuit to middle pipe

It was theorized that the setup of the inlet to the gully pot before the pipes would lead to a short circuit of particles from this main inlet (P1) to the middle pipe (P2-2) thus increasing the load on the middle pipe. This was examined by taking a sample from each inlet during the same event and comparing these. Since the values for each event can vary, each sample was set as a percentage deviation from the value of the middle inlet. 4 samples were taken from the left pipe (pipe 1) while 6 were taken from the two others. There are fewer samples from the first pipe since the pipe had to be closed due to a valve issue.

The t-test performed shows two-tailed and one-tailed value with an alpha value of 0.1 and 0.05. Determining if one should use a one-tailed or two-tailed test is difficult. On one hand we are mostly interested in seeing if the middle pipe has a higher value than the other two. On the other hand, it is entirely plausible for the middle pipe to have a lower value. The t-test for the right inlet (P2-3) compared to the middle inlet (P2-2) is the only one that provides us with a rejection of the null hypothesis. Although, this is only on a one-tailed test with 0.1 alpha level. Calling this a statistically significant difference is therefore not seen as appropriate since this is attained using an uncommon alpha level. Also, choosing the one-tailed test here is to choose it over the two-tailed to gain significance, and not necessarily because it is the more appropriate test.

Based on the data collected there does not seems to be any statistically significant short circuit to the middle pipe. It is however recommended to perform additional statistical test with a larger sample set. Preferably a minimum of 30 samples (between 15 and 40 is optimal for two-sample t-test) (Moore et al., 2014).

5.3.3. Particle size fraction and removal rate of small particles

Particle size distribution (PSD) analysis was performed on two representative samples. Turbidity testing was prioritized meaning PSD sampling was started a while into the thesis work. A lack of events when particle size sampling was started, led to no more than two events being collected.

All samples collected showed a D90 below 8 µm (D90 = 90% of particles are smaller than)

The PSD collected shows a quite similar distribution for P1, P2 and P5. However, P1 and P2 were observed to take approximately 1-3 seconds to analyze 2000 particles, while P5 took around 25 seconds for the same sample size. Exploratory turbidity sampling during the same events showed the data in Table 5-1.

Table 5-1 NTU data from PSD samples

Pipe	21.04	09.05
P1	131 NTU	169 NTU
P2-2	111 NTU	153 NTU
P5-2	12 NTU	11 NTU

This difference in NTU between P1/P2 and P5 is between 10 and 14 times, which corresponds to the difference in analysis time.

Nie et al., (2008) reports 70% of highway runoff is <45 µm and Li et al., (2006) reports 90% of highway runoff is <10 µm. Comparison between this literature and our samples show there is reason to believe our samples are representative for road runoff in the area sampled. Several articles have found that heavy metals such as Zn, Pb and Cu bind to fine particles (<45 µm) (Sansalone & Buchberger, 1997; Wang et al., 2006) Seeing as the PSD is similar at inlets and outlet, but the number of particles has been reduced, the facility is able to remove fine particles, at least for the events sampled. A removal of fine particles leads to a removal of bound heavy metals (Sansalone & Buchberger, 1997). Based on the samples collected the facility can, and is effective in removing particle bound heavy metals. Further testing on this topic is discussed in section 5.8.2.

5.4. Is the pilot facility to prefer over an open pond system

From the data collected the tested facility is expected to have a TSS removal efficiency close to, or at the required removal efficiency of traditional sedimentation facilities in Norway. Comparably, there are currently 161 open wet pond systems in Norway (H Paus et al., 2013) that have been used and proven to be effective in removing road runoff constituents. When and why would a new system like the one tested be to prefer?

The test facility is set up so cleaning of the sedimentation pipes and gully pot can be done with a vacuum truck in the same way roadside gully pots are emptied. Wet ponds on the other hand often has to be emptied using a combination of vacuum trucks and excavators. H Paus et al., (2013) did a survey of 26 randomly chosen wet ponds in Norway. They examined whether the facilities were built according to recommendations and if they were maintained appropriately. They showed a lack of adequate maintenance on 9 out of 26 sites. This was mainly a lack of adequate sediment and vegetation removal. The report concludes there is a large deviation on maintenance of the ponds, and few include instructions on maintenance.

Wet ponds have more extensive maintenance requirements. Where an underground sedimentation pipe will need vacuum sludge removal and flushing, a wet pond required removal by vacuum and excavators, including regular removal of vegetation.

An underground facility is also beneficial if there is limited space for a pond. With expanding urban development around the world, more space saving solutions might be beneficial. On the other hand, a wet pond can have a dual purpose by also functioning as a pond with recreational value. A wet pond will attract animals and plants and become esthetically pleasing. This should not affect the treatment efficiency however and an increase in vegetation can negatively affect this (Hvitved-Jacobsen et al., 2010).

5.5. Verification/correlation

Samples taken for the correlation and verification study were stored for 24 days in a cold and dark environment. Long storage of sample is not recommended since it can lead to microbial decomposition of solids**.** (Standards methods committee, 1997). Long storage was necessary due to limited access to the lab at UiS. Covid-19 regulations lead to closing of student access at the university, and lab access was not possible until 24 days had passed after sampling. Collecting new samples was considered but sampling needed to happen during a precipitation event and preferably before starting to use the instrument that was to be verified. Also, a new lockdown was possible. The samples were therefore tested to make sure the testing would happen. We are also measuring solids that have possibly been in the system even longer than 24 days when measuring outlet. The long storage is not seen as problematic since this was done for a correlation study and the TSS and turbidity was both measured on the same sample on the same day. The TSS samples and turbidity samples would therefore have both degraded equally.

The Pearson correlation coefficient (r) shows a value of 0,998 meaning there is a near perfect correlation between the TSS filtration and turbidity measurements. With the small p-value of $6{,}81 * 10^{-6}$ we can easily reject the null hypothesis. The correlation study shows a strong connection between TSS and turbidity and the conversion equation found is therefore seen as usable in converting our turbidity values to mg/l.

5.6. Conductivity, TDS, and salinity

In addition to measuring turbidity, the instrument used also had the capability of measuring pH and conductivity. The conductivity was converted to TDS and salinity values. This was chosen not to be included too much since the focus of the thesis is on TSS, and the facility is not made to have any significant effect on these parameters. However, when taking comparative samples from the outlet, there were some interesting differences in measurements. t-tests were performed on the measurements and comparing salinity between the left (p5-1) and middle (P5-2) pipe the t-test gives a rejection of the null hypothesis on 0.05 alpha value. However, this is only true for a one-tailed test, and for this thesis, a test only true as one-tailed is not seen as sufficient. It is hypothesized that with more samples, a two-tailed test might prove true. It is not known why there might be a difference as the facility has no systems in place to remove TDS or salinity. The inlet measurements have not had any difference in measurements that have been relevant to mention. The only obvious difference between the pipes is the placement of the dividing walls. Due to the low number of tests it is likely the difference in concentration is a random occurrence. This should be further examined.

An interesting result was also found when looking at the SMC and median reduction from inlet to outlet. Here a reduction of 42%-46% was found when viewing SMC while median showed an increase of approx. 700%-800%. (Table 4-22) This can likely be explained when viewing Table 4-23. Here the EMC of 14-15.02 stands out with a large measurement on the inlet. It is likely this measurement was made shortly after the road was salted. This large value will have less impact on the median value. The median with an increase in conductivity on the outlet can be expected this time of year due to the accumulation of salts in the facility from the road.

5.7. Quality assurance of data

A set of concepts for quality assurance of data is presented by Hvitved-Jacobsen et al., (2010, p. 254). We attempt to define and apply these to road runoff and the data collected. The concepts are applied here to see any problem-areas with sampling and the nature of urban runoff. From this, recommendations for further testing can be set.

5.7.1. Accuracy

The accuracy is determined by how close the reported result or value is to the true value. The goal for this thesis was to have 10-15 events (Hvitved-Jacobsen et al., 2010) sampled for both inlet and outlet. Due to an issue with the measuring instrument where it was unavailable for use for approximately 1,5 months lead to a reduced number of samples. Using a lab turbidimeter was considered but samples would have needed to be brought to the lab for testing. Looking at the variation within an event from previous events showed that bringing one or a couple of samples to the lab for testing could give an unrepresentative reading. The sample could have been taken on a first flush for example and skew the results to a value much higher than the true EMC.

The accuracy is also dependent on the variation in length of sampling and when sampling was ended. Some were chosen to end early since readings were stabilizing and the instrument was needed to measure outlet. Others were chosen to end due to low flow (end of event). Some events may therefore look like they have been stopped prematurely. Ending readings before the event was over is nonideal but was seen as necessary on some cases to also get a reading of the outlet while there was flow through the system. In hindsight, with some long dry periods and the issue with the turbidimeter, it is good this was done, or the number of events measured would be much lower. For events where both inlet and outlet were measured, the inlet was measured first so any first flush/extreme measurements could be collected before readings would stabilize and the instrument moved to the outlet.

The accuracy also includes the systemic or stochastic errors associated with sampling. A continuous in situ measurement instrument was chosen to decrease the sampling errors by repeatedly taking measurements during an event.

5.7.2. Precision

The precision of the samples is determined by the standard deviation (SD) of the samples, or more accurately, the reproducibility of the results (Hvitved-Jacobsen et al., 2010). Ideally, the precision is the deviation when sampling an ideal data set (such as in a lab). The issue with road/urban runoff is the natural variation between events and during events. The data collected show a relatively large SD. For SMC of 291 NTU on the inlet there is an SD of 244 NTU. At outlet there is an SD of 40 on an SMC of 87 NTU. This is quite a large SD, especially for the inlet, but it is expected as there is such a large variation between events. This SD further underlines the difficulty in determining an overall removal efficiency for a facility like this.

The precision of the turbidimeter used was determined during the verification study with a resulting SD of 2,28%.

5.7.3. Selectivity and sensitivity

The selectivity of a method is the methods ability to accurately measure a specific characteristic, while the sensitivity is how accurate the change in a measured value is when the true value changes (Hvitved-Jacobsen et al., 2010).

For this thesis, we focus on TSS measurements. As TSS includes all suspended particles, turbidity measurements are little influenced by other factors. One factor that could have some influence is a high concentration of dissolved solids. A high TDS concentration can lead to some reflection. Turbidity measurements can also have the issue with some particles that either reflect too much light or too little.

To view the selectivity and sensitivity of our method on the specific runoff collected, the correlation study was conducted with comparison to TSS vacuum filtration. The correlation study showed the method was accurate and usable with a correlation coefficient of 0,998.

As mentioned, when reaching high turbidity values, there are more and more factors that can skew the readings. The standard method for turbidity (American Public Health Association, 2017) therefore includes a reporting sheet shown earlier in the thesis: Table 4-3 Turbidity reporting. (American Public Health Association, 2017)

5.8. Further testing

The main function of the test facility is not to prove a concept or demonstrate a new, specific method in removing constituents. The facility is created to test out different purification methods and test their functionality together. This way, new facilities can be tailored to the specific site and its removal needs. By dividing a facility into different degrees of removal and points of purification there can be installed only what is necessary at a site, saving building and maintenance costs. Further testing parameters and suggestions for testing is presented in the follow section.

5.8.1. Filter size

Further tests for size fractioning to properly estimate heavy metal binding should use a filter size of 0,45 micrometer. There is large difference in literature on relevant size fractions. Hvitved-Jacobsen et al., (2010) sources the U.S department of Agriculture and the International society of soil science when they point out that particles <10 µm will typically not settle and particles between 10-100 µm will typically have a very low settling speed. They also define particles down to 1 µm as suspended particles, particles from 0,001 to 1 µm as colloidal and below 0,001 µm as dissolved. For this paper focusing on total suspended solids, a filter size of 1 µm was chosen for the correlation study between TSS and turbidity. Further testing is recommended using a 0,45 µm or smaller since heavy metals usually bind to finer particle sizes (Sansalone & Buchberger, 1997). 0,45 µm is the filter sized found to be used in several papers focusing on heavy metals in urban runoff (Tuccillo, 2006) (Karlsson et al., 2010). It is also the filter size provided by the standards method for water and wastewater to distinguish between a dissolved fraction and a particulate fraction (APHA-AWWA-WEF, 1995).

Addition of a filtration system for heavy metals to the facility should include a filter as small as feasibly possible. A filter size of above 1 µm will remove the remaining suspended solids not removed by sedimentation but will not remove the smallest metal binding particles. A filter size of maximum 0,45 µm should be used. (Karlsson et al., 2010; Tuccillo, 2006)

5.8.2. Particle size distribution

Further examinations should be done on the PSD at different times and event characteristics. Samples should also be taken directly from the road runoff before any treatment to assess the removal efficiency of the gully pots. Further, a particle size profile should be made for each point in the removal process with corresponding TSS values. This will give an overview over where the different sizes are removed. An overview like this will also be useful for estimating filter size and how much is expected to require filtration. A PSD can also further help in getting an overview of heavy metals in the water. It has been shown that heavy metals bind to fine particles (<45 µm) (Sansalone & Buchberger, 1997) but where the highest binding is, can depend on the characteristics of the site. Measuring heavy metal concentration and correlating it to particle size means a PSD can be used as an estimate for heavy metal concentrations and removal efficiency of these. Due to the varying constituents in road runoff from site to site, A PSD and heavy metal correlation should be done on a site basis.

5.8.3. Continuous measuring

To get a proper overview of the facility, continuous measurements should be conducted over a year. This would help reduce the SD and therefore increase the precision of sampling. As discussed earlier, road runoff events are extremely varied depending on dry periods, salting and rain intensity. During winter months there is often longer between events and particles can get bound to snow and then released during melting (Hvitved-Jacobsen et al., 2010, p. 130). During the summer months precipitation is often more intense, releasing more water in a short period of time. During this thesis, measurements have been made in the end of winter/start of spring. Further testing during summer and fall would give a better overview of the efficiency of the facility during all types of events. Continuous measurements should be set up to measure P1, P2 and P5 to get a complete overview over all steps in the facility.

There is little data sets over long time (a year) for open facilities in Norway. A similar setup should be made for an open facility to properly compare the two systems.

5.8.4. Outlet conductivity (TDS/salinity)

The t-tests done on the outlet conductivity shows some interesting results, however the low number of samples available means no proper conclusion can be drawn. A bigger number of samples might reject or confirm the null hypothesis. Further sampling should be done, and statistical tests performed to see if there is a statistical difference on conductivity on the outlets. This should be combined with a similar test on turbidity to see if an increase in conductivity follows an increase in turbidity. If a statistical difference is found further testing should be performed in the compartments to examine if the placement of the walls is what affects the concentration.

5.8.5. Wall setup

Li et al., (2006) concludes a two compartment system for sedimentation facilities is necessary/useful since most particles in road runoff are small (<10 µm) They suggest a setup with a large settling tank first for main settling, then a smaller compartment that handles large particles when the flow is high, so the larger particles are removed at both high and low flow. The fv505 facility is designed with a gully pot first to remove heavy particles, A large compartment for main settling, then a holding tank with a narrowed outlet to control outflow.

The setup of the walls in the main settling pipes should be further examined. Following the setup of Li et al, placing the wall towards the end of the pipe (3/4 size first then 1/4) should be the optimal setup for removing small particles. A larger detention tank means particles are longer in the system and are more likely to settle. Seeing the effect from the different placements of the walls is an interesting area for further study. Further empirical studies should be performed due to the varying nature of urban runoff. One setup that might be effective at an average flow or a specific site might not be effective at another.

following the setup by Li et al., (2006) we can hypothesize that an optimal setup for removing small particles would be a large compartment, with a long retention time first for catching small particles, then a smaller compartment for catching large particles in overflow. Further testing on this should be done with measuring the particle size distribution of different setups. Total concentration (TSS) should also be examined simultaneously to see that the total removal efficiency is not reduced.

5.8.6. More parameters

Research is being conducted on different constituents in urban runoff and their effect. Current guidelines only include at what degree TSS should be removed. Later guidelines might include the removal efficiency of microplastics, nutrients etc. Testing different parameters at this site will allow it to be tailored for any new guidelines.

6. Conclusion

In this thesis the underground sedimentation facility at fv505 in Sandnes was examined for its efficiency in removing particles and particle bound pollutants. It is observed that TSS removal efficiency changes depending on what method is applied. Examining the sedimentation pipes a total removal rate of 68% was found for SMC method. 65% was obtained using the median value of all samples and 59% was obtained with FWMC. The use of FWMC in this thesis is more a proof of concept and to examine if a differing volume can have an impact. Due to the use of precipitation data for the volume estimation, the accuracy of the FWMC removal rate is questionable. The focus should therefore be on SMC and median. Since the median value used all samples taken and does not differ between events, the SMC seems as the best choice. However, as the removal rates show, the difference between these is only 3% meaning in the case of the measurements here, both methods seem appliable. It was chosen to do turbidity testing only for the sedimentation pipes in this thesis, thus skipping the gully pots. This was done to give a better view over the efficiency of the pipes for later testing and the efficiency of gully pots is something that has been examined extensively before (Butler & Karunaratne, 1995; Deletic et al., 2000; Hvitved-Jacobsen et al., 2010; Rietveld et al., 2020). However, determining the total removal efficiency of the facility to see if it fulfills the demands, need to include the gully pots. For this thesis an exact measurement of this is not done but by using literature on gully pots the facility is expected to reach 80% removal rate even with the lowest removal rates found in literature for gully pots. This also means its efficiency is comparable to open sedimentation ponds which are the standard in Norway.

Calculations were performed according to different sources on when a first flush is present, due to the use of precipitation data for flow estimations the usability of some calculations is lessened. Graphical representations and the angle of increase on the Mass-volume curves leads to the conclusion that, under certain conditions such as long dry-periods and snowmelt, there is significant first flush tendencies in the facility.

With the exploratory samples collected and the t-tests performed there does not seem to be a statistically significant short circuit from the main inlet to the middle pipe. The t-test on the outlet does not give a conclusive result for a difference between the pipes when looking at conductivity. More sampling and testing will likely give a conclusive result.

Overall, the Fv505 sedimentation facility seems to be near or at the removal efficiency of similar open systems but takes less space and requiring less and cheaper maintenance. The facility is promising for further development and for tailoring to specific purification demands.

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Appendix

Appendix A. Exploratory testing raw inlet and outlet data

Date	Inlet	Conductivity		Turbidity		TDS		Salinity	
2021/02/15	P2-1	15,4	mS/cm	281	NTU	9,57	g/L	8,4	ppt
2021/02/15	P2-1	15,2	mS/cm	303	NTU	9,41	g/L	8,2	ppt
2021/02/15	P2-1	13,5	mS/cm	203	NTU	8,37	g/L	7,3	ppt
2021/02/15	P2-2	15,3	mS/cm	361	NTU	9,49	g/L	8,3	ppt
2021/02/15	P2-2	15,2	mS/cm	293	NTU	9,4	g/L	8,2	ppt
2021/02/15	P2-2	13,9	mS/cm	200	NTU	8,59	g/L	7,5	ppt
2021/02/15	P2-3	15,2	mS/cm	238	NTU	9,45	g/L	8,2	ppt
2021/02/15	P2-3	15,2	mS/cm	263	NTU	9,42	g/L	8,2	ppt
2021/02/15	P2-3	14,2	mS/cm	200	NTU	8,8	g/L	7,7	ppt
2021/02/18	P2-1	5,5	mS/cm	920	NTU	3,47	g/L	2,8	ppt
2021/02/18	P2-1	5,49	mS/cm	918	NTU	3,46	g/L	2,8	ppt
2021/02/18	P2-1	5,55	mS/cm	891	NTU	3,5	g/L	2,8	ppt
2021/02/18	P2-2	5,52	mS/cm	898	NTU	3,48	g/L	2,8	ppt
2021/02/18	P2-2	5,43	mS/cm	891	NTU	3,42	g/L	2,8	ppt
2021/02/18	P2-2	5,23	mS/cm	913	NTU	3,3	g/L	2,7	ppt
2021/02/18	P2-3	5,3	mS/cm	913	NTU	3,34	g/L	2,7	ppt
2021/02/18	P2-3	5,25	mS/cm	926	NTU	3,31	g/L	2,7	ppt
2021/02/18	P2-3	5,26	mS/cm	888	NTU	3,31	g/L	2,7	ppt
2021/02/20	P2-1	0,132	mS/cm	49,2	NTU	0,086	g/L	0,1	ppt
2021/02/20	P2-1	0,129	mS/cm	36,9	NTU	0,084	g/L	0,1	ppt
2021/02/20	P2-1	0,129	mS/cm	35,3	NTU	0,084	g/L	0,1	ppt
2021/02/20	P2-2	0,128	mS/cm	36,2	NTU	0,083	g/L	0,1	ppt
2021/02/20	P2-2	0,128	mS/cm	33,3	NTU	0,083	g/L	0,1	ppt
2021/02/20	P2-2	0,128	mS/cm	34,4	NTU	0,083	g/L	0,1	ppt
2021/02/20	P2-3	0,127	mS/cm	36,3	NTU	0,082	g/L	0,1	ppt
2021/02/20	P2-3	0,127	mS/cm	34,4	NTU	0,083	g/L	0,1	ppt
2021/02/20	P2-3	0,127	mS/cm	33,7	NTU	0,083	g/L	0,1	ppt
2021/02/24	P2-1	0,118	mS/cm	211	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-1	0,118	mS/cm	189	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-1	0,118	mS/cm	194	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-2	0,119	mS/cm	201	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-2	0,119	mS/cm	203	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-2	0,119	mS/cm	194	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-3	0,118	mS/cm	163	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-3	0,118	mS/cm	166	NTU	0,077	g/L	0,1	ppt
2021/02/24	P2-3	0,118	mS/cm	164	NTU	0,077	g/L	0,1	ppt
2021/04/22	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P2-2	0,736	mS/cm	110	NTU	0,471	g/L	0,4	ppt

2021/04/22	P2-2	0,752	mS/cm	111	NTU	0,481	g/L	0,4	ppt
2021/04/22	P2-2	0,752	mS/cm	113	NTU	0,481	g/L	0,4	ppt
2021/04/22	P2-3	0,719	mS/cm	107	NTU	0,46	g/L	0,3	ppt
2021/04/22	P2-3	0,731	mS/cm	107	NTU	0,468	g/L	0,4	ppt
2021/04/22	P2-3	0,733	mS/cm	108	NTU	0,469	g/L	0,4	ppt
2021/05/09	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P2-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P2-2	0,311	mS/cm	150	NTU	0,202	g/L	0,1	ppt
2021/05/09	P2-2	0,312	mS/cm	157	NTU	0,203	g/L	0,1	ppt
2021/05/09	P2-2	0,306	mS/cm	152	NTU	0,199	g/L	0,1	ppt
2021/05/09	P2-3	0,327	mS/cm	151	NTU	0,212	g/L	0,2	ppt
2021/05/09	P2-3	0,323	mS/cm	157	NTU	0,21	g/L	0,2	ppt
2021/05/09	P2-3	0,322	mS/cm	141	NTU	0,209	g/L	0,2	ppt

Date	Outlet	Conductivity		Turbidity		TDS		Salinity	
2021/02/15	P5-1	1,57	mS/cm	1,1	NTU	1,01	g/L	0,8	ppt
2021/02/15	P5-1	1,57	mS/cm	2	NTU	1	g/L	0,8	ppt
2021/02/15	P5-1	1,57	mS/cm	2	NTU	1,01	g/L	0,8	ppt
2021/02/15	P5-1	1,57	mS/cm	1,7	NTU	1,01	g/L	0,8	ppt
2021/02/15	P5-2	0,9	mS/cm	8	NTU	0,576	g/L	0,4	ppt
2021/02/15	P5-2	0,895	mS/cm	5,6	NTU	0,573	g/L	0,4	ppt
2021/02/15	P5-2	0,894	mS/cm	5,1	NTU	0,572	g/L	0,4	ppt
2021/02/15	P5-2	0,893	mS/cm	5,1	NTU	0,572	g/L	0,4	ppt
2021/02/15	P5-3	7,22	mS/cm	0,2	NTU	4,55	g/L	3,8	ppt
2021/02/15	P5-3	7,29	mS/cm	0	NTU	4,59	g/L	3,9	ppt
2021/02/15	P5-3	7,36	mS/cm	0	NTU	4,64	g/L	3,9	ppt
2021/02/15	P5-3	7,38	mS/cm	0	NTU	4,65	g/L	3,9	ppt
2021/02/19	P5-1	3,61	mS/cm	126	NTU	2,31	g/L	1,8	ppt
2021/02/19	P5-1	3,63	mS/cm	115	NTU	2,32	g/L	1,8	ppt
2021/02/19	P5-1	3,62	mS/cm	116	NTU	2,32	g/L	1,8	ppt
2021/02/19	P5-2	3,25	mS/cm	111	NTU	2,08	g/L	1,6	ppt
2021/02/19	P5-2	3,23	mS/cm	119	NTU	2,06	g/L	1,6	ppt
2021/02/19	P5-2	3,22	mS/cm	119	NTU	2,06	g/L	1,6	ppt
2021/02/19	P5-3	3,91	mS/cm	117	NTU	2,5	g/L	2	ppt
2021/02/19	P5-3	3,94	mS/cm	112	NTU	2,52	g/L	2	ppt
2021/02/19	P5-3	3,94	mS/cm	108	NTU	2,52	g/L	2	ppt
2021/02/20	P5-1	0,981	mS/cm	48,6	NTU	0,628	g/L	0,5	ppt
2021/02/20	P5-1	1,36	mS/cm	57,6	NTU	0,871	g/L	0,7	ppt
2021/02/20	P5-1	1,32	mS/cm	55,4	NTU	0,844	g/L	0,6	ppt
2021/02/20	P5-2	0,938	mS/cm	70,8	NTU	0,6	g/L	0,4	ppt
2021/02/20	P5-2	0,94	mS/cm	69,1	NTU	0,602	g/L	0,4	ppt
2021/02/20	P5-2	0,94	mS/cm	68,4	NTU	0,601	g/L	0,4	ppt
2021/02/20	P5-3	2,16	mS/cm	47	NTU	1,38	g/L	1,1	ppt

2021/02/20	P5-3	2,17	mS/cm	45,7	NTU	1,39	g/L	1,1	ppt
2021/02/20	P5-3	2,17	mS/cm	44,8	NTU	1,39	g/L	1,1	ppt
2021/02/24	P5-1	0,739	mS/cm	118	NTU	0,473	g/L	0,4	ppt
2021/02/24	P5-1	0,773	mS/cm	119	NTU	0,495	g/L	0,4	ppt
2021/02/24	P5-1	0,816	mS/cm	119	NTU	0,522	g/L	0,4	ppt
2021/02/24	P5-2	0,681	mS/cm	102	NTU	0,436	g/L	0,3	ppt
2021/02/24	P5-2	0,68	mS/cm	90,8	NTU	0,435	g/L	0,3	ppt
2021/02/24	P5-2	0,676	mS/cm	94,2	NTU	0,433	g/L	0,3	ppt
2021/02/24	P5-3	1,1	mS/cm	131	NTU	0,706	g/L	0,5	ppt
2021/02/24	P5-3	1,12	mS/cm	128	NTU	0,715	g/L	0,5	ppt
2021/02/24	P5-3	1,12	mS/cm	124	NTU	0,716	g/L	0,5	ppt
2021/04/22	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/04/22	P5-2	0,63	mS/cm	11,2	NTU	0,403	g/L	0,3	ppt
2021/04/22	P5-2	0,629	mS/cm	11,6	NTU	0,403	g/L	0,3	ppt
2021/04/22	P5-2	0,632	mS/cm	12,6	NTU	0,404	g/L	0,3	ppt
2021/04/22	P5-3	1,47	mS/cm	23,3	NTU	0,944	g/L	0,7	ppt
2021/04/22	P5-3	1,48	mS/cm	23,2	NTU	0,948	g/L	0,7	ppt
2021/04/22	P5-3	1,49	mS/cm	24	NTU	0,951	g/L	0,7	ppt
2021/05/09	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P5-1	x	mS/cm	x	NTU	x	g/L	x	ppt
2021/05/09	P5-2	0,951	mS/cm	13,8	NTU	0,608	g/L	0,5	ppt
2021/05/09	P5-2	0,974	mS/cm	9,7	NTU	0,623	g/L	0,5	ppt
2021/05/09	P5-2	0,979	mS/cm	9,5	NTU	0,627	g/L	0,5	ppt
2021/05/09	P5-3	1,42	mS/cm	11,1	NTU	0,908	g/L	0,7	ppt
2021/05/09	P5-3	1,44	mS/cm	10,6	NTU	0,92	g/L	0,7	ppt
2021/05/09	P5-3	1,44	mS/cm	10,5	NTU	0,924	g/L	0,7	ppt

Appendix B. Coulter counter data

Multisizer 4	9:38 11 May 2021
File name:	samples 09_P1 kl 12.0_01.#m4
File ID:	samples 09.05
Sample ID:	P1 kl 12.00
Control mode:	Total count 2000
Acquired:	9:29 11 May 2021
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	6000
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	3.570
Median:	2.874
D(0,0):	3.219
Mean/Median ratio:	1.242
Mode:	2.145
95% Conf. Limits:	3.519
95% Conf. Limits:	3.621
S.D.:	2.045
Variance:	4.181
C.V.:	57.28
Skewness:	3.167
Kurtosis:	15.jul
d10:	2.115
d50:	2.874
d90:	5.807
Specific Surf. Area:	8648

Multisizer 4	10:19 11 May 2021
File name:	samples 09_P2-2 kl 12_01.#m4
File ID:	samples 09.05
Sample ID:	P2-2 kl 12.00
Control mode:	Total count 2000
Acquired:	9:41 11 May 2021
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	6000
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	4.125
Median:	3.273
D(0,0):	3.634
Mean/Median ratio:	1.260
Mode:	2.145
95% Conf. Limits:	4.062
95% Conf. Limits:	4.188
S.D.:	2.569
Variance:	6.599
C.V.:	62.27
Skewness:	3.344
Kurtosis:	21.70
d10:	2.164
d50:	3.273
d90:	7.064
Specific Surf. Area:	6792

Multisizer 4	10:20 11 May 2021
File name:	samples 09_P5-2 kl 12_01.#m4
File ID:	samples 09.05
Sample ID:	P5-2 kl 12.00
Control mode:	Total count 2000
Acquired:	9:48 11 May 2021
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	6000
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	2.912
Median:	2.448
D(0,0):	2.711
Mean/Median ratio:	1.190
Mode:	2.145
95% Conf. Limits:	2.870
95% Conf. Limits:	2.954
S.D.:	1.669
Variance:	2.786
C.V.:	57.31
Skewness:	6.893
Kurtosis:	70.91
d10:	2.077
d50:	2.448
d90:	4.052
Specific Surf. Area:	8334

Multisizer 4	########
File name:	21.04.2021_P1-16.30 1_02.#m4
File ID:	########
Sample ID:	P1-16.30 100 micron
Control mode:	Total count 2000
Acquired:	########
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	11167
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	3.179
Median:	2.657
D(0,0):	2.953
Mean/Median ratio:	1.197
Mode:	2.145
95% Conf. Limits:	3.152
95% Conf. Limits:	3.207
S.D.:	1.525
Variance:	2.327
C.V.:	47.98
Skewness:	3.503
Kurtosis:	22.85
d10:	2.097
d50:	2.657
d90:	4.873
Specific Surf. Area:	11160

Multisizer 4	########
File name:	21.04.2021_P2-2.16.34_01.#m4
File ID:	########
Sample ID:	P2-2.16.34.100micron
Control mode:	Total count 2000
Acquired:	########
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	8000
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	3.107
Median:	2.633
D(0,0):	2.891
Mean/Median ratio:	1.180
Mode:	2.145
95% Conf. Limits:	3.071
95% Conf. Limits:	3.144
S.D.:	1.695
Variance:	2.873
C.V.:	54.55
Skewness:	7.156
Kurtosis:	90.61
d10:	2.098
d50:	2.633
d90:	4.466
Specific Surf. Area:	8200

Multisizer 4	########
File name:	21.04.2021_P5-2.16.44_01.#m4
File ID:	########
Sample ID:	P5-2.16.44.100micron
Control mode:	Total count 2000
Acquired:	########
Size bins:	200
From	2.000
To	60.00
Sizing threshold:	0
Total pulses:	6000
Counting threshold:	0
Counts above threshold:	0
Coincidence corrected:	0
From	2.000
To	60.00
Number	100
Mean:	3.144
Median:	2.415
D(0,0):	2.804
Mean/Median ratio:	1.302
Mode:	2.145
95% Conf. Limits:	3.085
95% Conf. Limits:	3.204
S.D.:	2.358
Variance:	5.559
C.V.:	74.99
Skewness:	5.897
Kurtosis:	48.69
d10:	2.069
d50:	2.415
d90:	4.701
Specific Surf. Area:	5764