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Implications for Local Stormwater Treatment and Rainwater-use for Wastewater Treatment in Oslo

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NTNU
Norwegian University of
Science and Technology

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Abstract

This master thesis is written as a collaboration between NTNU and the NIVA project New Water Ways. Vestfjorden treatment plant (VEAS) and Bekkelaget treatment plant (BRA) has been the focus of this project. The main aim of the thesis is to calculate VEAS and BRA operational cost in the treatment process due to stormwater. The operational cost is calculated based on chemical and energy consumption. The operational cost will be compared with actual operational costs at the treatment plants. The possible extra operational costs due to stormwater could incentive more use of Sustainable Drainage Systems (SUDS) to avoid the stormwater entering the wastewater treatment plant in the first place.

The aim of the thesis is dependent on real data. Therefore, a big part of the total workload has been to collect data from the treatment plants. I have also collected primary data such as precipitation data, chemical prices and power prices. Another time-consuming assignment has been to make the excel-model functional. The last period has been used to test the results in a statistically significant test and compare the chemical and energy cost due to stormwater with total operational cost at the treatment plants.

First the assumption, that chemicals and energy is used more in periods of high inflow due to stormwater was verified. The chemicals Iron Chloride (PIX) and Polymer were used more at VEAS and BRA in wet periods. Aluminum Chloride (PAX) and Iron Sulfate (FeSO4) was the only chemicals that were used less in wet periods. The differences in use of FeSO4 in wet and dry periods was not found to be significant in the statistical analysis. The difference in use of PIX, Polymer and PAX was significant, and the conclusion that the amount of chemicals used are different in wet and dry periods is valid.

The highest total cost assigned to stormwater during one year was found in 2016 at VEAS and was 853 879 NOK, which included the maximum yearly cost of energy consumption and costs for chemical consumption. This cost was 0,27 % of the total operational cost for wastewater treatment at VEAS in 2016. The highest yearly cost assigned to stormwater during one year was found in 2017 at BRA and was 3 349 631 NOK. This cost includes only the costs for chemicals consumption. This cost was 3,56 % of the total operational cost for wastewater treatment at BRA in 2017.

Sammendrag

Denne masteroppgaven er skrevet som et samarbeid mellom NTNU og NIVA-prosjektet New Water Ways. Behandlingsanleggene Vestfjorden og Bekkelaget har vært i fokus for prosjektet. Hovedformålet med avhandlingen er å beregne VEAS og BRA sin driftskostnader i behandlingsprosessen på grunn av overvann. Driftskostnadene beregnes ut fra kjemikalie og energiforbruk. Driftskostnadene vil bli sammenlignet med de faktiske driftskostnadene på renseanlegget og utviklingskostnader. De mulige ekstra driftskostnadene på grunn av overvann kan stimulere mer bruk av Sustainable Drainage Systems (SUDS) for å unngå at vannet når avløpsnettet og renseanleggene.

Formålet med avhandlingen er basert på reelle data. Derfor har en stor del av den totale arbeidsbelastningen vært å samle inn data fra behandlingsanleggene. Jeg har også samlet primære data som nedbørsdata, kjemiske priser og energipriser. En annen tidkrevende oppgave har vært å gjøre Excel-modellen funksjonell. Den siste perioden har blitt brukt til å teste resultatene i en statistisk signifikant test og sammenligne kjemiske og energikostnader på grunn av overvann med totale driftskostnader på behandlingsanleggene.

Antakelsen om at kjemikalier og energi brukes mer i perioder med høy tilstrømning på grunn av overvann ble verifisert. Kjemikaliene Jernklorid (PIX) og Polymer ble brukt mer på VEAS og BRA i våte perioder. Aluminiumklorid (PAX) og Jernsulfat (FeSO4) var de eneste kjemikaliene som ble brukt mindre i våte perioder. Forskjellen i bruk av FeSO4 i våte og tørre perioder var ikke signifikant i den statistiske analysen, og vi kan ikke vite om det ble brukt mindre mengder av kjemikalet i våte perioder. Forskjellen i bruk av PIX, Polymer og PAX var signifikant, og konklusjonen om at kjemikaliemengden som brukes er forskjellig i våte og tørre perioder er gyldig.

Den høyeste totalkostnaden til overvann gjennom ett år ble funnet i 2016 på Vestfjorden renseanlegg og var 853 879 NOK. Denne kostnaden inkluderer maksimal årlig kostnad for energiforbruk og kostnader for kjemisk forbruk. Kostnaden var 0,27% av den samlede driftskostnaden for avløpsvannbehandling ved VEAS i 2016. Den høyeste totalkostnaden til overvann gjennom ett år ble funnet i 2017 på Bekkelaget renseanlegg og var 3 349 631 NOK. Denne kostnaden inkluderer kun kostnader for kjemikalieforbruk. var 3,56% av den samlede driftskostnaden for avløpsvannbehandling ved BRA i 2017.

Preface

This master's thesis is submitted to the Norwegian University of Science and Technology (NTNU) as a part of the master program of Civil and environmental engineering within the field of water supply and wastewater technology. The thesis is a continuation of the project thesis (Holmberg, 2018) written at NTNU in the subject TVM 4510 Water and Wastewater Engineering Specialization Work.

Trondheim 6. June 2018

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List of abbreviations

BRA	Bekkelaget Treatment Plant
PAX	Aluminum Chlorides
PIX	Iron Chlorides
VEAS	Vestfjorden Treatment Plant
VAV	Oslo Kommune Vann- og avløpsetaten
WWTP	Wastewater Treatment Plant
RVR	Rainwater Treatment
Af-on	Actiflo on
Bp-on	Bypass on
Mr	Much rain
C-on	Chemical Treatment on
CPI	Consumer Price Index
BEVAS	Bekkelaget Vann AS
Pe	People Equivalents
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
NH_4^+	Ammonium
CH_3OH	Methanol
UBRA	Project Extension Bekkelaget Sewage Treatment plant

1 Introduction

1.1 Research Project

New Water Ways is a project that researches and explores ways to move beyond today's conventional urban water management. The projects main purpose is to make Norwegian cities frontrunners in the transition to sustainable urban water management. The need for this transition is partly caused by the climatic changes which increases the quantity of precipitation as well as the rainfall intensity (NOU:10, 2010). Population growth and urbanization are other drivers that encourages a new mindset when rehabilitating, rebuilding and designing new wastewater systems. In 2014 there were approximately 620 000 inhabitants in Oslo, and in 2030 it is estimated that the city will inhabit 800 000 people (Oslo kommune Vann- og avløpsetaten, 2014).

Today residential areas, city centers and industrial areas is built in a different way than 50 years ago (Tegelberg & Gilbert, 2013). Our cities have a higher number of impervious surfaces which accumulates more stormwater than natural vegetated surfaces. The increased amount of water and its various quality sets new requirement in terms of capacity, sustainability and adaptability for Oslo's infrastructure. Especially with regards to the city's pipe system including overflows, pumps and the wastewater treatment plants (VEAS, 2019).

1.2 Background

1.2.1 The Wastewater System in Oslo

There exist two wastewater treatment plants in Oslo, Bekkelaget treatment plant (BRA) and Vestfjorden treatment plant (VEAS) (Oslo kommune Vann- og avløpsetaten, 2014). Bekkelaget treatment plant handles 40 % of the wastewater accumulated in Oslo (Eliassen, 2016).At Fagerlia it exists a slot, where VAV has the possibility to flexibly divert the water in parts of the city. BRA is owned by Oslo municipality and operated by the private company Bekkelaget Vann AS (BEVAS). BRA also handles part of the wastewater from Oppegård and Nittedal. Vestfjorden treatment plant handles the remaining 60 % of wastewater accumulated in Oslo (Eliassen, 2016). VEAS is owned by Oslo municipality, Bærum municipality and Asker municipality. Therefore, in addition to treating the wastewater from Oslo, VEAS also treats wastewater from Bærum, Asker, Røyken and Nesodden (VEAS, 2018)

One challenge for VEAS and BRA is the high amount of extraneous water that is led to the wastewater treatment plant. In 2014 Oslo Kommune Vann- og avløpsetaten (VAV) estimated that the amount of extraneous water in Oslo`s wastewater system was 58 % for all areas in the city. Where the biggest bulk of these areas had either combined sewer pipes or older separate pipes. However relatively new wastewater pipes were found to have a lower percentage of extraneous water (Oslo Kommune Vann- og avløpsetaten, 2014).

The flow to a wastewater treatment plant (WWTP) has an impact on operational costs at the treatment plant as well as the environment at the near lying sites (Gerly Hey, 2016). Operational cost such as chemical use, energy for pumping and manpower are presumed to be higher when more water is transported to the WWTP, (Vann- og avløpsetaten, 2014). In periods after rain and snow melting the flow exceeds the capacity of some

important parts of the treatment plants which may result in overflows and direct releases of untreated wastewater into receiving waters (Ann Mattsson, 2015).

In addition to the overflows connected to the wastewater treatment plant, there exists 218 other overflows in Oslo. In situations with a high downpour, wastewater is led via overflow to the nearest watercourse. The wastewater emitted are highly diluted but are still a major source of pollution to the watercourses and the Oslo fjord (Vann- og avløpsetaten , 2018). As of 01.01.2015, VAV has responsibility for a total of 185 overflows, of which 157 are precipitation-dependent overflows and 28 emergency overflows. It's the rainfall dependent overflows that will increase emissions due to the extraneous water (Vann- og avløpsetaten, 2014). There exist no quantity meters on the overflows in the sewage pump stations, and therefore these overflows are difficult to consider further in this report.

1.2.2 Local Stormwater Treatment

Local treatment of stormwater with nature-based solutions like rain beds, bioswales and green roofs, are measures to reduce the amount of stormwater in the piped wastewater system. In Oslo the stormwater treatment follows a three step strategy. In the first step the water is infiltrated, in the second step the water is delayed and detained and in the third step we ensure secure flood ways (Oslo Kommune, 2013). When treating the stormwater locally, digging and installation of larger wastewater pipes or separate stormwater pipes can be avoided. Less water needs to be transported to (pumping costs) and be treated at the wastewater treatment plant and the wastewater is less diluted by rainwater which might lead to savings in chemical use and better purification.

1.3 Problem Approach

To further investigate stormwaters contribution and its effects on the wastewater system in Oslo the following research questions was established:

1. Which impact does stormwater have on the treatment process at VEAS and BRA?

    1.2   What are the differences in the usage of chemicals and in electricity consumption in periods with and without stormwater coming to VEAS and BRA?

2. What costs are related to these changes in the treatment process?

    2.1   What are the total costs which can be assigned to stormwater during one year?

1.4 Report Structure

Section 1 is an introduction to the reports theme, goal and issue.

Section 2 is a presentation of relevant theory that were used to investigate the goals and issues presented in section 1. Section 2 is meant to give the reader an overview of the wastewater system in Oslo and stormwaters theoretical effects.

Section 3 presents the case area, as well as the methodology for data collection and calculations. Section 4 explains and evaluate the results from the calculations.

Section 5 contains discussion of the results found in section 4. And put them into a larger context.

2 Theory

2.1 The Wastewater System

The main function of the wastewater system is to transport polluted water from households, business and public enterprises to the treatment plants. In addition, the wastewater network leads stormwater and drainage water from buildings and other structures. Which should be carried out in a way that does not adversely affect the external environment. As a thumb rule, we can say that the wastewater system is designed to transport a volume equivalent with the volume of drinking water supplied to the consumers. In practice, the volume transported in the wastewater network is much larger because of all the extraneous water that gets added to the system (Ødegaard, 2014).

The wastewater system is a conglomerate built out at an uneven pace over 170 years. Large grips have been made in the construction of the treatment plants BRA and VEAS, and the tunnel system that connects them. In 2014, the tunnel system received and additional tunnel Midgardsormen (Oslo kommune Vann- og avløpsetaten, 2014).

In addition to maintenance and rehabilitation, as well as almost 100% connection to the sewer network, we have increasingly cleaner urban waterways and fjords.

The Key numbers, Figure 1 shows the huge complexity of the wastewater system in Oslo. It includes treatment plants, sewage system, wastewater network, stormwater network, common network, pumping stations, overflows, discharges to the tunnel system, detention basins, valves, tunnels, man holes, and septic basins (Oslo kommune Vann- og avløpsetaten, 2014).

Key numbers

Two treatment plants
VEAS
BRA

2250 km sewer system
670 km wastewater network
760 km stormmwater network
820 km combined network (wastewater and stormwater in the same network)

75 public pumping stations
18 private pumping stations (operated by the VAV)

218 overflows
751 stormwater discharges
28 tunnel discharges
33 km tunnels
2 Septic basins

44750 man holes
(sewagewater wastewater,stormwater, and drinking water)
125 non return valves
236 intakes to stream with screens

Figure 1: Key Numbers for the Wastewater System in Oslo

2.1.1 Stormwater

In this report I have chosen to use (Det Kongelige Miljøverndepartement, 2012-2013) definition of surface water; "Stormwater includes water moving on ceilings, roads, and other dense surfaces as a result of precipitation or meltwater". Expanding cities and more impervious surfaces lead to less natural infiltration and increased surface runoff, as seen in Figure 2.
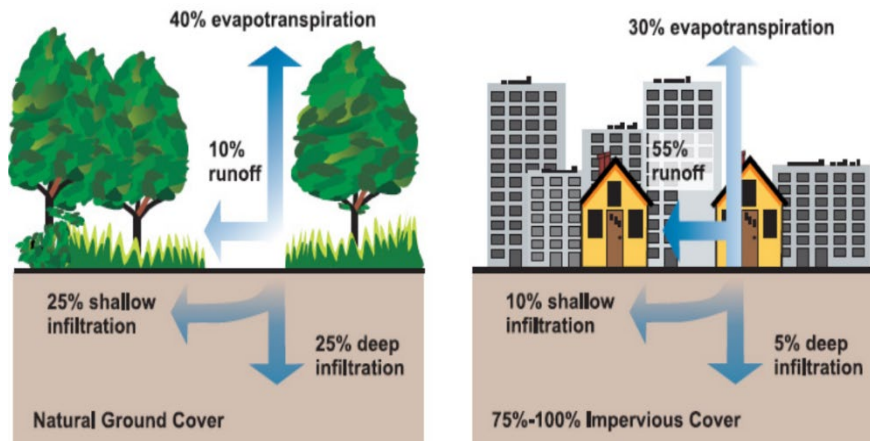
Figure 2: Urban Cities (EPA, United States Environmental Protection Agency, 2003)

The impervious surfaces decrease the time the water needs to runoff over a surface. This means that we have more rainwater at the same time and therefore a higher peak runoff rate. Traditionally, we have built combined sewer and stormwaters systems to handle the peak runoff rate for bigger catchments in urban cities. These catchment areas often have a high density in material values that has a high socioeconomic cost if they get damaged (NOU, 2015). Roads, water management, electricity, transport and buildings are examples of such material values that are vulnerable and has a high damage cost for the society.

2.1.2 Conventional Stormwater Management

Traditionally, grey infrastructure has been built to transport stormwater away from the site it was propagated. "Stormwater runoff is undesirable and must be removed from the site as quickly as possible to achieve good drainage". This strategy can be called the one-step strategy. Every feature of a conventionally designed site is planned to quickly convey runoff to a centrally located management device, usually at the end of a pipe system. Roadways, roofs, gutters, downspouts, driveways, curbs, pipes, detention basins, and parking are designed to dispose of the runoff in a rapid fashion. The magnitude of hydrologic changes (increases in volume, frequency, and rate of discharge) are amplified as natural storage is lost. The conventional management increase the percentage of impervious surface, decreases the time of concentration, decreases the runoff travel times, which results in more hydraulic connection. Typical conventional site design results in developments missing natural features that detain, retain or infiltrate runoff. Lack of these features affects the ecosystem (County, 1999).

**Figure 3: Conventional one-step
Strategy (OVASE, 2018)**

2.1.3 Pipe Systems

The conventional site designs most important infrastructure is the pipe system. Combined system is the term for pipe systems that disposes of both wastewater and stormwater. Combined system has been the most used solution since the first pipes was installed in the 1850s (Ødegaard, 2014). In separate systems we have one pipe for wastewater and one pipe for stormwater. We separate the different quality of precipitation runoff and sewer runoff. Experience shows that most pipes that are rehabilitated and installed today is done with separate systems, due to the lack of capacity in the existing combined solution. At high precipitation intensities the stormwater/sewage runoff is led to sea or watercourses, through overflows due the insufficient capacity in the combined system (Lindholm, 2008). This can lead to pollutant contamination in drinking water and bath water, which pose environmental and health related risks. At the same event we can experience flooded buildings, destruction of infrastructure and possible leakage into drinking water pipelines, with significant damage costs (Det Kongelige Miljøverndepartement, 2012-2013).

2.1.4 Sustainable Drainage Systems

The transition in stormwater management are designed by the means of flexible, adaptable and sustainable solutions, called Sustainable Drainage Systems (SUDS). The common features of the SUDS are the push from a central management device (as in conventional solutions) to decentralized solutions (Robert Sitzenfrei, 2013). In other words, the SUDS are to manage the stormwater on site where the precipitation runoff is accumulated. The transition is supported by Norwegian rules and reports. In report 200-2014 "Landowner is responsible to manage stormwater on own property" (Norsk Vann , 2014) and Building Technology Regulations (TEK 10) § 15-10 "Stormwater including drainage water should as far as possible be infiltrated or otherwise handled locally to ensure the water balance in the area and avoid overloading of the sewerage system". Both incentives increase the awareness of stormwater, and the alternative solutions that exists for local stormwater management.
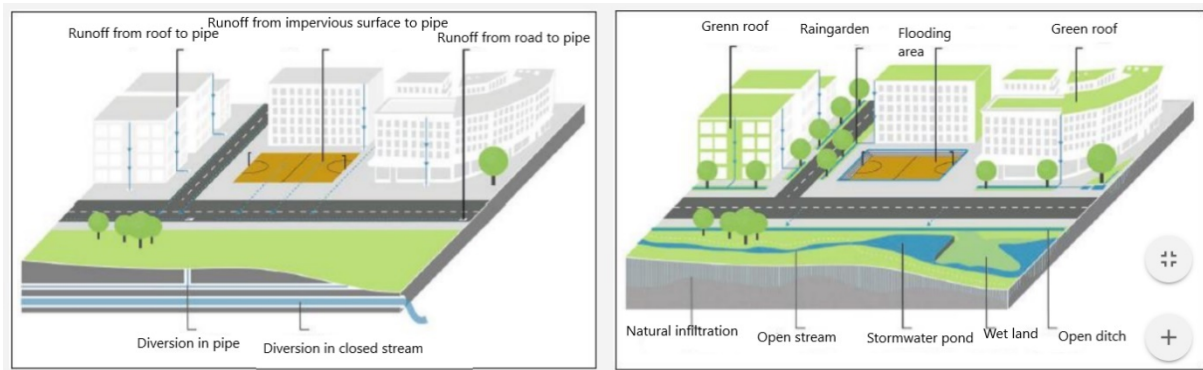
Figure 4: Conventional and Sustainable Stormwater Management (Per Møller-Pedersen, Storm Aqua AS, 2018)

These solutions are often referred to as blue green solutions. The solutions are designed based on the three-step strategy for stormwater management, Figure 5. In the first step we infiltrate moderate rainfall events by solutions like raingardens, green roofs and pervious surfaces. In this step we also lead the stormwater from roofs, roads and open spaces to green areas, open diches and channels. In the second step we collect, detain and retain heavy rainfall events by dedicating areas to store and manage the stormwater, e.g. raingarden, green roofs and open detention basins. In this step it is also important to reduce the risk of floods in areas where the surface water often accumulates and cause critical damages. In the third step we facilitate open flood ways for the extreme rainfall events. We assure that the heavy quantities of water are safely transported thru the city to the floodways (roads and watercourses) and further into the sea. In some areas we might also need to implement subterranean tunnels (Oslo Kommune, 2013).

Figure 5: The three-step Strategy (OVASE, 2018)

2.2 VEAS

2.2.1 Background
Vestfjorden Avløpsselskap also known as VEAS treats water from industry and households in Oslo, Bærum Asker, Røyken and Nesodden (VEAS, 2017). VEAS receives and treats wastewater from approximately 576 000 people, 386 000 people equivalents (pe) is coming directly from the western parts of Oslo (Oslo Kommune, 2013).

VEAS was built in the 1970s and was designed for the hydraulic and material load of the time. At that time, the plant had only requirements for the removal of phosphorus. The operation of the plant went through 8 processing halls where the flow was treated chemically with coagulant in sedimentation basins. In the 90's VEAS got new requirements for the removal of nitrogen and carbon (Chemical oxygen demand and Biochemical oxygen demand). In 1995 the plant was upgraded to withhold the new standards. The old processing halls were modernized by expanding the capacity of the sedimentation tanks and placing nitrification and denitrification pools at the end of the halls. The sludge treatment started operation in 1993. To further increase the hydraulic capacity a rainwater treatment line was opened at VEAS in 2008. The rainwater treatment line (RVR) includes the Actiflo treatment line and the Bypass line.

VEAS is one of the most compact plants available that removes both phosphorous, nitrogen and carbon. In the later years the water flow in the region have increased because of population growth. This has led to a higher mass flow of nutrients. However, the hydraulic load does not seem to increase notably. In 2016 VEAS treated 97 mill m3 including rainwater, in 2017 the amount of wastewater and rainwater being treated was 96,4 mil m3 and in 2018 87,6 mil m3 was treated (VEAS, 2018). The yearly annual precipitation for the same years was 729mm 941mm and 657mm.

VEAS has a total of 8 lines, including 6 lines of "full treatment": chemical dosage with sedimentation, nitrification and denitrification. In addition, the plant had 2 pure chemical lines. Which were taken out of operation early summer 2018 for rebuilding.

Before 2018, the chemical lines have operated much of the time to hydraulically relieve the full-cleaning lines. Over the years, there has been concrete rehabilitation and replacement of nozzles in the biological filters, and there have been occasional lines out of service.

2.2.2 Flowchart and Buildup
The flow that enters VEAS is a combination of rain and melt water, shower/bath water, toilet flushing, wastewater, washing machine water, water from business and industry, and inleak from drinking water. All of the water enters VEAS in an inlet sump, where there are pumps pumping the water about 20 m up to the main facility and the rainwater treatment (RVR) (VEAS, 2018). The pumps going to RVR is placed higher up than the ones going to the main facility. Mostly because RVR doesn't have a sand trap, and with the altitude substances such as gravel, toilet wipes, napkins, tampons and diapers are not able to reach RVR. RVR pumps are only operative when there is a high amount of inflow to VEAS, for example in periods with heavy precipitation.

2.2.2.1 Main Facility
The first step in the treatment for the main facility is the screens, where coarse-particulate matter is separated from the waste water, which may create operational

problems later in the treatment plant. At VEAS the screens are built up of perforated steel plates with 6 mm openings. The larger particles are thereon washed and sent to landfill.

After the screens the flow enters the sand trap, here sand and heavier particles such as coffee grounds sink to the bottom and gets sucked out. At the same time fat flows up to the surface and are collected with a scraper. Also, here all the waste collected is washed before it goes to landfill. Simultaneously in the sand trap the chemical cleaning starts by dosage of felling chemicals. At VEAS Iron Chlorides (PIX) and Aluminum Chlorides (PAX) are used. The water still consists of tiny particles and some dissolved substances, such as phosphates the aluminum/iron ions have a positive charge, so they adhere to the negatively charged particles in the waste water. Hydroxide bonds are formed between them, and we get to form slightly larger but still very small particles. In addition, the aluminum ions react with the negative ions of phosphate, which we want to remove. We get formed a sparingly soluble salt that precipitates out of the water. This process directly after the dosage of chemicals is called coagulation and is the first step in the chemical treatment. For the small particles to clump into larger particles which is a process called flocculation, we add negatively charged Polymer (Anion Polymer) just before the water enters the sedimentation pool. A Polymer is a long chain organic compound that bonds the smaller flocs to larger flocs.

In the sedimentation pool the chemical purification is completed by continued flocculation, the large and heavy flocks fall to the bottom at the 12 m deep pool, and the precipitate is called sludge. At the same time water rises slowly upwards and crosses into the gutters at the top of the pool.

After crossing the gutters at the top of the sedimentation pool, the water continues to the biological purification stage. After the sedimentation basin, most of the phosphorus and the organic material are removed, but the water is still rich in nitrogen in the form of ammonium (NH_4^+). In the biological purification step, we don't add chemicals but facilitate the conditions so that the bacteria can perform the job. There is a specific bacterium we want to thrive, so the conditions must be tailored to this bacterium.

The biological purification is done in two steps nitrification and denitrification. Nitrification is the conversion of ammonium to nitrate. This process occurs in a large pool where air is injected in the bottom. Denitrification is the conversion of nitrate to nitrogen gas. There is no oxygen present and we have anoxic conditions. For the denitrifying bacteria to work it must be fed food in the form of a carbon source, and at VEAS they use methanol (CH_3OH). The last step in the process is when gas bubbles up from the water. In both nitrification and denitrification new bacteria (biofilm) are formed. Finally, after the denitrification, the water is completely cleaned.

2.2.2.2 Rainwater Treatment (RVR)
The rainwater treatment includes both the Actiflo treatment line, and the amounts of water entering the Bypass line.

2.2.2.2.1 Actiflo
The RVR pumps transports the water to the rainwater treatment called Actiflo at VEAS. Here the water meets screens like the ones in the main facility where coarse particles and garbage are separated from the water. After the screens the flow is transported to a basin where felling chemicals; PIX, Microsand and Polymer are added to the water. The coagulation starts immediately, before the flocculation and larger flocks are formed. As in the main facility, the particles sink to the bottom, and are sucked out. The chemical

treatment with coagulant is the last treatment step at Actiflo. After screens and chemical treatment, the water is released to the Oslo fjord at a 50 m depth.

2.2.2.2.2 Bypass

At times where the inflow is higher than the capacity of the Main facility and Actiflo combined, the water is led to the Bypass lines. At the Bypass the only treatment step is screens, to remove large particulate matter. After the screens the water is released to
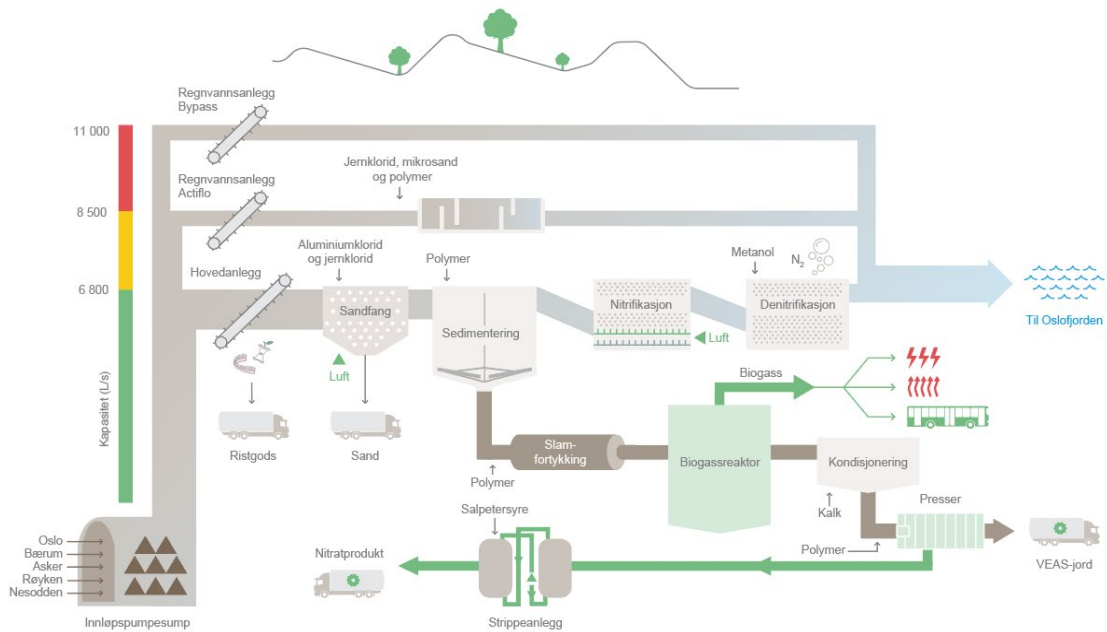

Figure 6: Flowchart Vestfjorden Treatment Plant (VEAS, 2018)

the Oslo fjord at the same depth as Actiflo and the Main facility.

2.3 BRA

2.3.1 Background

Bekkelaget treatment plant was built as an outdoor facility in 1963 (Røsland, 2013). The old facility was replaced by todays indoor facility in 2001. The facility was originally designed for 270,000 pe. During the period 2007-2012, several upgrade measures were carried out so that the design capacity increased to 290,000 pe. In 2010, the load of approximately 320,000 pe, i.e. 10% overload in relation to the plant's design capacity after completed upgrade measures. The tunnel system connected to BRA has a magazine volume of 35 m3. Midgardsormen is a collection system for stormwater and overflow water that was put into operation in the summer 2014, which adds 75 000 m3 of tunnel capacity to BRA. In addition to increasing the magazine volume at BRA, Midgardsormen have increased the possible hydraulic and chemical load reaching BRA. Midgardsormen has resulted in an additional load of around 50,000 pe to Bekkelaget treatment plant (Røsland, 2013). Project Extension Bekkelaget sewage treatment plant (UBRA) was approved in Oslo City Council in December 2013. The project includes expansion of the current plant with new mountain halls north and south of existing mountain facilities, as well as new access tunnel. The expansion will increase the plant's design cleaning capacity from a population of approx. 290,000 to approx. 540.000. Construction work started in October 2014 and the plant is expected operational in 2020.

2.3.2 Flowchart and Buildup

The flow enters BRA at the pumping station, where three pumps are operating. Thereon, the water is pumped to the step screens where garbage and bigger particles are removed. The flow continues to the fat and sand separator where the sand sinks to the bottom, and fat rise to the surface.

BRA is an activated sludge treatment plant, and during normal operation the water is led directly to the biological cleaning step after pretreatment and mechanical treatment. In the biological treatment step, we have pre-denitrification and simultaneous precipitation with the use of Iron Sulfate ($FeSO_4$). For an activated sludge process the addition of air, and the return of sludge from the sedimentation tank to the air basins is essential for the process to be effective. There exist certain filamentous bacteria that are poorly removed in the sedimentation basins and experience has shown that the addition of Aluminum Chlorides (PAX) reduces the growth of these filamentous bacteria. Therefore, PAX and Polymer are also added to get better sedimentation. The air addition is prerequisite for a high degree of organic material (BOD) removal and the nitrification. The amount of air added via blowers is controlled by oxygen sensors in the air basins. This also means that when there is a lot of water, which contains little organic material and is rich in oxygen, the need for air addition is smaller. Parts of the flow are returned to the inlet ("anox zone" in Figure 7) for pre-denitrification where no air is added. The addition of $FeSO_4$ is prerequisite for the phosphorus removal. The amount of $FeSO_4$ is dosed after residual phosphorus at the outlet and should not be affected much by high hydraulic load, provided that the high amount of water does not contain much phosphorus. When the concentration of phosphorus at the outlet is high, the dosage $FeSO_4$ is increased. The specific boundaries are; > 0.2 mgPO4 / l dosage is increased <0.1 mgPO4 / l dosage is reduced. Since BRA uses a pre-denitrification the process does not need to add an external carbon source.

At high inflow, the biological step (to avoid loss of the biomass) is bypassed for flows above 1,9 m3/s, and only PAX and Polymer is dosed before pre-sedimentation and polished in the two-media filter at the outlet. The phosphorus removal and removal of

particles / colloids is maintained while nitrogen removal and removal of loose BOD is lost for all flows above 1,9 m3/s.

After the biological step the water continues to post sedimentation tanks where further removal of particles is achieved. After the post sedimentation the water goes through two media filters consisting of sand and Leca. This is the last treatment step before the water is pumped out in the Oslo fjord at a depth of 50 meters.
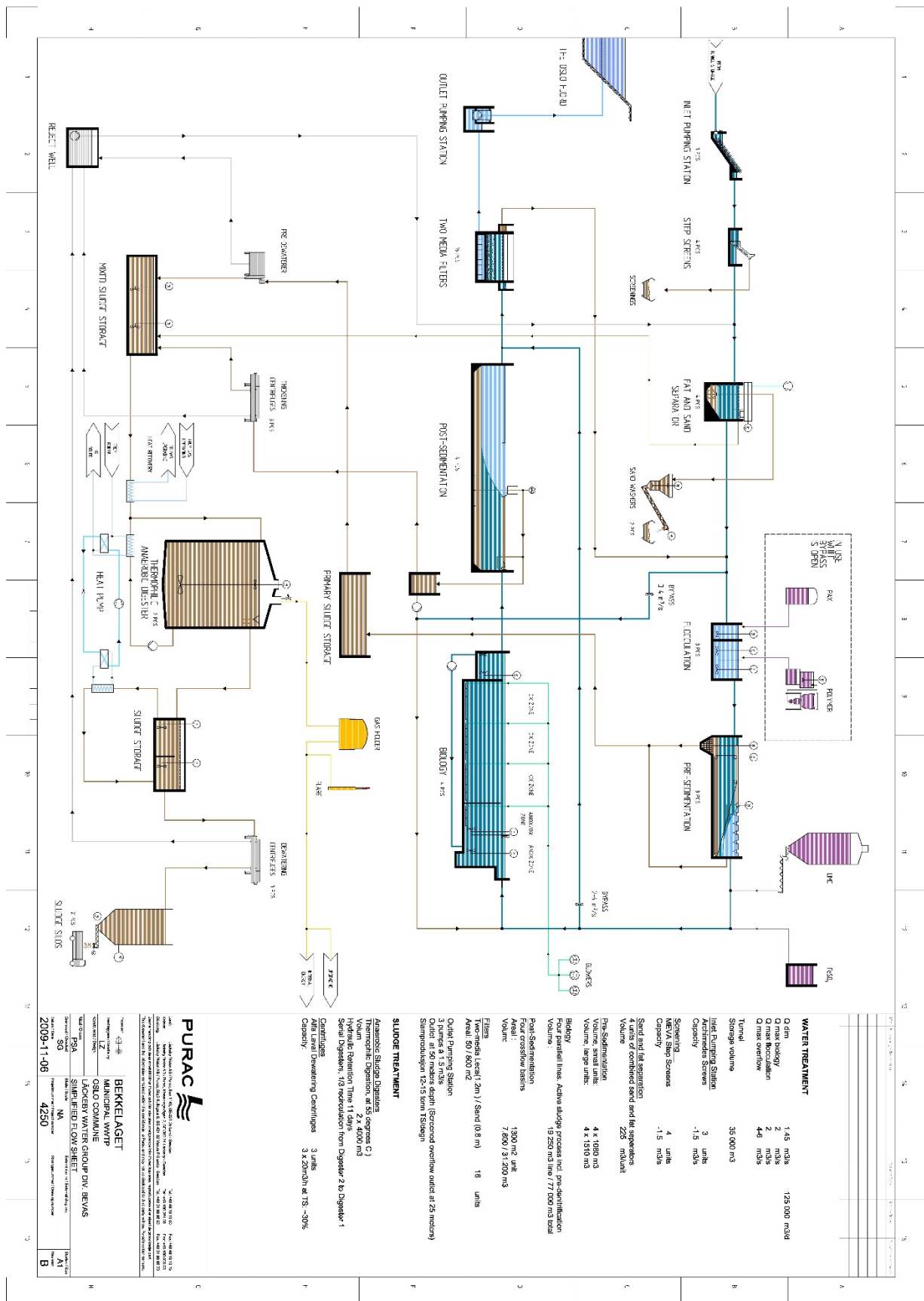
Figure 7: Flowchart Bekkelaget Treatment Plant

3 Methodology

Selection of Case Study

The main goal of this study is to investigate the extra costs caused by stormwater at VEAS and BRA. To limit the assignment, we choose to look at operational costs with respect to chemical dosage and energy use. As geographical study area the watersheds connected to VEAS and BRA was chosen for further investigation. When we had sat the geographical boundaries, we needed to limit the assignment with regards to the time frame.

Daily data would be collected from April, May, June, July, August and September for 2016, 2017 and 2018. Limiting the data to 6 months was mainly to have a manageable amount of data. The summer period was chosen to include the summer rains, and the heavy precipitation that appears in the fall. The summer of 2018 was exceptionally dry,

Figure 8: The Watersheds in Oslo connected to VEAS and BRA (VEAS, 2018)

and that is another reason why we choose the summer and these years as our time frame. Summer is the time of year where the watercourses are most sensitive to pollution, since it is at summertime we swim and bath in the watercourses and seas (Oslo Kommune, 2013). BRA receives and treats wastewater from Oslo's eastern and southern districts, as well as wastewater from parts of Oppegård and Nittedal. The quantity of water being treated

represents wastewater from approximately 290 000 people. VEAS on the other hand receives and treats wastewater from approximately 576 000 people.

The wastewater treated is accumulated in the westerns part of Oslo including Bærum, Asker, Røyken and Nesodden. Whereas wastewater from 386 000 people is coming directly from the west of Oslo city (Oslo kommune Vann- og avløpsetaten, 2014).

In Figure 8 we can see the catchments connected to VEAS and BRA. The hatched orange and hatched green fields are the catchments where accumulated wastewater can be transported to both VEAS and BRA. At the slot Fagerlia VAV can control the distribution of this amounts of water transported to the two different treatment plants, to reduce overflows (Vann- og avløpsetaten , 2017).

3.1 Data Collection

To be able to answer the research questions set out in the problem approach a wide and large collection of data was needed. I want to investigate the operational costs at the treatment plants in wet days where stormwater is present. For this investigation I needed precipitation data to define criteria for wet and dry days. I needed quantities of water that had been treated at the facilities, the energy that was used for the inlet pumps, and the amount of chemicals used at the plants. To collects data, it was crucial to establishing a good contact with VEAS and BRA represented by the VAV. In addition, precipitation data, chemical prices and power prices were collected to answer the research questions.

3.1.1.1 Precipitation Data

Precipitation data representative for all the watersheds connected to VEAS and BRA were collected from three weather stations using eklima.no. Blindern weather Station (18700) in the north of Oslo, Hovin weather station (18210) in the east of Oslo, and Asker weather station (19710) placed outside of Oslo, to represent the watersheds placed west. The approximate position of these weather stations can be seen in Figure 8. The weather stations selected do not represent the whole watershed (e.g. not Nittedal and Nesodden), but large parts of the watershed.
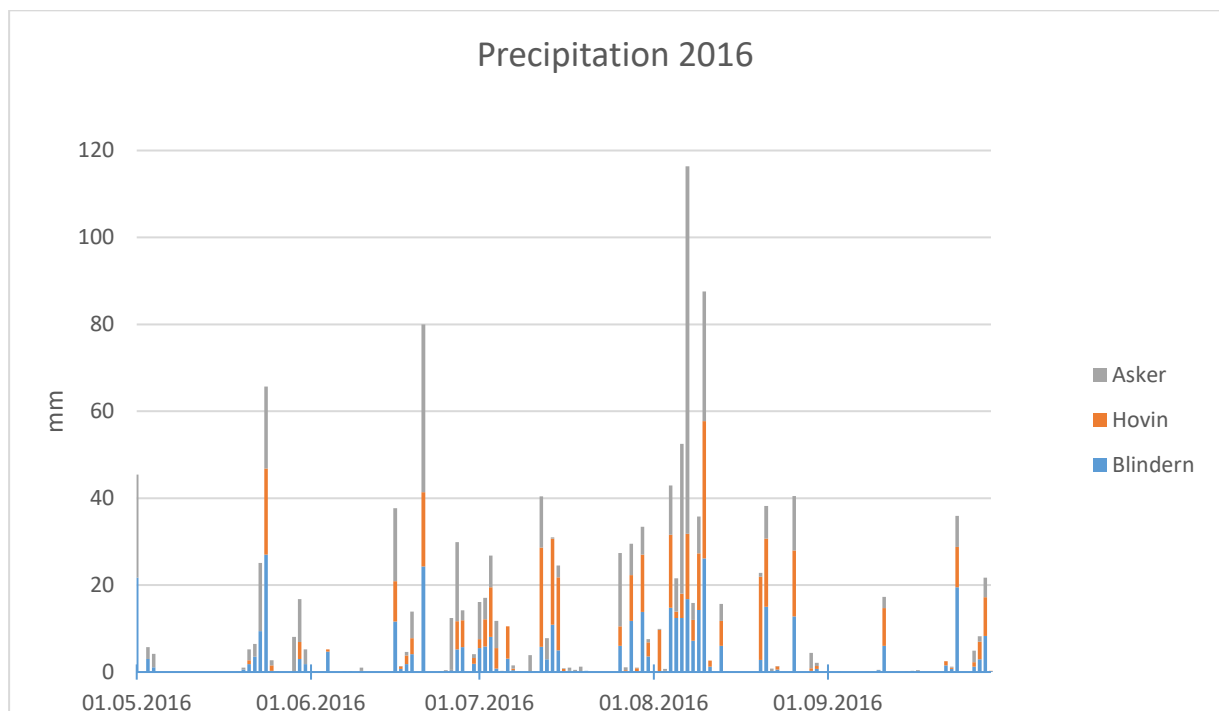
Figure 9: Precipitation 2016
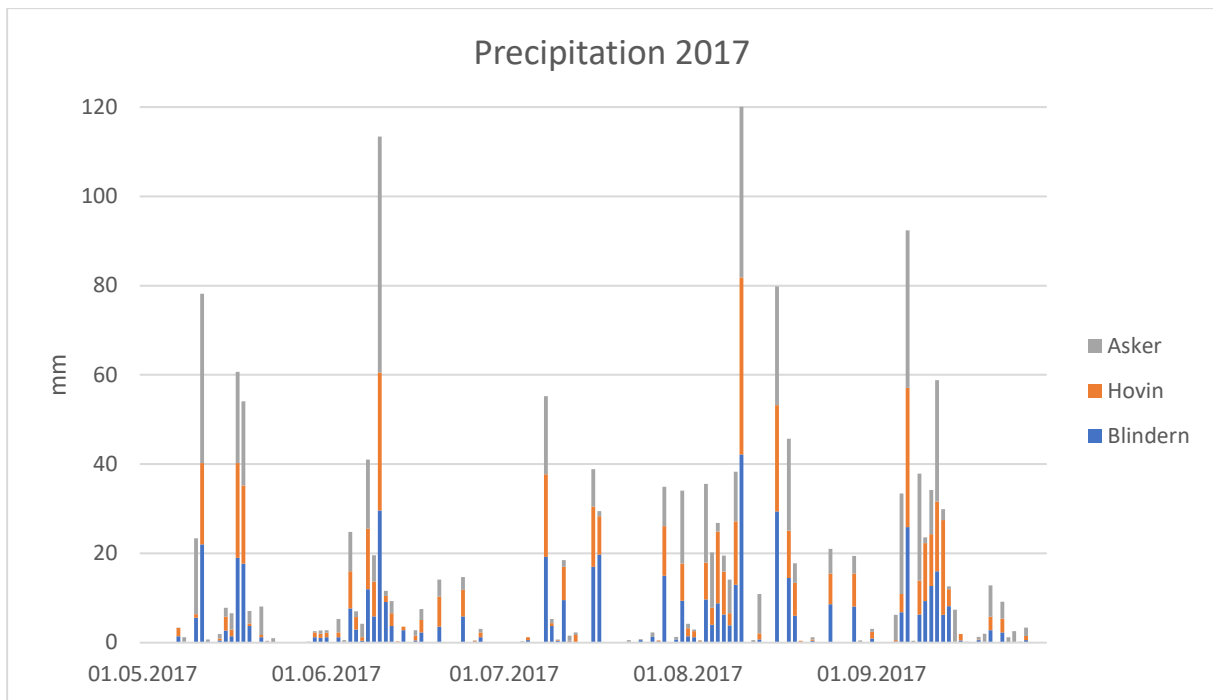
Figure 10: Precipitation 2017
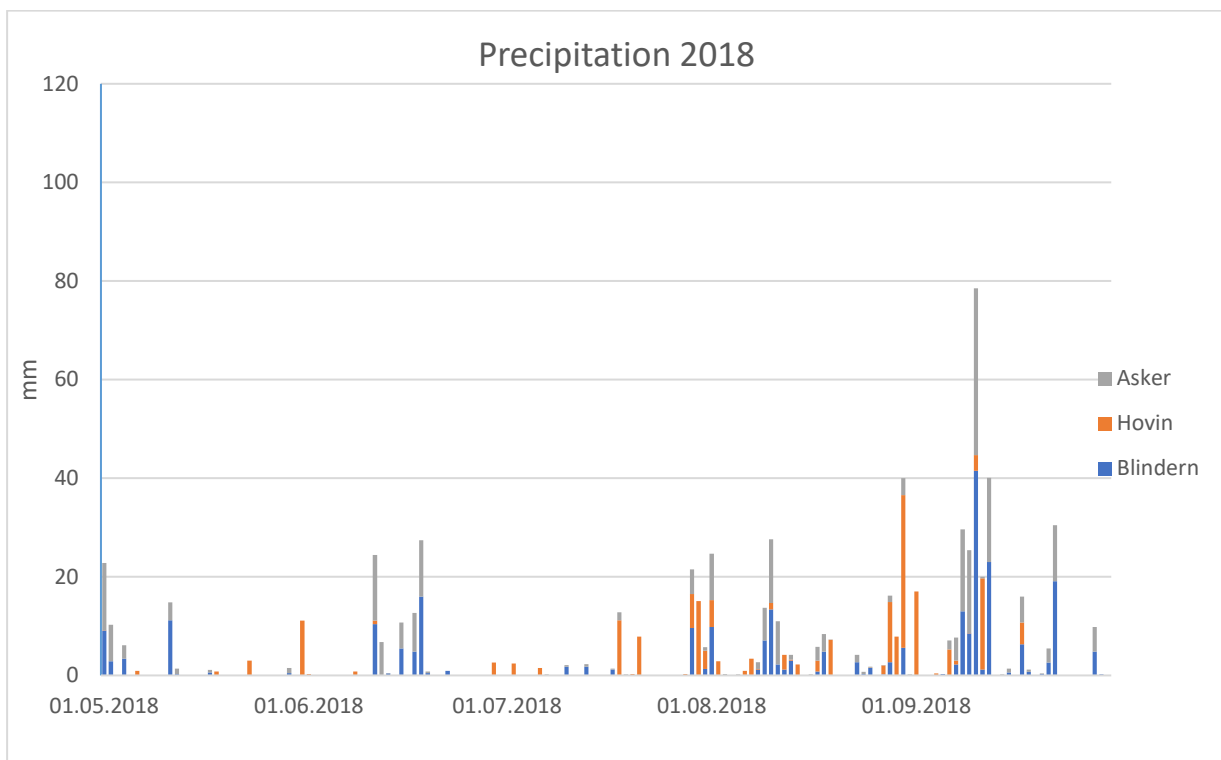
Figure 11: Precipitation 2018

In this report the months May, June, July, August and September are defined as Summer. By comparing Figure 9, Figure 10 and Figure 11 we see that precipitation in the summer of 2018 were lower than the summer of 2016 and 2017. With a total of 1631 mm 2017 was the wettest year, as shown in Table 1.

Year	2016	2017	2018
Summer Precipitation (mm)	1299	1631	713,2

Table 1: The Sum of Summer Precipitation for Blindern, Hovin and Asker.

3.1.1.2 Power Prices

The power prices were collected from historical data presented by LOS AS which is currently the largest power supplier in the corporate market, and third largest in the private market in Norway (Forbrukernet, 2019). The monthly average energy prices from May to September was collected for 2016 ,2017 and 2018.

South East-Norway - Oslo (NO)	2016 NOK/Kwh	2017 NOK/Kwh	2018 NOK/Kwh
May	26,28	32,95	39,40
June	28,11	27,90	52,86
July	27,42	30,80	62,34
August	25,15	31,22	61,85
September	27,30	35,18	55,94
Yearly Average	54,49	31,61	26,85

Table 2: Monthly Power Prices, (Forbrukernet, 2019)

In Table 2 we can see that the power prices increased in 2018. This might be due to the low amount of precipitation that fell in the summer of 2018. To further estimate the cost of extra energy in this assignment the minimum yearly value of 26,85 NOK/kWh and the maximum yearly value of 54,49 NOK/kWh was used.

3.1.1.3 Chemical Prices

VEAS and BRA both use felling chemicals in their treatment process. The treatment plants agreements and their respective purchase prices with the distributor of the chemicals are classified due to market competition. Therefore, the prices used for calculation are suggested prices given in an interview with sales manager at Kemira Norge, Ove Sanna (Sanna, 2019). Kemira delivers Aluminum Chlorides (PAX) and Iron Chlorides (PIX) to VEAS, and PAX to BRA. The respective density of PAX, PIX and Polymer was also collected from the interview. Kemira does not deliver Iron Sulfate (FeSO4) to BRA, and the price of FesO4 was collected from Helge Eliassen my contact person at BRA, and the density was collected from (PubChem, 2019).

Chemical	Price per ton (NOK)	Density (kg/m3)	Price per l (NOK)
PAX	2450	1370	3,357
PIX	1350	1480	1,998
Polymer (Acrylamide)	30000	1130	33,9
FeSo4 (Iron Sulfate)	685	1900	1,945

Table 3: Suggested Chemical Prices from Kemira and BRA (Sanna, 2019)

3.1.1.4 VEAS and BRA

VEAS and BRA both contributed by collecting data on water supply, chemical use, and the power used by pumps at their treatment site. In addition to collecting these data for the summer of 2016,2017 and 2018, I visited Vestfjorden treatment plant at the 13. March 2019 to better understand their facility. BRA represented by VAV and Helge Eliassen has been interviewed to understand the flow chart of Bekkelaget treatment plant.

3.2 VEAS

In this section the methodology for defining criteria and calculations for VEAS will be revised.

```
Criteria
  • Rain
  • Bypass
  • Actiflo

Calculations
  • Chemical Consumption
  • Inletflow
  • Energy Use

Results
  • Operational Costs
```
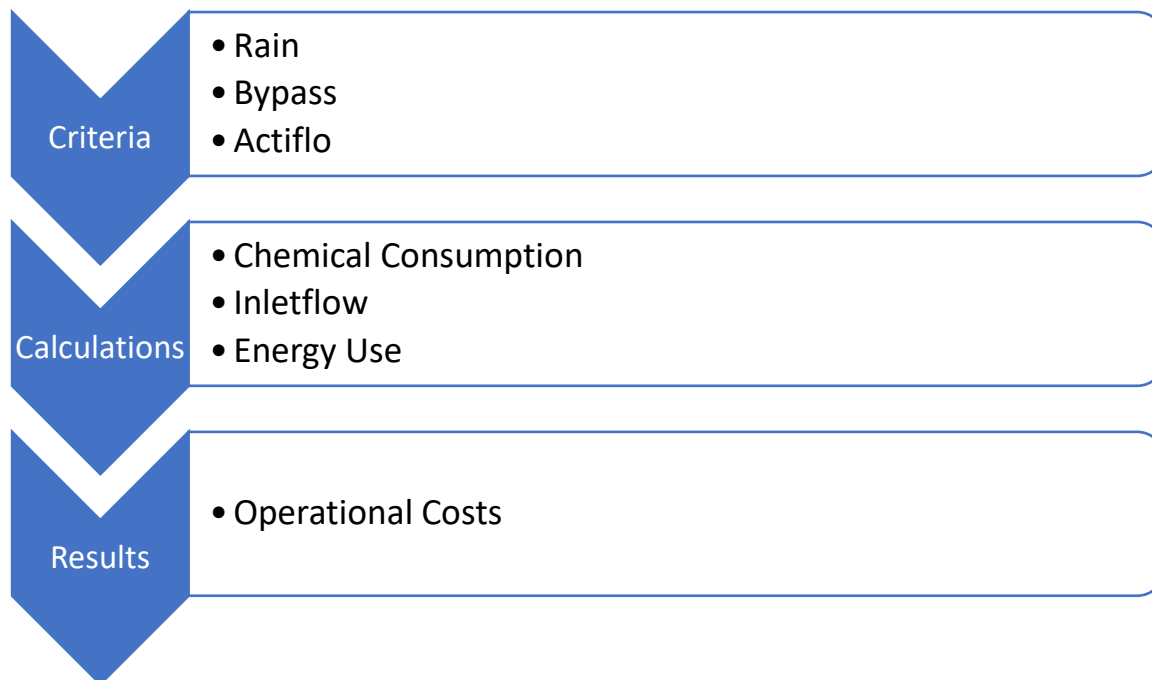
Figure 12 Methodology Flowchart VEAS

3.2.1 Stormwater Criteria

To be able to calculate operational costs due to stormwater in the treatment plants wet and dry periods needs to be defined. We want to compare treatment costs with and without a lot of stormwater in the system and we assumed that in "dry" periods there is no/little stormwater in the wastewater, while during/after rainfall a mix of stormwater and wastewater reaches the treatment plants. Four different criteria were established to define dry and wet periods for summer 2016,2017 and 2018.

3.2.1.1 Rain Criterion

The rain criterion was set based on the precipitation data collected from eklima.no. between May and September for 2016-2018. The precipitation at Blindern weather station, Hovin weather station and Asker weather station was summed up to make the criterion. The precipitation data collected had a high number of values < 0,1 mm and a high number of mid values, and did not follow a normal distribution. The Zr-2 boundary was set to represent dry periods, and the Mr boundary were to represent the wet periods. The criteria were set by summing the Mr, mid and Zr-2 precipitation values. The Mr boundary includes only 5 % of the data, Table 4.

Boundaries	Precipitation (mm)	Number	Percent
Zr-2	p < 0,1	189	41,18 %
Mr	p > 40	25	5,45 %
Mid	0 < p < 40	245	53,38 %
All values	0 < p < 121	459	100,00 %

Table 4: Rain Criterion

3.2.1.2 Actiflo

In the Actiflo criterion wet periods were defined as the number of days the Actiflo was on, and dry periods were the number of days the Actiflo was off. In the Actiflo treatment Iron chlorides and Polymer are the only chemicals dosed.

3.2.1.3 Bypass

The Bypass criterion defines wet periods as the number of days the Bypass is running and dry periods as the number of days the Bypass is not running. The Bypass line does not dose any chemicals and is only operating when the capacity of both the main facility and the Actiflo is reached.

3.2.2 Calculations

After establishing the criteria for wet and dry periods, the chemical use, power use, and total inflow to the treatment plant needs to be calculated.

3.2.2.1 Chemical Consumption

The dosage of chemicals at VEAS has a fixed amount for every hour of every day at normal operation when the inflow is < 1100 l/s the dosage of chemicals follows the normal dosage in Table 5. In addition to the fixed dose of chemicals, the dosage is regulated based on the turbidity in the water. The dosage of chemicals decreases when the turbidity is low < 8 Formazin Turbidity Unit (FTU), but it is not increased when the turbidity is high > 12 FTU. The dosage of chemicals also depends on the amount of inflow to VEAS. In cases where the inflow is > 1250 l/s the dosage of chemicals will be decreased. In these cases, the dosage follows the RVR dosage in Table 5. An average daily dosage of chemicals was calculated for Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday using the hourly values in the weekly table.

Day	Monday ml/l	Tuesday ml/l	Wednesday ml/l	Thursday ml/l	Friday ml/l	Saturday ml/l	Sunday ml/l
Normal dosage	0,0667	0,0710	0,0710	0,0710	0,0710	0,0604	0,0571
RVR dosage	0,0600	0,065	0,070	0,0660	0,0650	0,0550	0,0550

Table 5 Average Dosage of Chemicals ml/l

The "chemical consumption" for each day in ml was calculated. To be able to calculate the chemical consumption the dosage ml/l, Table 5 was multiplied with the total chemical use of aluminum chlorides (PAX), Iron chlorides (PIX) and Polymer for the treatment each day in l/day. Resulting in chemicals consumption in the unit ml per day.

3.2.2.2 Energy Consumption
The energy consumption by the inlet pumps at the treatment plant is another important parameter when it comes to operational costs. The energy consumption is important because the flow to the treatment plant varies, and therefore the amount energy needed to pump the water will vary. VEAS collected data kWh used for each day in the period summer 2016-2018.

3.2.2.3 Inlet flow
To see the total picture of the wastewater flow in Oslo, it is important to look at the total flow reaching VEAS and BRA each day for the summers of 2016, 2017 and 2018. It is interesting to see how much percent of water that reach each facility. The effect the wet periods of precipitation have in the inlet flow is especially interesting. The inlet flow at VEAS was calculated by adding the flow of the Main facility, Actiflo and Bypass for each day.

3.2.3 The Costs due to Stormwater
Finally, to be able to calculate the costs represented by the stormwater the average chemical use and energy used at inlet pumps was calculated for the wet and the dry periods. The wet and dry periods were defined based on the criteria mentioned in section 3.3.1.

I expected different amounts of consumptions of chemicals and energy in wet and dry periods. The average cost for a wet day and a dry day was calculated. The cost of chemicals was calculated multiplying the consumption with the chemical prices in Table 3. The cost of energy was calculated in the same matter, multiplying the consumption with the highest and lowest yearly power prices throughout the three summers showed in Table 2 This cost was also calculated for wet and dry days.

The differences in costs for wet and dry days were calculated by subtracting the average costs in dry days with the average costs in wet periods.

3.3 BRA
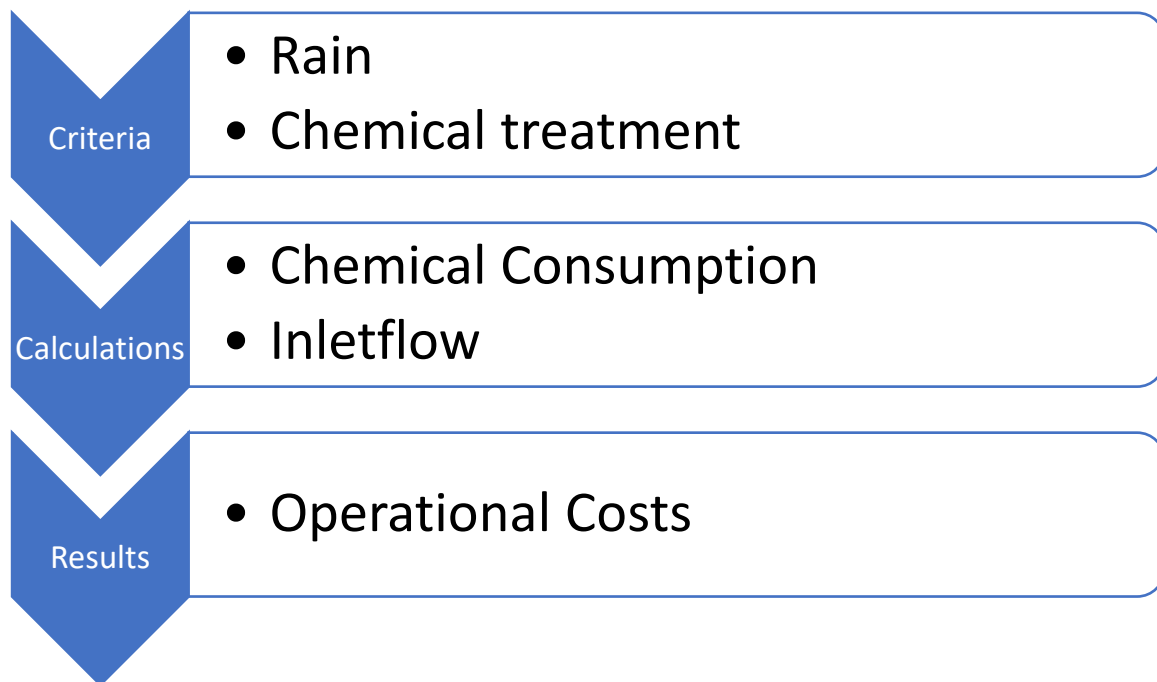
Figure 13: Methodology Flowchart BRA

3.3.1 Stormwater Criteria

The criteria for Bekkelaget treatment plant are slightly easier than the ones for VEAS. BRA has to different operational lines. The purely chemical line is only operative when there is a high amount of inflow to the treatment plant. The operational line which is always running is the activated sludge treatment, where chemical and biological treatment are placed in the same tank. To be able to calculate operational costs due to stormwater at BRA wet and dry periods needs to be defined. Two different criteria were established to define dry and wet periods for summer 2016,2017 and 2018.

3.3.1.1 Rain Criterion

The same rain criterion was used for defining wet and dry days for Bekkelaget treatment plant as for Vestfjorden treatment plant mentioned in section 3.3.1.1.

3.3.1.2 Chemical Treatment Criterion

To represent the treatment line which only runs in periods of high inflow, the chemical treatment criterion was established. Wet periods were defined as periods were the chemical treatment was running, and dry periods were periods when the chemical treatment was not running.

3.3.2 Calculations

After establishing the criteria for wet and dry periods, the chemical consumption, and total inflow to the BRA needs to be calculated.

3.3.2.1 Chemical Consumption

The data provided from BRA had already calculated the chemical consumption of PAX, FeSO4 and Polymer for the whole facility, adding up the chemical treatment and the

biological treatment. The values were given in liters for PAX and FeSO4 and in kg for the Polymer

The dosage of chemicals at BRA are regulated by the residual concentration of phosphorous at the outlet of the treatment plant. If the concentration at the outlet is < 0,1 mgPO4/l the dosage is reduced. If the concentration is > 0,2 mgPO4/l the dosage is increased.

3.3.2.2 Energy Use

At BRA the inlet pumps and the blowers adding air to the biological process uses energy. Whilst it is only the energy used for the inlet pumps that is affected by the amounts of stormwater entering the treatment plant. Unfortunately, it was only possible to retrieve kWh used for each month at BRA, and therefore the data would not be compatible with my other data that has a daily resolution.

3.3.2.3 Inlet Flow

The inlet flow to BRA was also already calculated when I got the data from BRA. The inlet flow contains of the flow entering solely chemical treatment the flow entering the biological treatment (with phosphorous removal) and the flow entering the three overflows connected to BRA. As mentioned in section 3.3.2.3 the percentage entering each treatment facility is interesting with regards of the total image of the wastewater flow in Oslo, and how this flow is affected by the wet and dry periods established in the criteria section.

3.3.3 The Costs due to Stormwater

In the same matter as for VEAS the costs represented by the stormwater were calculated based on the average use of chemicals in the wet periods defined by the rain criterion and chemical treatment criterion for BRA.

I expected different amounts of consumptions of chemicals and energy in wet and dry periods. The average cost for a wet day and a dry day was calculated. The costs of chemicals were calculated multiplying the consumption with the chemical prices in Table 3.

The differences in costs for wet and dry days were calculated by subtracting the average costs in dry days with the average costs in wet days.

3.4 The Relationchip between Yearly Operational Costs and Stormwater Costs

To calculate the relationship between yearly operational costs and the stormwater costs due to energy and chemicals consumption for VEAS and BRA I used the yearly reports from VEAS and BRA.

The yearly operational costs at VEAS and BRA were collected from (VEAS, 2018), and (Vann- og avløpsetaten , 2018). The yearly operational costs detected in 2018-NOK was multiplied with the Consumer price index (CPI) for 2019 to turn it in to 2019-NOK.

The stormwater costs for VEAS were calculated by multiplying the number of wet days defined by the stormwater criteria with the total cost due to chemical and energy consumption for a wet day. A wet day at VEAS was a day where either the Actiflo was running, the Bypass was running, or it was a day with more than 40 mm precipitation. The calculation of the costs of chemical and energy consumption for VEAS are explained in section 3.2.3.

The stormwater costs for BRA were calculated in the same matter as for VEAS, but the difference is that these costs are only due to chemical consumption, as explained in 3.3.3. A wet day at BRA was a day where the Chemical Treatment was running or a day with more than 40 mm precipitation.

For both treatment plants the stormwater costs for each summer 2016,2017 and 2018 were divided with the total operational costs for each year.

4 Results

The results from the stormwater costs calculations are divided in four parts, the cost due to chemical use, the cost due to energy use and the statistical analysis of these costs. The costs due to stormwater in one year was also calculated.

4.1 Costs in wet and dry days

Like mentioned in section 3.2.2.1 the chemical consumption was calculated for wet and dry days based on the stormwater criteria for both VEAS and BRA. Theron, the costs due to chemicals were calculated for both treatment plants. The energy consumption was only calculated for VEAS, and therefore we only have stormwater costs due to energy for VEAS.

4.1.1 Chemical Costs

Criteria	PAX Consumption [ml/day]	PIX Consumption [ml/day]	Polymer Consumption [ml/day]
Af-off	926,25	389,97	1287,28
Af-on	913,91	1048,71	5766,77
Difference	-12,34	658,74	4479,49
Bp-off	927,25	487,79	1926,23
Bp-on	865,09	1040,84	6167,64
Difference	-62,15	553,05	4241,42
Zr-2	891,96	371,30	1268,63
Mr	910,79	1371,35	8612,35
Difference	18,83	1000,05	7343,72

Table 6**: Chemical Consumption VEAS**

At VEAS it was used more Iron chlorides and Polymer for the wet days defined by three stormwater criteria. At the same time VEAS used less Aluminum chlorides at wet days defined by the Bypass and the Actiflo criteria, Table 6.

The decreased consumption of PAX at wet days according to Bypass and Actiflo criteria at VEAS might be a random effect. Another possible explanation is that the consumption of PIX and Polymer increases drastically and, so it might be that PAX is replaced by the consumption of PIX and Polymer.

Criteria	PAX Cost [NOK/day]	PIX Cost [NOK/day]	Polymer Cost [NOK/day]
Af-off	3,11	0,78	43,64
Af-on	3,07	2,10	195,49
Difference	-0,04	1,32	151,85
Bp-off	3,11	0,97	65,30
Bp-on	2,90	2,08	209,08
Difference	-0,21	1,10	143,78
Zr-2	2,99	0,74	43,01
Mr	3,06	2,74	291,96
Difference	0,06	2,00	248,95

Table 7: Cost due to Chemical Consumption VEAS

Table 7 shows the costs due to chemical consumption at VEAS, and we see the same trends as for the consumption. The cost of PAX consumption decreases according to Bypass and Actiflo criteria, but the difference is very small in NOK/day. The cost of PIX and Polymer consumption increases more drastically than the PAX cost decreases.

Criteria	PAX Consumption [l/day]	FeSO4 Consumption [l/day]	Polymer Consumption [kg/day]
Zr-2	81,85	26590,30	0,24
Mr	4939,87	26698,90	41,76
Difference	4858,02	108,60	41,52
C-off	0,00	26670,25	0,00
C-on	4189,37	26266,65	34,92
Difference	4189,37	-403,60	34,92

Table 8: Chemical Consumption BRA

At BRA the use of chemicals increased during the wet days based on two stormwater criteria for the treatment plant. Aluminum chlorides and Polymer were dosed more than in the dry days, Table 8 .The differences in consumption is high between wet and dry days at BRA for PAX and Polymer, this is mostly because the chemical treatment line is not running in dry weather, and then there is not consumed much of these chemicals.

FeSO4 on the other hand was consumed less in the wet days defined by the chemical treatment criterion. The decrease of consumed FeSO4 is expected since this chemical is added in the biological treatment line, which is less operative when the inflow is high, and the chemical treatment is running.

Criteria	PAX Cost [NOK/day]	FeSO4 Cost [NOK/day]	Polymer Cost [NOK/day]
Zr-2	274,72	51728,77	7,12
Mr	16580,67	51940,05	1252,81
Difference	16305,96	211,28	1245,69
C-off	0,00	51884,30	0,00
C-on	14061,63	51099,13	1047,51
Difference	14061,63	-785,17	1047,51

Table 9: Cost due to Chemical Consumption BRA

The chemical consumption at BRA was high, and this is also represented in the costs due to chemical consumption. The difference in costs between wet and dry days is highest for PAX based on the rain criterion, Table 9. The costs due to the consumption of FeSO4 at BRA are high, but the difference in costs in wet and dry days is not as high as for Polymer and PAX.

4.1.2 Energy Costs

The energy cost was assumed to be higher in the wet periods, due to an increase of stormwater at the treatment plant. The energy cost was calculated for VEAS.

Criteria	Energy Consumption [kwh/day]	Minimum Cost of Energy [NOK/day]	Maximum Cost of Energy [NOK/day]
Af-off	19 267,47	5 173,70	10 498,84
Af-on	26 095,32	7 007,11	14 219,34
Difference	6 827,85	1 833,41	3 720,50
Bp-off	20 307,12	5 452,87	11 065,35
Bp-on	25 606,17	6 875,77	13 952,80
Difference	5 299,05	1 422,90	2 887,45
Zr-2	17 761,27	4 769,26	9 678,11
Mr	27 271,79	7 323,02	14 860,40
Difference	9 510,53	2 553,77	5 182,29

Table 10: Cost due to Energy Consumption VEAS

An increased consumption of energy in wet days was found for VEAS. The most extensive use was found for the rain criterion (Mr) in Table 10, which is purely based on precipitation. The consumption of energy increases when more water is needed to be pumped to the treatment facility, Figure 6. The Minimum and maximum average yearly cost used is previously presented in Table 2.

4.2 Analysis of stormwater criteria

Based on the four stormwater criteria established for VEAS and BRA in section 3.3.1 and section 3.4.1 the number of wet and dry days were found.

Criteria	Number of days	Days that are weekdays	Percent	Days that are weekends	Percent
Mr	25	19	76 %	6	24 %
Zr-2	120	88	73 %	32	27 %
Af-on	89	65	73%	24	27%
Af-off	370	265	72 %	105	28%
Bp-on	25	16	64%	9	36 %
Bp-off	434	314	72 %	120	28 %

Table 11: Number of Wet and Dry days according to the Stormwater Criteria

I checked if there were incidences where dry days and weekends or wet days and weekends fall together. In Table 11 we see that the percentage of days that are weekdays and weekends for wet days and dry days is similar for the stormwater criteria. The only exception is the Bypass criterion where the percentage of days that are weekdays for wet days is a about 10 % less than the other criteria. The reason for doing this analysis is to see if the differences in chemical and energy consumption we see are not due to wet and dry weather but caused by different dosage during weekdays and weekends. Based on this analysis, that is not the case.

4.3 Flow quantity analysis at VEAS and BRA

4.3.1 Inflow
Based on the total 4 stormwater criteria the total inflow at VEAS and BRA was calculated for wet and dry periods.

Criteria	VEAS Inflow	BRA Inflow	Total Inflow
Mr	72 %	28 %	100 %
Zr-2	65 %	35 %	100%
Af-on	70 %	30 %*	100 %
Af-off	65 %	35 %*	100 %
Bp on	70 %	30 %*	100 %
Bp off	66 %	44 %*	100 %
C-on	65 %*	35 %	100 %
C off	66 %*	34 %	100 %

Table 12: Inflow BRA and VEAS based on Stormwater Criteria

The * indicates that the value was calculated by subtracting the known percentage of inflow at VEAS or BRA with 100 %. Which was done because the total inflow going to BRA and VEAS is 100 % This was done for the criteria where only one of the treatment plants inflow was known. In the Mr and Zr-2 criterion we know the flow at both VEAS and BRA.

According to the rain criterion the percentage of inflow to VEAS increases in wet periods. The Inflow to VEAS was 72 % for wet periods, and 65 % for dry periods. According to the same criterion the inflow to BRA decrease in wet periods 28 % and increase in dry periods 35 %. This might indicate that VEAS is more sensitive to precipitation than BRA.

The same increase in wet periods for VEAS and decrease in dry periods can be seen for the Actiflo criteria. At the same criteria BRA is at the same time increasing its flow in dry periods and decreasing it in wet periods.

For the chemical treatment criteria, which is the only criteria only regarding BRA, we can also see that the inflow to BRA decrease in dry periods and increase in wet periods. Even though this decrease is modest with only 1 % difference between dry and wet periods, Table 12

4.3.2 Yearly Treated Wastewater
To further investigate the relationship between stormwater and incoming wastewater at the two treatment plants, the numbers of treated wastewater was collected for the years 2016,2017 and 2018 (Vann- og avløpsetaten , 2018). This data was compared to the precipitation data for Blindern weather station for the whole year of 2016, 2017 and 2018,

Year	2016	2017	2018	Normal year
Precipitation Blindern (mm)	728	941	705	763

Table 13: Yearly Precipitation Blindern Weather Station

This precipitation data shows us that 2018 was a dry year, 2017 was a wet year and 2018 was drier than a normal year. The difference in precipitation for 2016 and 2018 was higher for the data where three weather stations was used based on only summer precipitation Table 1. This difference can be explained by the dry summer 2018, where we had very little precipitation.

Treated Wastewater

	BRA	VEAS	Tot
2016	46,13	97,02	143,15
2017	48,4	96,43	144,83
2018	44,7	87,59	132,29
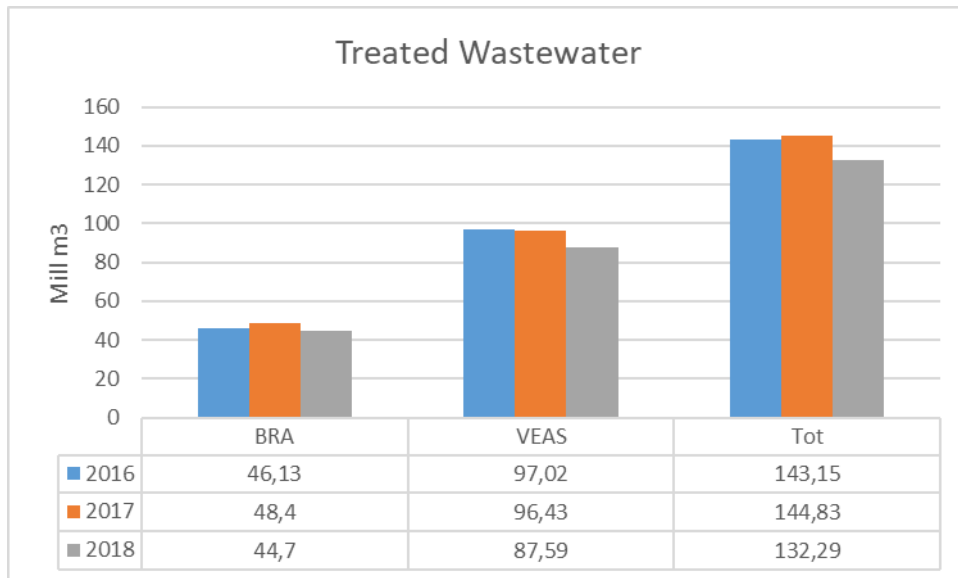
Figure 14: Treated Wastewater at VEAS and BRA

From Figure 14 we can see that the amount wastewater treated at BRA increased from the relatively normal year 2016 to the wet year of 2017. The wastewater treated at BRA was a little bit higher for the wet year 2017 than for the dry year 2018. At VEAS the amount treated wastewater decreased when the precipitation increased from 2016 to 2017.The amount treated at VEAS further decreased from 2017 to 2018. We know that in 2018 more wastewater was transferred to BRA at Fagerlia, which meant that less wastewater was transferred to VEAS (Vann- og avløpsetaten , 2018).

Figure 15: The Amount of Treated and Untreated Wastewater at VEAS and BRA

The untreated wastewater going to the overflows connected to BRA and VEAS increases from 2016 to the year of much precipitation 2017 and decrease for the year of low precipitation 2018.

4.4 Stormwater Cost compared to Yearly Operational Cost

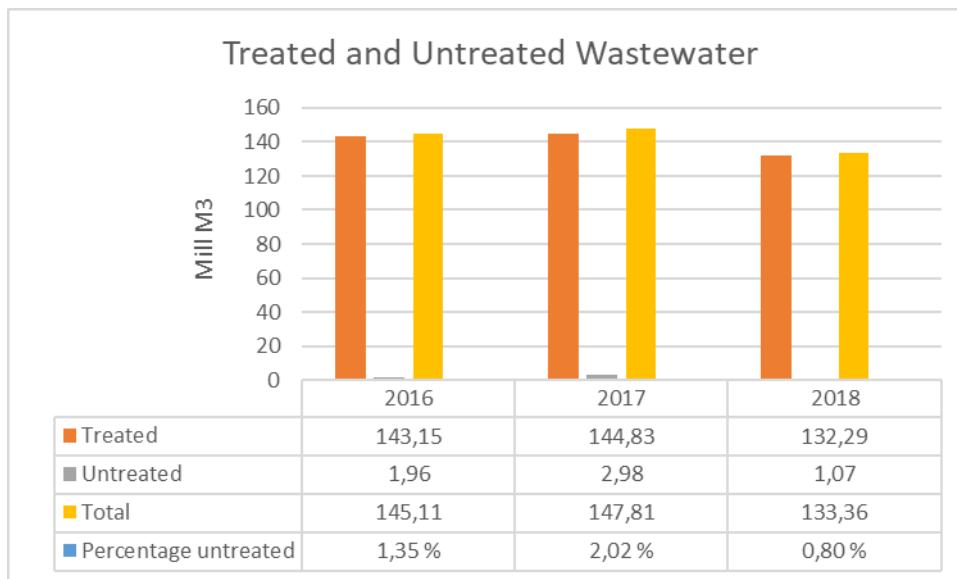| Year	Af-on [days]	Bp-on [days]	Mr [days]	Total Maximum Stormwater Cost [NOK]	Total Minimum Stormwater Cost [NOK]	Total Operational Cost [NOK]	Minimum Stormwater Cost / Operational Cost [%]	Maximum Stormwater Cost / Operational Cost [%]
2016	36	14	9	kr 853 879	kr 427 324	kr 315 663 000	0,14 %	0,27 %
2017	38	2	11	kr 743 033	kr 371 904	kr 346 107 000	0,11 %	0,21 %
2018	15	9	5	kr 419 593	kr 210 029	kr 298 635 000	0,07 %	0,14 %

Table 14 Yearly Stormwater and Operational Cost VEAS

After calculating the stormwater costs as explained in section 3.4, the total minimum and maximum stormwater costs for all the wet days in the six months of my data were compared with the total operational costs at VEAS treatment for years 2016,2017 and 2018. From Table 14, we see that 2016 was the year where the stormwater costs were the highest percentage of the total operational costs . The year where the stormwater costs mattered the least was 2018, with only 0,07 % (minimum) or 0,14 % (maximum) of the total operational cost. That the percentage is lowest for 2018 is not unexpected since this year was the dries, and the year with fewest wet days.

Year	C-on [days]	Mr [days]	Total Cost C-on [NOK]	Total Cost Mr [NOK]	Total Stormwater Cost [NOK]	Total Operational Cost [NOK]	Stormwater Cost/ Operational Cost [%]
2016	37	9	2449706	627961	3077668	kr 87 737 605	3,51 %
2017	39	11	2582122	767508	3349631	kr 94 087 528	3,56 %
2018	8	5	529666,	348867	878533	kr 96 776 669	0,91 %

Table 15: Yearly Stormwater and Operational Cost BRA

The total stormwater costs in the summer were compared with the total operational costs for BRA for the years 2016,2017 and 2018. For BRA the stormwater costs due to chemicals consumption in the summer were the highest percentage of the operational costs in 2017. This was the year with the highest amount of wet days due to the rain criterion and the Chemical treatment criterion. As for VEAS the year where the stormwater costs were the lowest percentage of the total operational costs was the dry year 2018.

4.5 Statistical analysis

To investigate whether the variations in consumption of chemicals and energy in wet and dry days was due to coincidence a statistical analysis was needed for the data.

4.5.1 Non parameteric test

The consumption of PAX, PIX, Polymer, FeSO4 and energy were all found to not be normally distributed. To be able to say whether my results are statistically significant or not I used the non-parametric Mann-Whitney U test in in SPSS.

Assumptions for the Mann Whitney test also called the two-sample problem (Ross, 2009):

1. Observation are not normally distributed. However, they should follow the same shape (i.e. both are bell-shaped and skewed left).
2. The dependent variable should be measured on an ordinal scale or a continuous scale.
3. The independent variable should be two independent, categorical groups.
4. Observations should be independent. There should be no relationship between the two groups or within each group.

The null hypothesis was formed for all the groups for the different stormwater criteria relatable for that group.

The three different null hypothesis is shown for the group PAX at Main facility at VEAS;

H_0: "The distribution of PAX is the same across categories of much rain / zero rain for two days"

H_0: "The distribution of PAX is the same across categories of Actiflo on / Actiflo off"

H_0: "The distribution of PAX is the same across categories of Bypass on / Bypass off"

The level of significance of the test was set to $\alpha=0,05$, with a confidence interval 95 %.

If the p-value < 5 % we reject the null hypothesis.

If the p-value > 5 & we retain the null hypothesis.

VEAS Main facility	Criteria	Probability value	Conclusion
PAX	Precipitation	0,00	Reject the null hypothesis
PAX	Actiflo	0,00	Reject the null hypothesis
PAX	Bypass	0,00	Reject the null hypothesis
PIX	Precipitation	0,00	Reject the null hypothesis
PIX	Actiflo	0,00	Reject the null hypothesis
PIX	Bypass	0,00	Reject the null hypothesis

Polymer	Precipitation	0,00	Reject the null hypothesis
Polymer	Actiflo	0,00	Reject the null hypothesis
Polymer	Bypass	0,00	Reject the null hypothesis
Energy	Precipitation	0,00	Reject the null hypothesis
Energy	Actiflo	0,00	Reject the null hypothesis
Energy	Bypass	0,00	Reject the null hypothesis

Table 16: Significant Level for Use of Chemicals and Energy at Main facility VEAS

For all the groups of use at the Main facility at VEAS the p-value or significant level is less than 5 %,Table 16.This is a reasonable basis for rejecting the null hypothesis that is the basis for the study. The results indicate that there is not an even distribution of the use of chemicals or energy in the different criteria defining wet and dry periods. The difference in use between wet and dry days is not by coincidence since the probability of the observations being the same for wet and dry days is 0 %.

VEAS Actiflo line	Criteria	Probability value	Conclusion
PIX	Precipitation	0,00	Reject the null hypothesis
PIX	Actiflo	0,00	Reject the null hypothesis
PIX	Bypass	0,00	Reject the null hypothesis
Polymer	Precipitation	0,00	Reject the null hypothesis
Polymer	Actiflo	0,00	Reject the null hypothesis
Polymer	Bypass	0,00	Reject the null hypothesis

Table 17: Significant Level for Use of Chemicals at Actiflo VEAS

All the groups tested for the Actiflo line also have a p-value= 0,Table 17. Which means that there is not due to random variations that the distribution of chemicals in wet and dry days is different.

BRA	Criteria	Probability value	Conclusion
FeSO4	Precipitation	0,367	Retain the null hypothesis
FeSO4	Chemical treatment	0,512	Retain the null hypothesis
PAX	Precipitation	0,00	Reject the null hypothesis
PAX	Chemical treatment	0,00	Reject the null hypothesis
Polymer	Precipitation	0,00	Reject the null hypothesis
Polymer	Chemical treatment	0,00	Reject the null hypothesis

Table 18:Significant Level of Chemical Use at BRA

The results are somewhat different at BRA. The p-value for the use of FeSO4 being eve distributed between wet and dry days is 37 % based on the precipitation criteria, Table 18. The p-value is 51% for the use of FeSO4 based on the chemical treatment criterion for wet and dry days. This means that there is a 37% or 51% chance that the FeSO4 use is the same at wet and dry days. The null hypothesis is retained for FeSO4.

The p-value for use of PAX and Polymer for both precipitation and chemical treatment criteria is 0 %. We reject the null hypothesis and can say that there 0 % chance that the use of PAX and Polymer is the same for wet and dry days at BRA.

5 Discussion

5.1 Research Questions

In this section I will discuss to what degree I reached my research questions, and which parts of the researched questions I found difficult to answer.

1. Which impact does stormwater have on the treatment process at VEAS and BRA?

The first research question focusses on the quantities of water and the effect stormwater has on operation at Vestfjorden treatment plant and Bekkelaget treatment plant in wet and dry days. The results presented in section 4.3.1 gives us percentage inflow at BRA and VEAS. The result of this analysis was that VEAS treats a higher percentage of the total wastewater in Oslo in wet days. BRA on the other hand treats a lower percentage of the total wastewater in wet days. From the same relationship we have that the percentage treated at BRA of the total wastewater increases in dry days. The relationship can be explained by the maximum capacity at VEAS and BRA. VEAS has a higher capacity than BRA, and therefore the extra water in wet days might be transported to VEAS. The delay capacity at Midgardsormen has been well utilized from the start of operation in 2014, which also might lead to a delay in water being treated at BRA in wet days (Vann- og avløpsetaten , 2018). BRA also has high leveling capacity and distributes water flow over several days, which leads to a lower percentage treated wastewater at BRA than VEAS in wet days. The data for the inflow at VEAS and BRA includes the treatment facility and the overflows connected directly to the treatment plants.

To discuss the research question further the total wastewater treated at VEAS and BRA in 2016, 2017 and 2018 was compared to the yearly amounts untreated wastewater that reached the overflows in the same years. The total hydraulic load that reached VEAS and BRA in the relatively normal year 2016 was lower than the one that reached the facilities in the wet year 2017. The lowest hydraulic load that reached the facilities was the load found in the dry year 2018, Figure 14. The highest amount of untreated wastewater that reached overflows was found in the wet year 2017 and was 2,02 % of the total hydraulic load reaching VEAS and BRA, Figure 15. The number for untreated wastewater reaching overflows was only 0,80 % of the total hydraulic load reaching VEAS and BRA in 2018. We see that the amount of diluted wastewater going to overflows at VEAS and BRA is very low, Figure 15.To further look at how the operation at the treatment plants is impacted by stormwater research question 1.2 is answered.

1.2 What are the differences in the usage of chemicals and in electricity consumption in periods with and without stormwater coming to VEAS and BRA?

The second part of the first research question is based on the null hypothesis from section 4.5.1. It was found that the consumption of Iron Chloride (PIX) and Polymer increased for wet days at VEAS,Table 6. At VEAS the use of Aluminum Chlorides (PAX) decreased in wet days according to the stormwater criteria Bypass and Actiflo. The consumption of Iron Sulfate (FeSO4) decreased in wet days at BRA, Table 8.

Furthermore, the Mann Whitney test in section 4.5.1 proved that there was in fact a significant difference in consumption of PAX, PIX and Polymer in wet and dry days. The differences in consumption of the precipitation chemical FeSO4 at Bekkelaget was found to not be significant for wet and dry days, Table 16. Verifying that the consumption of FeSO4 at BRA is not different in wet and dry days. This result is not unexpected since the addition of FeSO4 is done in the biological step. At wet days, or days with a high inflow both the chemical treatment line and the biological step is active, and therefore there might not be a difference in the consumption of FeSO4.

The energy consumption in wet and dry days was found for VEAS. At VEAS based on the rain criterion it was used an average of 9510 more kWh per day for wet days than for dry days, Table 10. The statistical analysis found the differences in energy consumption for wet and dry days to be significant.

For this thesis I was not able to retrieve daily data for the energy consumption at BRA. The activated sludge system they use at BRA, uses blowers to add air in the biological step in the treatment. This energy consumption is directly connected to the treatment step, and not only the amount of water needed to be pumped to the treatment plant. Therefore, this data would be of interest for calculating the differences in energy consumption in wet and dry days at BRA.

2. What costs are related to these changes in the treatment process?

The chemical use and energy consumption in research question 1.2 gave bases for calculating the costs due to chemicals and energy at VEAS and BRA.

The results give us a higher cost related to use of PIX and Polymer at VEAS in wet days. The cost of PIX was 2 NOK higher for a wet day than a dry day based on the rain criterion. The cost of Polymer was 248,95 NOK more for a wet day than a dry day based on the rain criterion. At the same time the cost for PAX at VEAS is 0,06 NOK less in dry days than in wet days based on the rain criterion.

We also have higher costs for PAX and Polymer at BRA in wet days. The cost for PAX was 16306 NOK more for a wet day than a dry day based on the rain criterion. The cost of Polymer was 1246 NOK more for a wet day than a dry day for the rain criterion. The decreased use of FeSO4 based on the chemical treatment criterion indicated that the cost of FeSO4 was 403 NOK less for a wet day than a dry day.

All the cost calculated in this thesis is based on the stormwater criteria. The rain criterion define dry days at two consecutive days without precipitation. To estimate hydraulic loads in wastewater systems we usually use dry weather flow (DWF). The value of DWF is defined as the flow measured after a period of seven consecutive days of dry weather in which the total rainfall over that period did not exceed 0,25 mm, (Rendell, 1999). This definition yields a flow rate that reflects the flow contribution to a catchment without any contribution from stormwater. In other words, the definition guarantees a minimum flow at the treatment plant. My methodology only used two days of zero rain to define minimum flow and might not obtain a flow as low as the DWF. If the minimum flow would be lower, it is possible that the deviation in use of chemicals and energy is higher due to the stormwater since the difference in flow in dry and wet days would increase.

2.2 What are the total costs which can be assigned to stormwater for one year?

The costs that can be assigned to stormwater for one year in this thesis is the costs of the summers. This means that the stormwater costs are costs for wet days between May and September for the years 2016, 2017 and 2018. If one were to add costs for the remaining seven months of the year, the total stormwater costs would be higher.

The total costs that can be assigned to stormwater at VEAS for one year based on the calculation in this thesis is 853 879 NOK (maximum) and 427 324 NOK (minimum) for 2016. For 2017 the stormwater costs at VEAS were 743 033 NOK (maximum) and 371 904 NOK (minimum). In 2018 the stormwater costs at VEAS were 419 593 NOK (maximum) and 210 029 NOK (minimum). The stormwater costs at VEAS were based on energy and chemical consumption and were highest in 2016. The main reason why the stormwater costs at VEAS were higher for the year with "normal" precipitation 2016 than the year with high precipitation 2017, was that the stormwater criteria counted more wet days for 2016 than for 2017.

The total costs that can be assigned to stormwater at BRA for one year were 3 077 668 NOK for 2016. The stormwater costs were 3 349 631 NOK for 2017, and 878 533 NOK for 2018. The stormwater costs were highest for the wet summer 2017, because that was the year the stormwater criteria at BRA counted the highest number of wet days.

To be able to say something about the scale of the cost due to stormwater for the three summers calculated in this thesis, I compared the stormwater cost to the total yearly operational costs at VEAS and BRA.

For VEAS the percentage of operational costs that were due to stormwater in 2016 was 0,14 % (minimum) or 0,27 % (maximum). In 2017 the percentage was 0,11 % (minimum) or 0,21 % (maximum), and in 2018 the percentage was 0,07 % (minimum) or 0,14 % (maximum). From this percentages we see that the stormwater costs at VEAS were the highest share of the total operational costs in 2016.

For BRA the percentage of operational costs that were due to stormwater in 2016 was 3,51 %. In 2017 the percentage stormwater costs were 3,56 %, and in 2018 the percentage costs that were due to stormwater was 0,91 % of the total operational cost that year. The share of operational costs that are due to the stormwater costs are the highest for 2017 at BRA.

5.2 Limitations in the Methodology

The limitations is mainly related to how much data that was available at the time the thesis was written.The main goal of the methodology is to estimate the cost presented by stormwater in the wastewater system in Oslo.

Ideally, we would retrieve data regarding all the overflows in Oslo, all the pumps and the treatment plants. The overflows in Oslo does not at this point have quantity meters, and therefore the overflows couldn't be included in the methodology. There exists a lot of pumps in Oslo, and they are connected to the quantities of water reaching the overflows. Because of the difficulty to retrieve pump data, the pumps were left out of the methodology.

The data collected is chemical use, inlet flow and energy use at VEAS and BRA. Unfortunately, the energy use at BRA was not retrieved in a daily resolution and couldn't be used in the cost calculations. The precipitation data was collected for three different weather stations that is meant to represent the precipitation in all the catchments connected to VEAS and BRA.

6 Conclusion

The aim of the thesis was to calculate the operational costs at Vestfjorden Treatment Plant (VEAS) and Bekkelaget Treatment Plant (BRA) in the treatment process due to stormwater. The operational costs were calculated based on chemical and energy consumption. The operational costs due to stormwater were compared with the annual operational costs at the treatment plants. The extra operational costs found due to stormwater could incentive more use of Sustainable Drainage Systems (SUDS) to avoid parts of the stormwater entering the wastewater treatment plant.

The operational costs due to stormwater were higher for wet days than dry days for the consumption of Iron Chlorides (PIX) and Polymer. The consumption of Aluminum Chlorides (PAX) and Iron Sulfate (FeSO4) was not higher for wet days, and therefore the costs due to stormwater were not more in wet days than in dry days for these chemicals. The cost of energy consumption at VEAS also increased for wet days compared to dry days.

The total costs due to stormwater were expressed in NOK and compared with the annual operational costs in NOK at VEAS and BRA for 2016, 2017 and 2018. The stormwater costs due to energy and chemical consumption at VEAS were 853 879 NOK (maximum) for 2016, and 0,27 % of the total operational costs that year. In 2017 the stormwater costs were 743 033 NOK (maximum), and 0,21 % of the total operational costs at VEAS. In 2016 the stormwater costs were the lowest 210 029 NOK (maximum), and 0,07 % of the total operational costs at VEAS.

The stormwater costs due to chemical consumption at BRA were 3 077 668 NOK in 2016, and 3,51 % of the total operational costs that year. The highest stormwater costs at BRA were found in 2017 3 349 631 NOK and were 3,56 % of the total operational costs that year. In 2018 we had the lowest costs for stormwater at BRA 878 533 NOK and it were 0,91 % of the total operational costs that year.

We have detected that the treatment has operational costs due to chemical and energy consumption at VEAS and BRA. However, the treatment plants need some stormwater to function, the wastewater in Oslo is led all the way from Frognerparken to VEAS by fall. The fall is so low that it will sediment masses in the tunnel if the water becomes too thick and the amounts of water too low or the water speed is too low. The stormwater prevents this sedimentation from happening

This master thesis has revealed that there are operational costs connected to treating stormwater at the two wastewater treatment plants in Oslo. Further work that could be interesting is to compare the stormwater costs detected in this thesis with expansion cost, and future cost for treatment of new substances such as microplastic entering the wastewater system. In addition, it would be interesting to collect data for the overflows in Oslo that is not connected to the treatment plants. If on were able to collect data of the quantities at the overflows one could calculate the amount of stormwater for Oslo and compare it to the wastewater flow.

It would also be interesting to estimate and calculate the impact system separation and local stormwater constructions have on the amount of stormwater and wastewater treated at VEAS and BRA.

7.References

Ann Mattsson, B.-M. W. ,. C. M. ,. D. I. ,. M. R., 2015. Quantifying the impact of high flow conditions on some Swedish Wastewater Treatment Plants, Bergen: Proceedings of NORDIWA 4-6 November.

County, P. G., 1999. Low-Impact Development An integrated Design Approach. I: s.l.:s.n.

Det Kongelige Miljøverndepartement, 2012-2013. Klimatilpassing i Norge, Meld. St 33, s.l.: Regjeringen.

Eliassen, H., 2016. Sentrale renseanlegg – nye utslippstillatelser "Optimalisering av Bekkelagets renseanlegg", s.l.: Oslo kommune Vann- og avløpsetaten.

EPA, 2014. Guide for Estimating Infiltration and Inflow , s.l.: United Stated Envionmental Protection Agency.

Forbrukernet, 2019. Forburkernet.com. [Internett]
Available at: https://forbrukernet.com/str%C3%B8m/billigste-str%C3%B8mleverand%C3%B8r.php
[Funnet 10 April 2019].

Forurensningsforskriften, 2019. Forskrift om begrensning av forurensning. [Internett]
Available at: https://lovdata.no/dokument/SF/forskrift/2004-06-01-931
[Funnet 19 February 2019].

G. Weiß, H. B. B. H., 2002. Infiltration and inflow in combined sewer systems: long-term analysis. Vol 45 No 7 pp 11-19 red. s.l.:Water Science & Technology.

Gerly Hey, K. J. a. A. M., 2016. The Impact of infiltration and Inflow on wastewater treatment plants, Lund: VA-teknik Södra.

Ghasemi, A. a. Z. S., 2012. Normality Tests for Statistical Analysis: A Guide for Non-Staticticans. I: s.l.:International Journal and Endrocinology and Metabolism , pp. 486-489.

Holmberg, T. H., 2018. The Effiency of Sustaianble Drainage Systems in Urban Areas . I: Trondheim: s.n.

J. Bryan Ellis, J.-L. B.-K., 2010. Assesing infiltration and exfiltration on the performance of Urban Sewer Systems (APUSS). Volume 9 red. s.l.:IWA Publishing.

Lindholm, O. E. S. T. S. S. J. G. &. A. L., 2008. Veiledning i klimatilpasset overvannshåndtering , s.l.: Norsk Vann .

LOS AS, 2019. [Internett]
Available at: https://www.los.no/kundeservice/strompris/historiske-strompriser/
[Funnet 9 April 2019].

Meterologisk institutt, 2018. met.no. [Internett]
Available at: https://www.met.no/vaer-og-klima/ekstremvaervarsler-og-andre-farevarsler/vaerfenomener-som-kan-gi-farevarsel-fra-met/farevarsel-for-nedbor?fbclid=IwAR3nN04TfljRqlTH7Tf7876S6nZQ14fFyDjOL9KZelm14SKdBOHe-k2oqOA
[Funnet April 2019].

Moors, A., 2015. Sewage overflows management in the Sydney coastal region, s.l.: s.n.

Norsk Vann , 2014. Håndtering av overvann fra urbane veger, Hamar: Norsk Vann .

NOU:10, 2010. Tilpassing til eit klima, s.l.: s.n.

NOU, N. o. u., 2010. Tilpassing til eit klima i endring, s.l.: s.n.

NOU, N. o. u., 2015. Overvann i byer og tettsteder, s.l.: s.n.

Oslo kommune Vann- og avløpsetaten, 2014. HOVEDPLAN AVLØP OG VANNMILJØ 2014-2030, s.l.:
        s.n.

Oslo Kommune, 2013. Strategi for overvannshåndtering i Oslo 2013-2030, s.l.: s.n.

OVASE, 2018. https://www.ovase.no/fagwiki. [Internett].

Per Møller-Pedersen, Storm Aqua AS, 2018. Overvannsdisponering i praksis, s.l.: s.n.

PubChem, 2019. [Internett]
        Available at: https://pubchem.ncbi.nlm.nih.gov/compound/ferrous_sulfate#section=Density
        [Funnet 2 May 2019].

Rendell, F., 1999. Water and Wastewater Project Development. s.l.:Thomas Telford Publishing .

Robert Sitzenfrei, M. M. W. R., 2013. Assessing the impact of transitions from centralised to
        decentralised water solutions on existing infratructure , s.l.: Water Research .

Ross, S. M., 2009. Introduction to Probability and Statistics for Engineers and Scientists. Fourth
        Edition red. Califonia: Elselvier Academic Press.

Røsland, S. B. &. M. G., 2013. Investeringsprosjekt utvidelse Bekkelaget renseanlegg,
        tilleggsinstillingen 2014, s.l.: s.n.

Sander, K., 2017. estudie.no. [Internett]
        Available at: https://estudie.no/metoder-datainnsamling-feltundersokelse/
        [Funnet 10 April 2019].

Sanna, O., 2019. Chemical prices [Intervju] (23 April 2019).

Schilperoort, R., 2004. Natural water isotopes for the quantification of infiltration and inflow in sewer
        systems (MSc Thesis) , s.l.: Delft University of Technology.

SINTEF Byggforsk , 2015. Byggforskserien. s.l.:s.n.

Statistics How To, 2015. Mann Whitney U Test. [Internett]
        Available at: https://www.statisticshowto.datasciencecentral.com/mann-whitney-u-test/
        [Funnet 14 May 2019].

Tegelberg, L. & Gilbert, S., 2013. Utvärdering Svenskt Vattens rekommenderade sammanvägde
        avrinningkoefficienter, s.l.: Svenskt Vatten AB.

Vann- og avløpsetaten , 2017. Fagrapport Avløp og vannmiljø 2017, Oslo: Oslo Kommune.

Vann- og avløpsetaten , 2018. Fagrapport Avløp og vannmiljø 2018 , Oslo: Oslo kommune.

Vann- og avløpsetaten, 2014. Fagrapport Avløp og vannmiljø 2014, Oslo: Oslo Kommune.

Vann og avløpsetaten, 2016. Fagrapport avløp og vannmiljø 2016, Oslo: Oslo Kommune.

VEAS, 2016. Årsmelding 2016, Asker: VEAS.

VEAS, 2017. Årsrapport 2017, Asker: VEAS.

VEAS, 2018. Omvisning Norsk. Oslo, s.n.

VEAS, 2018. Årsrapport 2018, Asker: VEAS.

VEAS, 2019. VEAS. [Online]
Available at: https://www.veas.nu/om-veas
[Accessed 19 February 2019].

Ødegaard, H., 2014. Vann og avløpsteknikk. 2. red. Hamar: Norsk Vann.