Post-Denitrification on Sand Filter at Bromma Wastewater Treatment Plant

Emil Blocksjö

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Examiner: Zeynep Cetecioglu Gurol
Supervisor at SVOA: Hanna Gottås
Supervisor at KTH: Isaac Owusu-Agyeman

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Abstract

This thesis work aimed to investigate opportunities of denitrification on sand filters (SFs) at industrial scale and how it relates to conventional methods of achieving denitrification and its effect on the process at Bromma WWTP. Investigated parameters were ammonium and nitrate removal, oxygen and aeration, temperature, pH, phosphorus removal, removal of organic material, removal of suspended solids, water bypass of SF and activated sludge facility (ASF), operational times of the SFs and total water load on ASF and SF. The measurements were made with aCurve, an online internal program at Bromma WWTP where online analyzers and operational parameters were logged. The online values for nitrate and nitrite were controlled using standard cuvettes methods.

The removal of Tot-N achieved values of 0.62-0.94 for denitrification on SF. Increased clogging of SFs occured due to dosage of methanol on SFs and growth of microorganisms causing an increased risk of SF bypass especially during high water load. Removal of TSS (total suspended solids), BOD7 and phosphate were unaffected by the implementation of denitrification on SFs.

The findings of the thesis can be used to further optimize conventional methods of nitrogen removal in WWTPs. For further studies the clogging of SFs when using methanol dosage on sand filters could be investigated as well as comparing the methods in a controlled environment.

List of Abbreviations

ASF - Activate Sludge Facility
BOD - Biological Oxygen Demand
BOD7 - Biological Oxygen Demand for microorganisms to digest organic matter in water in 7 days
SF - Sand filter
SS - Secondary sedimentation
WWTP - Wastewater Treatment Plant

Contents

1 Introduction

Expanding hypoxia is a problem for the Baltic sea. The problem is caused by increased summer blooming of cyanobacteria which is caused by increased anthropogenic nutrient loading (Gustafsson et al., 2012). Nitrogen and phosphorus are the most common eutrophication causing nutrients (USGS, 2019). Reducing the emissions of nitrogen and phosphorus is of interest to reduce the expanding hypoxia.

Bromma Wastewater Treatment Plant (WWTP) treats the wastewater of about 375,700 people (130 000 m^3 water/day) living in the western parts of Stockholm (Eriksson, 2022). The WWTP plans on closing 2026 and the plan is to treat all the wastewater of the Stockholm region at Henriksdal WWTP. Together with Henriksdal WWTP Bromma has to release a maximum yearly average of 10 mg/l total nitrogen to the Baltic Sea according to their environmental permit MMD M 3980-15.4 from 2019. In order to fulfill this requirement Bromma has to make sure they remove enough nitrogen to compensate for potential issues as Henriksdal while Henriksdal is renovating. The permit (see Appendix B) also include a maximum yearly average of 0.4 mg/l total phosphorus and 8 mg/l BOD7.

1.1 Aims and objectives

The aim of the following research study is to investigate the opportunities of denitrification on SFs and how it relates to conventional methods of achieving denitrification and how this affects the process at Bromma WWTP.

The following research objectives are examined:

- The influence of temperature on the denitrification process on the sand filters (SFs) and the activated sludge process.
- The impact of carbon source dosage on the denitrification in SFs.
- Determination of feasibility of dosage on SFs compared to conventional methods.
- Determine the effects of increased aeration in the activated sludge process due to denitrification on SFs instead of denitrification in the activated sludge process.
- The influence of denitrification on SFs on operational time of the SFs between backwashes.

- The influence of denitrification on SFs on BOD7, phosphorus and suspended solids treatment.

1.2 Delimitations

The thesis only includes the treatment of different forms of nitrogen in the wastewater and excludes other compounds even if this is of high relevance for Bromma WWTP. The thesis work is also limited to the SFs, but will include the activated sludge process since the treatment of nitrogen at Bromma WTTP is impacted by this process.

2 Background

2.1 Nitrogen

Nitrogen is a nutrient common in nature. Overabundance of nutrients such as nitrogen, but also phosphorus increases algae production in the water. When algae dies they are decomposed by bacteria consuming oxygen in the process. When enough oxygen is removed the water can become hypoxic and so called "dead zones" appears at the bottom of the ocean where there is insufficient oxygen to sustain life (USGS, 2019) This is a common problem in the Baltic Sea (Gustafsson et al., 2012).

The nitrogen is mainly present in wastewater as ammonia (NH_3) and ammonium (NH_4^+) while a smaller part consists of nitrate (NO_3^-). The ammonia and ammonium is toxic to fish and is unstable in the environment and are easily transformed into nitrate in water with dissolved oxygen. The nitrate is more stable in the environment but causes health problems and is easily transported in water stream and groundwater. (USGS, 2019)

2.2 Treatment of Nitrogen in Wastewater

Nitrogen is present in municipal wastewater mainly as ammonium (NH_4^+) due to naturally occuring processes and urea (Persson, 2018). The conventional way of treating ammonium in wastewater is through the process of nitrification and denitrification (Shah & Rodriguez-Couto, 2021). Besides biological ways of treating ammonium in wastewater, other ways of treating ammonium could be ammonia stripping, ion-exchange and chemical precipitation. (Persson, 2018)

At municipal WWTPs about 20% of the ammonium is removed naturally in the biological treatment step. In municipal WWTPs the biological treatment step's main task is to reduce organic material, usually measured through biological oxygen demand (BOD) or chemical oxygen demand (COD). This process produces sludge. The passive removal of nitrogen is usually due to assimilation of nitrogen in the cells of the microorganisms in the sludge. The conventional method of reducing the amount of ammonia and ammonium in the wastewater is by using nitrification and denitrification which are biological processes caused by microorganisms. (Persson, 2018)

2.2.1 Nitrification

The process of nitrification is mainly described as $(NH_4^+)/(NH_3)$ oxidizing to (NO_3^-) which is caused by two groups of bacteria. Ammonia oxidation is caused by ammonia oxidized bacteria (AOB) in a process normally called nitritation which consists of a a two-step reaction. The first step corresponds to the oxidation of ammonia to hydroxylamine (NH_2OH), see eq. (1). The second step corresponds to the oxidation of hydroxylamine to nitrite, see eq. (2). The oxidation of (NO_2^-) to (NO_3^-) is carried out by nitrite oxidized bacteria (NOB), see eq. (3). Similar reactions are the case for ammonium. (Persson, 2018) In Sweden regulations regarding additional treatment of nitrogen was added during the 90s (Johansson & Wallström, 2001) .

$$NH_3 + O_2 + 2\,H + 2\,e \longrightarrow NH_2OH^- + H_2O \tag{1}$$

$$NH_2OH + H_2O + 0.502 \longrightarrow NO_2 + 5\,H + 4\,e \tag{2}$$

$$NO_2 + 0.5\,O_2 \longrightarrow NO_3 \tag{3}$$

The bacteria for nitrification as shown in eq. (1, 2 and 3) requires oxygen for the process to occur. This is usually done by implementing an activated sludge facility (ASF). The nitrification bacteria are sensitive to low pH and grow very slowly, especially at lower temperatures. (Persson, 2018) This results in a required sludge age of longer time and therefore return sludge is a must for the ASF. The required sludge age is highly dependent on water temperature. With a stable nitrification at a water temperature of 15°C a sludge age of 6 days is required. At a temperature of 5°C a sludge age of 20 days is required. (Persson, 2018)

2.2.2 Denitrification

The denitrification process is the process of reducing nitrate and nitrite to a gaseous form of nitrogen. The denitrification is an anoxic process (Persson, 2018) caused by heterotrophic anaerobic bacteria but also demands access to a degradable organic substance such as the organic matter in the waste water or an external carbon source. External carbon source is used when the organic substance in the wastewater is insufficient or unavailable for biodegradation (Van Niel, Arts, Wesselink, Robertson, & Kuenen, 1993). During denitrification the oxygen bound in the nitrate (NO_3^-) is used for oxidation of the organic substance. The denitrification process is shown in equation (4) (Persson, 2018). In practice the denitrification process is done in several steps where the nitrate is converted into a series of gaseous nitrogen oxides shown in equation (5). (Van Niel et al., 1993).

$$\text{Carbon source} + 2\,NO_3^- + H_2O \longrightarrow 2.5\,CO_2 + 2\,OH^- + N_2 \quad (4)$$

$$NO_3^- \longrightarrow NO_2^-\,(aq) \longrightarrow NO\,(g) \longrightarrow N_2O\,(g) \longrightarrow N_2\,(g) \quad (5)$$

2.2.3 Factors influencing Denitrification

The factors influencing the Denitrification process are:

- pH: According to a study the optimal pH value is 7.5 for biological denitrification and the biological denitrification rate decreased gradually when diverting from 7.5 pH.(YATONG, 1995)
- Temperature: A study concluded that temperature had a major impact on denitrification rate. At lower temperatures ranging 6-10°C the denitrification rate was lower than when the temperature was ranging 10-25°C and the highest denitrification rate was at 25°C. (Carrera, Vicent, & Lafuente, 2004)
- Phosphorus: Besides nitrogen content of the wastewater phosphorus is also a nutrient causing eutrophication in the recipient and is present in wastewater as phosphate ions (Bunce, Ndam, Ofiteru, Moore, & Graham, 2018). In the UK about 70% of the phosphorus entering rivers are from sewage discharges (Bowes et al., 2015).
- BOD7: BOD7 (Biochemical Oxygen Demand) is a measure of the oxygen needed for microorganisms to degrade organic material in water in seven days and determines the organic content of wastewater (Türker, Okaygün, & Almaqadma, 2009).
- Suspended solids: Total suspended solids (TSS) is a measure on the total amount of suspended solids in wastewater. Suspended solids are inorganic and organic easily sedimented solid particles bigger than .45 m in diameter.(Persson, 2018)
- C/N ratio: the carbon to nitrogen (C/N) ratio is significant for growth of microorganisms. (Sobieszuk & Szewczyk, 2006)

2.3 Bromma Wastewater treatment plant

Bromma WWTP (see Figure 1) consists of two facilities; Nockebyanläggningen, which is focusing on the biological treatment and Åkeshovsanläggningen which is focusing on the mechanical and sludge treatment. The Bromma WWTP consists of several process steps:

1. Wastewater comes from Riksby, Hässelby and Järva.
2. The wastewater passes through a step screen of 3 mm gaps in order to remove larger particles from the wastewater.
3. Precipitation chemicals iron sulfate and ferric chloride are added. The ferrous chloride is added for increased precipitation during cold periods to increase the separation in the pre-sedimentation step to be able to increase the sludge age in the ASF. The iron sulfate is used to precipitate phosphorus. The water then arrives at the sand trap where sand and larger particles sediment. The sand is removed and reused.
4. The water is taken to a pre-aeration step. The wastewater is aerated to let fats, oils and lighter particles reach the surface to be removed.
5. The water is then taken to a pre-sedimentation step to let heavier particles settle where the primary sludge is taken to a strainpress and the water is then taken to the Nockeby facility for biological treatment together with the water from the reject.
6. As the water arrives at the Nockeby facility it is usually mixed with a carbon source before taken to the ASF, usually the carbon source used is methanol.
7. The activated sluge facility has 8 zones with different zone control (see figure 1). The recirculation from the ASF and the post sedimentation recycles water rich of nitrate and sludge to the first zone where it meets the influent water rich of organic content to enable pre denitrification in the first 2 zones. It is important that zone 2 does not contain excess of oxygen since this will disable denitrification and enable nitrification causing the organic content to be digested by other microorganisms. Zone 3 and 4 are flexible zones which can be controlled individually in order to enable nitrification or denitrification depending on ammonia content. Zone 5 and 6 are used for nitrification. Zone 7 is a flexible zone, most often not aerated in order to allow the water to lose oxygen content to allow the recirculation to have low oxygen content. Due to the low content of degradable organic material in the waste water methanol is usually added as a carbon source to enhance the pre-denitrification especially during cold periods. This can be a problem since some of the added methanol can be removed by the aeration in zone 5 and 6. Outgoing water is usually sent back to Zone 1 to get nitrate in the first zones and therefore cause pre-denitrification and secondary sludge from the secondary sedimentation (SS) tank is sent back to the first zone to

increase sludge age. The pumping of recirculated water is controlled by a regulator based on nitrate content.

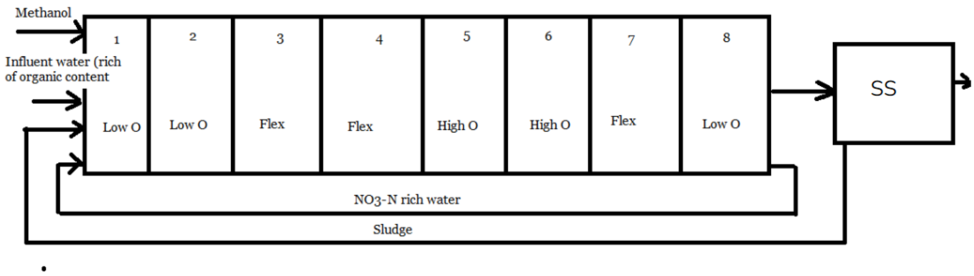

Figure 1: Zones for the ASF

8. Polymer can then added to improve the flocking of particles to enhance the secondary sedimentation, but depends on outgoing total suspended solids (TSS).

9. The water then comes to the secondary sedimentation tank where some of the sludge is recycled back to the ASF and the rest of the sludge goes back to the Åkeshov facility for sludge treatment.

10. Before the water comes to the SFs iron sulfate can be added to further reduce phosphorus levels.

11. The water then comes to the SFs where the water is filtered. The SFs filter a lot of water and needs backwashing as the filter is clogged.

12. After the SFs, heat is extracted for district heating and the water is released to the Baltic Sea.

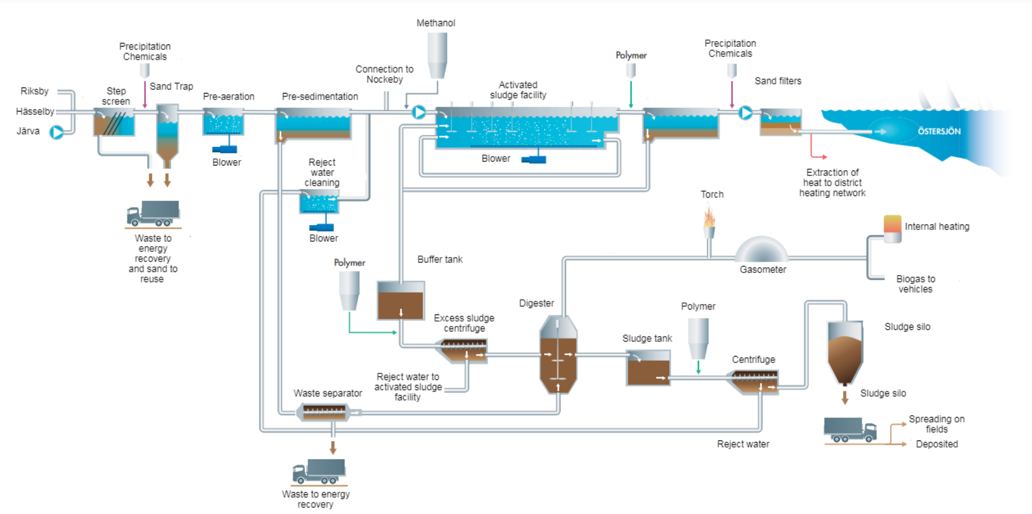

Figure 2: Flowchart of Bromma WWTP

2.4 Sand filters at Bromma

The SF hall consist of 24 SF pools filled with natural sand. The filters have an area of 60 m^2 ($6 * 10$ m). The filter material cosists of two fractions. One fraction is sand which is 0.5 meter deep and the other fraction is Filtralite® MC 2.5-4 mm which is 1 meter deep.

According to the dimensions the filters are supposed to be able to filter a flow of 14 400 m^3/h, the biological treatment step is dimensioned for 10 800 m^3/h. For higher flows the filters will be bypassed and therefore part of the water will be unfiltered. The filter pools are designed to keep a water level of 3.4 m and when the water level increases the outlet valve opens more. When the outlet valve is 95% or more open for 15-20 minutes backwash of the filters are done automatically.

Backwashing is done in the following way: the outlet valve opens fully and the water flow to the filter is closed to empty the filters. Then the outlet valve closes and backwash starts. Backwash is done twice in a row with 20 m/h water and 30 m/h air. After backwashing the sorting starts which fluidises the bed and the backwashing pumps are started again. This is dimensioned to be done with a flow of 90 m/h water.

In each SF the pressure difference over the filter is measured. The pressure difference is the difference of the pressure above the filter minus the pressure under the filter. The pressure difference lowers as the filter is clogged and increases after backwashing. Usually the filters are backwashed every 36 hours regardless of the pressure difference.

2.4.1 Wastewater bypass

When the flow of water to the SFs exceeds the capacity of the SFs, bypass of wastewater occurs. Bypass means the wastewater is released to the effluent without passing through the SF. This lowers the quality of the released wastewater to the recipient. Because of clogging the capacity of the SFs vary. Bypass of wastewater also occurs at the ASF.

This mixes biologically treated and biologically untreated wastewater as well as filtered and unfiltered wastewater causing dilution of the Wastewater streams making it ineligible to measure the nitrogen when bypass occurs. The bypass and water streams as well as the measuring spots where the measurements are done at Bromma WWTP are shown in Figure 2.

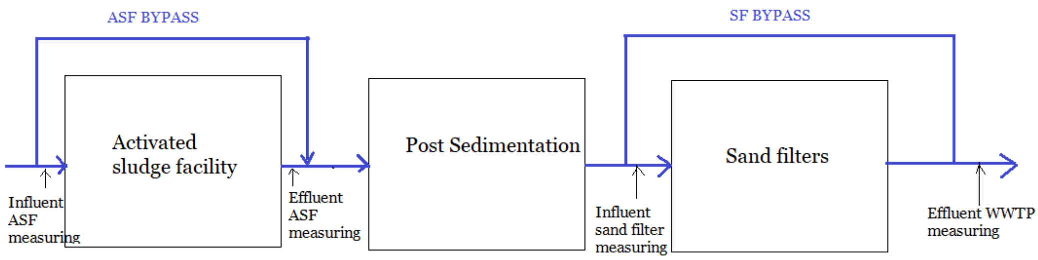

Figure 3: Wastewater streams for the system boundaries used during measurements as well as measuring spots and bypass streams

2.5 Sustainable development goals

To analyze how this thesis impacts the sustainable development goals (SDGs) is relevant since this is the reason for conducting the thesis. The SDGs most relevant to this thesis is SDG 6 *Clean water and sanitation*, SDG 11 *Sustainable cities and communities*, SDG 12 *Responsible consumption and production* and SDG 14 *Life below water*.

This thesis aims to investigate how different methods have an impact on the removal efficiency of nitrogen (SDG 6) of current wastewater (SDG 12 and 14) treament plants which is an industrial facility and uses industrial technologies (SDG 9). Cities (SDG 11) generate wastewater and the thesis aims to investigate other ways to treat nitrogen in wastewater compared to conventional methods of Bromma WWTP.

Subgoal 6.3 *Improve water quality, wastewater treatment and safe reuse* includes to, by 2030, improve water quality by reducing pollution and to halve the proportion of untreated wastewater and to increase recycling of wastewater. (*Goal 6: Clean water and sanitation*, 2022) This thesis aims to investigate the efficiency of different nitrogen treatment methods in current wastewater treatment plants

Subgoal 9.5 *Enhance research and upgrade industrial technologies* includes upgrading the technological capabilities of industrial sectors. (*Goal 9: Industry, innovation and infrastructure*, 2022)

Subgoal 9.4 *Upgrade all industries and infrastructures for sustainability* includes upgrading infrastructure and retrofit industries to make them sustainable with a focus on resource-use efficiency and a use of clean and environmentally sound technologies and industrial porocesses. (*Goal 9: Industry, innovation and infrastructure*, 2022)

Subgoal 11.6 *Reduce the enviromental impact of cities* includes reducing the per capita environmental impact impact of cities especially mentioning municipal waste management. (*Goal 11: Sustainable Cities and communities*, 2022)

Subgoal 12.4 *Responsible management of chemicals and waste* includes significantly reducing emissions of chemicals and all wastes to water. (*Goal 12: Responsible consumption and production*, 2022) This goal was for 2020, but could still be relevant.

Subgoal 14.1 *Reduce marine pollution* includes to, by 2025, prevent and reduce marine pollution of all kinds from specifically land-based activites, even mentioning nutrient pollution. (*Goal 14: Life below water*, 2022)

3 Methodology

In order to set up the process with the microorganisms in the SFs there has to be an external carbon source added to the SFs for the microorganisms to grow. Acclimatization time also has to be considered and in this first process 2 weeks was used since there had previously been no external carbon source. Methanol was used as an external carbon source and was dosed both on the activated sluge facility and the SFs for 2 weeks of acclimatization time. After 2 weeks the external dosaging of methanol was changed to being 100% on the SFs before starting the trials to allow for acclimatization. After the 3 weeks the trials conducted according to Table 1. The trials were changed based on the results from previous weeks in order to try to achieve a more optimal process.

Table 1: Test periods and the corresponding dosage used for the trials

Test	Week	Dosed on ASF $[m^3/d]$	Dosed on SF $[m^3/d)]$	Total dosage $[m^3/d]$
I	6-7	0	1.2	1.2
II	8-10	0	1.7	1.7
III	11-12	0.8	0.9	1.7
IV	13-15	1.1	0.6	1.7
V	16-17	0.6	1.1	1.7
VI	18-19	0	1.7	1.7

3.1 Analytical methods

Different types of measurements were used. The majority of the data used to analyze the outcomes of the trials were done as online optical measurements. The online tools were also tested against standard cuvettes methods in the laboratory in order to validate the accuracy of the online measurements. The online measurement tools were tested about once a week and also cleaned every monday in order to achieve more accurate data.

Equipment:

- Spectrophotometer: Hach Lange GmbH DR2800
- Nitrite Cuvettes: Hach Lange LCK342, 0.6-6.0 mg/l
- Nitrate Cuvettes: Hach Lange LCK339, 0.23-13.5 mg/l

The control values of influent NO_3-N to SF is provided in Table 2 and effluent NO_3-N to SF is provided in Table 3. The controls show that the NO_3-N online measurement tool for the influent shows errors in the range of 3-11% and the NO_3-N online measurement tool for the effluent shows errors in the range of 6-18%.

Table 2: Control measurements of NO_3-N for influent to sandfilter samples

Time	Cuvette [mg/l]	Online value [mg/l]	Error (%)
9.39 24 Feb 2022	9.78	10.8	10
9.39 24 Feb 2022	9.77	10.8	11
9.39 24 Feb 2022	9.78	10.8	10
9.43 24 Feb 2022	9.52	10.0	5
9.43 24 Feb 2022	9.50	10.0	5
9.43 24 Feb 2022	9.54	10.0	5
9.52 2 Mars 2022	9.74	10,3	6
9.53 2 Mars 2022	10.2	10.5	3
10.01 2 Mars 2022	9.75	10.5	8
10.03 2 Mars 2022	9.81	10.9	11
10.09 2 Mars 2022	9.81	10.9	11

Table 3: Control measurements of NO_3-N for effluent from sandfilter samples

Time	Cuvette [mg/l]	Online value [mg/l]	Error (%)
10.59 11 Apr	5.95	6.3	6
11.00 11 Apr	5.91	6.3	7
11.01 11 Apr	5.90	6.3	7
10.00 13 Apr	1.57	1.8	15
10.01 13 Apr	1.52	1.8	18

3.1.1 Daily collected samples

Some of the control samples were made with daily collected samples. Collecting a sample over 24 hours. This could then be controlled with the average of the daily value from the online optical tool. The results from this is provided in Table 4. The daily collected samples provide a smaller error, but have fewer data points.

Table 4: Control measurements of NO_3-N for effluent from sandfilter using daily samples

Day	Cuvette [mg/l]	Online value [mg/l]	Error (%)
12-13 feb	7.0	7.9	11
15 feb	8.0	7.5	7
24 feb	7.1	7.2	1

Table 5: Control measurements of NO_3-N for influent to sandfilter using daily sample

Day	Cuvette [mg/l]	Online value [mg/l]	Error (%)
15 feb	9.9	10.2	3

3.1.2 Measurements

The measurements included in the thesis are listed in table 2. Except for TSS and BOD7 which are mentioned later.

Table 6: Measurements included in the thesis, x marks where it is measured.

Unit	Inf ASF	ASF	Inf SF	SF	Eff WWTP
Water $[m^3/h]$	x		x		
NH_4-N $[mg/l]$	x		x		x
NO_3-N $[mg/l]$			x		x
NO_2-N $[mg/l]$			x		
Aeration $[Nm^3/h]$		x			
Bypass $[m^3/h]$		x		x	
Total pump frequency $[Hz]$				x	
Temperature (°C)					x
pH					x
Phosphate [mg/l]	x				x

Inf means influent and eff means effluent

Different types of measurements were conducted: online measurements and cuvette analysis. The most common measurements were online measurements done with SVOA's internal software aCurve which is a tool where all the online measurement tools automatically put in the values. The online measurements were only controlled for the NO_3-N using standard cuvettes and samples on influent to SF and effluent from SF. This resulted in the different quantities being measured the following way:

- Water $[m^3/h]$ - Online (not controlled)
- NH_4-N $[mg/l]$ - Online (not controlled)
- NO_3-N $[mg/l]$ - Online (controlled)
- NO_2-N $[mg/l]$ - Cuvettes
- Aeration $[Nm^3/h]$ - Online (controlled)
- Bypass $[m^3/h]$ - Online (not controlled)
- Total pump frequency $[Hz]$ - Online (not controlled)
- Temperature (°C) - Online (not controlled)
- pH - Online (not controlled)
- phosphate $[mg/l]$ - Online (not controlled)
- BOD7 $[ton/week]$ - Weekly samples influent and effluent
- TSS $[ton/week]$ - Weekly samples influent and effluent

The NO_2-N was only measured once using cuvettes in order to establish if the NO_2-N concentration was high enough to have an impact. To do this 10 samples were taken before the SFs because this is the measuring spot where NO_2-N is present the most. The results are shown in table 3. All the samples gave values lower than the intended area which means the accuracy of the measurements are low. It also means that the values are below than the cuvette range of 0.6 mg/l. This was low enough to not consider the NO_2-N

Table 7: Measurements of NO_2-N using Cuvettes ranging 0.6 mg/l - 6 mg/l

Sample	13:45 9 April 2022	13:52 9 April 2022
I	-0.044	0.205
II	-0.042	0.187
III	-0.040	0.192
IV	-0.051	0.160
V	-0.045	0.199

4 Results and Discussions

4.1 Data

The system boundaries for the data collection was over the ASF, secondary sedimentation and the SFs.

4.1.1 Total Nitrogen

The total amount of influent and effluent nitrogen for each day during the test period is shown in Figure 4. Only NH_4-N is considered for the influent because of the low NO_3-N in the influent. For the effluent both NH_4-N and NO_3-N are considered. The last 3 days of the measurements an operational error occured causing low values.

The averages for each test period is shown in table 8 including removal efficiency of total nitrogen.

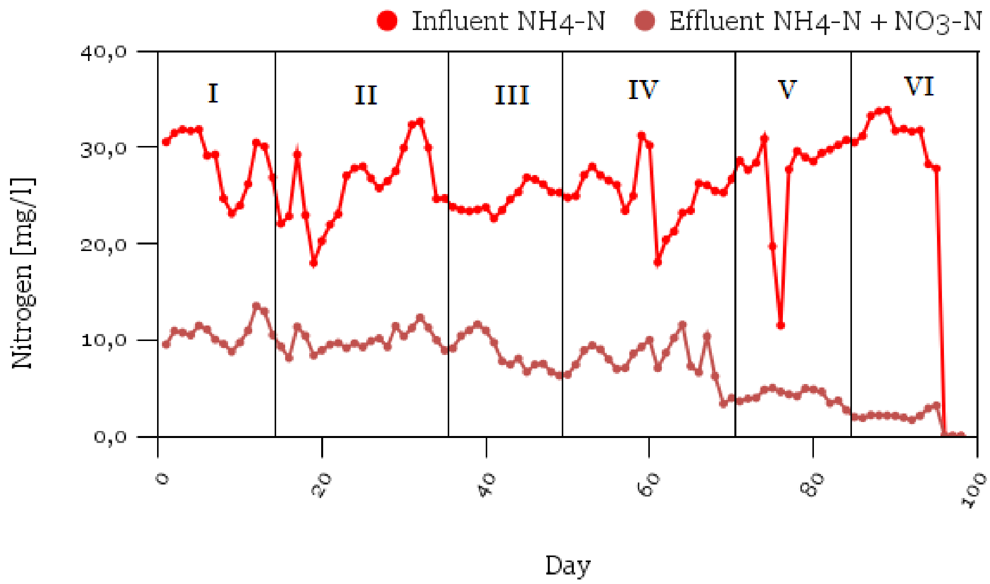

Figure 4: NH_4-N influent in the ASF $[mg/l]$ and effluent NH_4-N and NO_3-N $[mg/l]$

Table 8: Ammonium influent in the ASF $[mg/l]$ and effluent ammonium and nitrate $[mg/l]$ from the WWTP.

Test	Inf NH_4 $[mg/l]$	σ $[mg/l]$	Eff $NH_4 + NO_3$ $[mg/l]$	σ $[mg/l]$	Rem eff of Tot-N	σ
I	28.6	3.1	10.7	1.3	0.63	0.04
II	25.9	3.9	9.9	1.1	0.62	0.04
III	24.6	1.4	8.6	1.8	0.65	0.09
IV	25.2	3.0	7.9	2.0	0.69	0.09
V	27.3	5.3	4.2	0.7	0.85	0.08
IV	31.3	1.9	2,0	0.7	0.94	0.02

Inf = Influent
Eff = Effluent
Rem eff = Removal efficiency

The total nitrogen removal seemed to generally be better when using denitrification on SF as seen in Table 1, Table 8 and Figure 4. However it increased the longer the test period due to several potential factors such as water temperature increase (Carrera et al., 2004), better zone control of the

ASF and increased microorganism growth of the SFs due to longer acclimatization time (Persson, 2018).

The removal efficiency of nitrogen increased drastically for time period 5 and 6 and achieved the lowest emissions also considering that the influent of NH_4-N was the highest for all trials. During trial VI the removal efficiency achieved its highest value where 0.94 removal efficiency was achieved. For clearer comparisons however a constant climate should be used and the same C/N ratio should try to be achieved during all experiments (Sobieszuk & Szewczyk, 2006). The equipment available at Bromma WWTP did not allow for this. But the results have other strengths such as having a realistic environment.

4.1.2 Nitrification

All measurements concerning nitrification is shown in Figure 5. The nitrification is shown as all NH_4-N in all the measurement spots. The NH_4-N from ASF is higher than the effluent of the NH_4-N from the WWTP which means we have some nitrification in the water pipes, secondary sedimentation or the SFs.

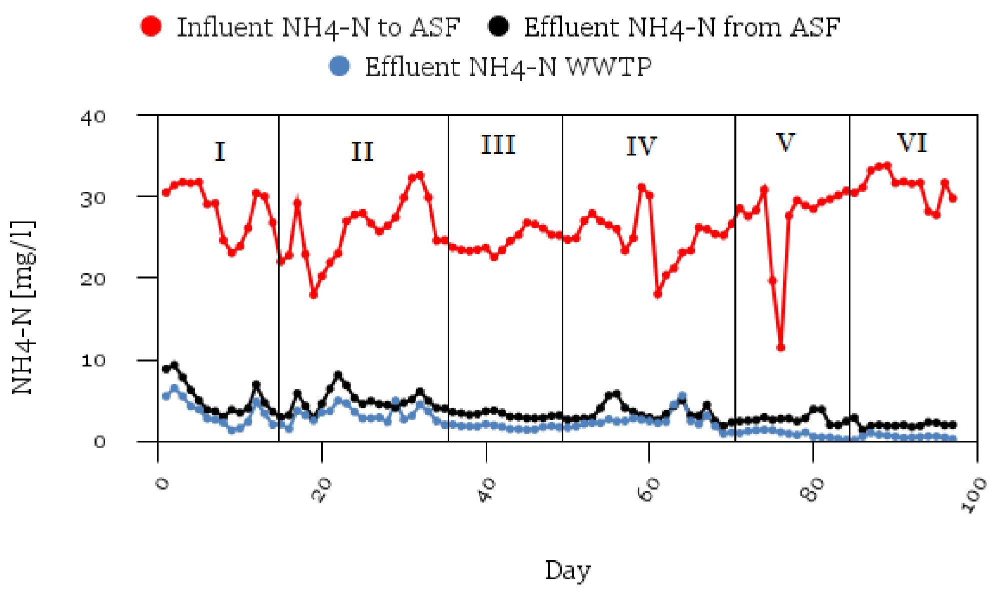

Figure 5: NH_4-N influent to the ASF $[mg/l]$ and effluent NH_4-N from the ASF $[mg/l]$ and effluent NH_4-N from the WWTP $[mg/l]$

The averages for each test period is provided in table 9 as well as removal efficiencies of NH_4-N together with the average aeration in table 10.

Table 9: NH_4-N influent in the ASF $[mg/l]$, effluent NH_4-N from the ASF $[mg/l]$ and effluent NH_4-N $[mg/l]$ for the entire WWTP.

Test	Inf. ASF NH_4-N $[mg/l]$	σ $[mg/l]$	Eff. ASF NH_4-N $[mg/l]$	σ $[mg/l]$	Eff. WWTP NH_4-N $[mg/l]$	σ $[mg/l]$
I	28.6	3.1	5.3	2.1	3.5	1.6
II	25.9	3.9	4.8	1.3	3.2	1.0
III	24.6	1.4	3.2	0.3	1.7	0.2
IV	25.2	3.0	3.4	1.1	2.4	1.0
V	27.3	5.3	2.7	0.6	0.8	0.4
VI	31.3	1.9	2.0	0.3	0.6	0.2

Table 10: NH_4-N removal $[mg/l]$ of the ASF, the NH_4-N removal efficiency of the ASF and aeration $[Nm^3/h]$.

Test	ASF Removal NH_4-N $[mg/l]$	σ $[mg/l]$	ASF Removal Eff.	σ	Aeration $[Nm^3/h]$	σ $[Nm^3/h]$
I	23.3	2.2	.81	0.06	41 900	5 400
II	21.1	3.6	.81	0.05	33 600	3 600
III	21.4	1.6	.87	0.02	36 800	1 100
IV	21.8	3.2	.87	0.05	36 600	5 100
V	24.6	5.3	.90	0.04	42 980	2 500
VI	29.3	2.0	.94	0.01	45 800	2 200

Nitrification is shown in Figure 5 and table 9 and 10. According to the data, the nitrification of NH_4-N mainly occurs in the ASF as shown in the figure and tables. When observing the differences between the effluent ASF NH_4-N and the effluent WWTP the removal NH_4-N is noticable. This should not theoretically occur since there is a lack of oxygen in the secondary sedimentation and the SFs (Persson, 2018). The SFs could however cause increased dissolved oxygen in the sand filters if the filtration speed is high enough in the SFs (Nakhla & Farooq, 2003).

An additional benefit of moving the denitrification process to the SFs is that it is possible to use all the zones in the ASF for the nitrification process which should increase the nitrification rate in the ASF (Persson, 2018). This is also shown in table 10 where the NH_4-N removal is correlated to the aeration of the ASF.

4.1.3 Denitrification

Denitrification on SFs is shown as the difference in Figure 6. Issues during two time intervals occured once due to maintenance on the influent NO_3-N to SF measurement tool. The other time where the value is ineligible to use is because of unknown operational error. Both of these intervals are shown as gray areas in Figure 6. In reality there is also denitrification in the ASF but this was not considered.

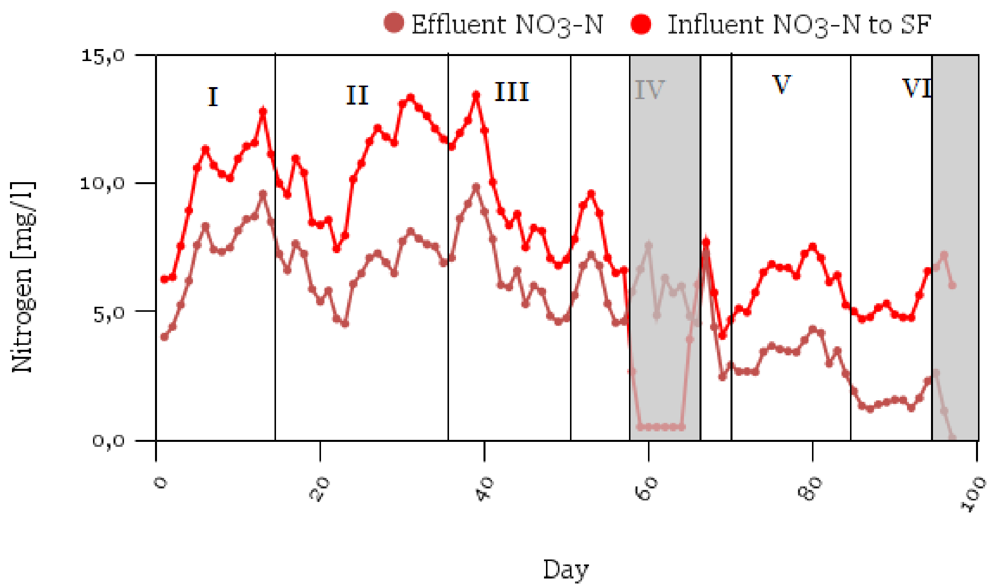

Figure 6: NO_3-N influent $[mg/l]$ on the SFs and effluent NO_3-N $[mg/l]$

The averages for the test periods are shown in table 11 together with the removal efficiencies of NO_3-N for the SFs.

Table 11: NO_3-N influent to the SFs $[mg/l]$ and effluent NO_3-N from the WTTP $[mg/l]$.

Test	Ingoing NO_3-N $[mg/l]$	σ $[mg/l]$	Outgoing NO_3-N $[mg/l]$	σ $[mg/l]$	Removal efficiency	σ
I	10.0	2.0	7.2	1.7	0.28	0.03
II	10.7	1.8	6.7	1.0	0.37	0.05
III	9.6	2.2	6.9	1.7	0.28	0.04
IV	4.8	3.2	5.5	1.4	-	-
V	6.3	0.8	3.3	0.6	0.48	0.03
VI	5.5	0.9	1.5	0.9	0.72	0.10

The denitrification of the SFs is dependent on the dosage on the SFs as can be seen in table 11 and table 1. As previously mentioned this is also significantly impacted by the temperature, growth of microorganisms and the C/N ratio.

4.1.4 Temperature and pH

The temperature and pH for the test periods is shown in Figure 7 together with the total removed nitrogen.

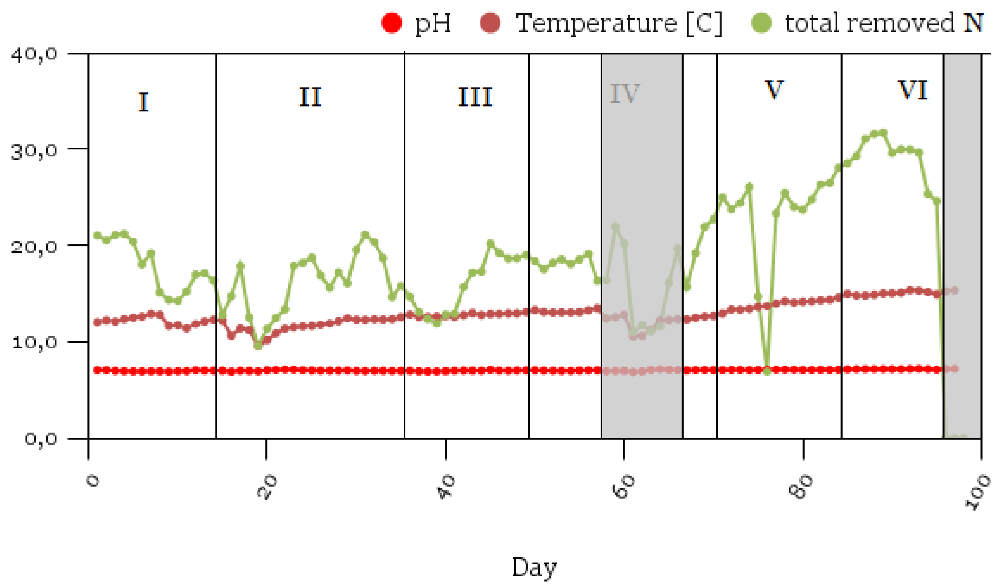

Figure 7: Nitrate influent $[mg/l]$ on the SFs and effluent nitrate $[mg/l]$

The averages for each test period is shown in table 12 together with total removed N

Table 12: Temperature [°C],pH of the effluent water and Tot-N removed $[mg/l]$.

Test	Temperature (°C)	σ	pH	σ	Tot-N Removed	σ
I	11.9	0.3	7.0	0.06	17.9	2.6
II	11.4	0.7	7.0	0.05	16.0	3.1
III	12.3	0.2	7.0	0.05	16.0	3.0
IV	12.0	0.6	7.0	0.07	17.3	3.5
V	13.2	0.7	7.1	0.02	23.1	5.6
VI	14.7	0.4	7.2	0.03	29.3	2.1

From the values in table 12 it is possible to see that the total removal efficiency increased every week. Table 8 and Figure 7 shows that there is a correlation between temperature and total removed nitrogen which agrees with the literature (Carrera et al., 2004).

pH is consistently between 7 and 7.2 during the trials. According to the literature a pH of 7.5 is beneficial for the denitrification process and diverting from it gradually decreases the biological denitrification rate (YATONG, 1995).

4.1.5 Phosphate

The result for phosphate removal for the ASF and SF are shown in table 9.

Table 13: Phosphate removal in terms of influent Phosphate $[mg/l]$, effluent Phosphate $[mg/l]$ and removal efficiency of Phosphate.

Test	Inf. Phosphate $[mg/l]$	σ	Eff. Phosphate $[mg/l]$	σ	Removal eff.	σ
I	0.94	0.20	0.059	0.03	0.94	0.04
II	0.84	0.20	0.061	0.07	0.93	0.17
III	1.0	0.16	0.039	0.02	0.96	0.02
IV	0.97	0.17	0.027	0.01	0.97	0.01
V	1.3	0.08	0.014	0.00	0.99	0.00
VI	1.9	0.13	0.024	0.1	0.99	0.00

The phosphate removal is quite consistent and does not seem to get impacted by the dosage form. However according to previous studies sand filter should not provide satisfactory result for phosphorus removal (Vidal, Hedström, & Herrmann, 2018). This can however be assumed to be consumed in the biological process due to it being a key component for the survival of microorganisms. The very low values of the effluent phosphate could however have an impact on the microorganism growth on the sand filters. However a phosphate concentration of 0.1 mg/l is sufficient for denitrification, but have negative performances when reaching 0.03 mg/L (Debarbadillo, Rectanus, Canham, & Schauer, 2006). For the trials I-III the effluent water was above this limit. For the other trials this could however have a negative impact but does not seem to have since the removal efficiencies are higher in trial IV-VI. The system achieves high removal efficiencies for all tests.

4.1.6 BOD7

The result for BOD7 removal for the entire WWTP are shown in Table 14 and are given from weekly samples.

Table 14: BOD7 removal in terms of influent BOD7 $[mg/l]$, effluent BOD7 $[mg/l]$ and removal efficiency of BOD7.

Test	Inf. BOD7 $[mg/l]$	Eff. BOD7 $[mg/l]$	BOD7
I	95.0	1.1	0.99
II	147.3	2.5	0.98
III	144.9	3.6	0.98
IV	151.8	2.5	0.98
V	145.4	2.9	0.98
VI	196.4	3.9	0.98

The BOD7 emissions are increasing according to Table 14. The influent however also increases. According to the literature the increasing temperature should increase the BOD removal rate (Lim, Huang, Hu, Goto, & Fujie, 2001). The removal efficiency in the trials is lowered for higher temperatures. It could suggest an overdosage of methanol, it is however uncertain since the removal efficiencies are close to 1.

4.1.7 Suspended solids

The result for TSS removal for the entire WWTP are shown in Table 15 and are given from weekly samples.

Table 15: TSS removal in terms of influent TSS $[mg/l]$, effluent BOD7 $[mg/l]$ and removal efficiency of TSS.

Test	Inf. TSS $[mg/l]$	Eff. TSS $[mg/l]$	TSS
I	155.1	2.7	0.98
II	258.5	1.8	0.99
III	219.9	5.7	0.97
IV	247.9	2.8	0.99
V	294.9	4.4	0.99
VI	112.9	3.6	0.97

One of the previously major uses for the sand filters was to remove suspended solids. Using the SFs for denitrification should increase clogging of the SFs. To investigate the impact on TSS treatment more water bypass was also considered. Water bypass also impacts other things. Bypass causes both increased TSS emissions and it causes unreliable data. The water bypass for the SF and the ASF for each test period is shown in table 16.

Table 16: ASF bypass $[m^3/h]$ and SF bypass $[m^3/h]$ for the test periods.

Test	ASF bypass $[m^3/h]$	σ	SF bypass $[m^3/h]$	σ
I	0	0	8.0	16.6
II	71.3	223.9	84.0	228.3
III	1.1	2.8	0	0.1
IV	35.7	118.9	91.6	231.0
V	0	0	0	0
VI	2.7	6.7	0	0

4.1.8 Operational time between backwashes

To investigate the operational time between backwashes the operational time for the backwash pumps is presented in table 13.

Table 17: Total operational time of backwash pumps for each time period $[h]$

Test	Operational time for pumps	σ
I	20.5	4.2
II	29.3	8.5
III	20.6	7.0
IV	21.8	9.5
V	20.8	5.8
VI	26.2	5.5

Increased operational time for pumps for the backwashing and increased aeration increases the energy consumption of Bromma WWTP which impacts economy and sustainaibility of the solution. It is clear that this is most impacted for trial II and trial VI.

The water bypass is not only caused by increased clogging of sand filters due to denitrification on sand filters but also the water flow into the WTTP. Water flow varies for different periods and will cause water bypass or increased stress on the WTTP. Water flow is shown in Figure 8.

The average water flow for the ASF and SF are shown in table 14.

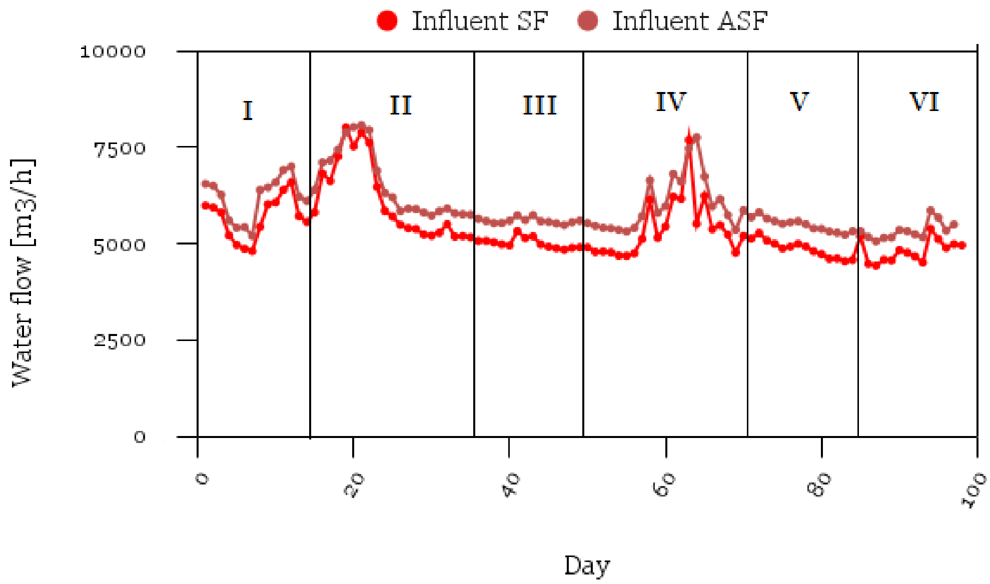

Figure 8: Water influent to SF $[m^3/h]$ on the SFs and water influent to ASF $[m^3/h]$.

Table 18: Water flow ASF and SF $[m^3/h]$.

Test	Water flow ASF $[m^3/h]$	σ	Water flow SF $[m^3/h]$	σ
I	6 200	500	5 700	600
II	6 600	1000	6 100	1000
III	5 600	0	5000	100
IV	6 000	900	5 400	700
V	5 500	200	4 900	200
VI	5 300	200	4 800	300

The operational time for the pumps was highest for trial II and VI. The dosage on the SFs was the highest during all of the trials during these tests according to table 1. The water flow was also high during trial II and IV but lower during trial VI. The load of methanol on the SFs was also lowest during trial IV. According to literature denitrification on slow SFs works well for low load of nitrogen (?, ?) this matches with the result.

4.2 Sustainability

Increased methanol use impacts the environent as well as increased energy use from the implementation of denitrification on SFs. Lower nitrate and ammonia emissions to the recipient is however a benefit.

The risk of overdosage of methanol when dosing methanol on SF and increasing the BOD7 emissions to the recipient is a risk when using denitrification on SF, but there is also a risk of overconsuming the carbon source when having denitrification in the ASF however that implies a lesser environmental risk.

5 Conclusion

The implementation of carbon dosage to cause denitrification on SFs is situational. The water temperature had a significant impact on the nitrogen treatment. The carbon dosage on SFs causes the SFs to manage high water flows worse due to increased clogging and higher operation times for the back wash pumps. The removal of Tot-N however improves when implementing denitrification on SFs compared to the process of pre-denitrification in the ASF but it is not certain for all operating conditions. The BOD7m, phosphate and TSS seemed to be unaffected by the implementation of denitrification on SF in the system. The carbon source dosage on sand filters however makes denitrification on sand filters occur even if the phosphate levels are low and achieves total removal of nitrogen of between 0.62 - 0.94 for different conditions and dosage. Increased aeration improves nitrification in the ASF.

5.1 Future studies

Future studies should consist of investigating C/N ration for SF denitrification and how to reduce the clogging of the SFs when implementing the process to let the SFs treat high loads of water.

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Appendix A - Data for test periods

day	Day	NO3-N out mg/l	NO3-N before filter mg/l	Flow methanol ASF l/h	Flow methanol SF l/h	Water flow SF m3/h	NH4-N out mg/l	Aeration Nm3/h	Bypass Filter m3/s	Bypass filter m3/h	NH4-N out ASF mg/l	NH4-N influent mg/l	Temp out c	Water flow ASF m3/h	pH out mg/l	ASF Bypass m3/s	ASF Bypass m3/h	NH4 + NO3 out	removed kväve	Pump time	Influent water WWTP m3/s	Influent Water WWTP m3/h	Phosphate influent ASF mg/l	Phosphate out ASF mg/l
02-07	1	4,0	6,3	0,1	56,3	5982,6	5,5	34876,1	0,0	0,0	8,8	30,5	11,9	6546,8	7,1	0,003	10,6	9,5	21,0	14,8	1,8	6576	1,0	0,1
02-08	2	4,4	6,3	0,1	50,2	5934,5	6,5	35405,1	0,0	0,0	9,3	31,5	12,1	6497,4	7,1	0,001	5,2	10,9	20,5	14,7	1,8	6506	1,0	0,1
02-09	3	5,3	7,5	0,1	50,5	5803,8	5,5	34954,8	0,0	0,0	7,8	31,8	12,0	6262,7	7,0	0,001	3,1	10,8	21,1	21,9	1,7	6269	1,0	0,1
02-10	4	6,2	8,9	0,1	50,5	5211,3	4,3	34763,3	0,0	0,0	6,3	31,7	11,6	5600,2	6,9	0,000	0,0	10,5	21,2	24,3	1,6	5651	0,9	0,1
02-11	5	7,6	10,6	0,1	50,5	4962,3	3,9	41221,3	0,0	0,0	5,0	31,8	11,8	5408,9	6,9	0,000	0,0	11,5	20,4	18,3	1,5	5499	0,9	0,1
02-12	6	8,3	11,3	0,1	50,5	4862,6	2,7	47177,8	0,0	0,0	3,8	29,1	12,0	5426,2	6,9	0,000	0,0	11,1	18,0	16,9	1,5	5416	1,0	0,0
02-13	7	7,4	10,7	0,1	50,5	4801,6	2,6	48735,9	0,0	0,0	3,6	29,2	12,1	5194,9	6,9	0,000	0,0	10,0	19,2	16,0	1,5	5339	1,0	0,1
02-14	8	7,3	10,3	0,1	50,5	5433,3	2,3	46250,5	0,0	0,0	2,9	24,7	12,4	6387,2	6,9	0,001	4,6	9,6	15,1	16,4	1,7	5954	1,0	0,1
02-15	9	7,5	10,2	0,1	50,5	6015,6	1,3	40605,6	0,0	0,0	3,8	23,1	11,5	6455,6	6,9	0,003	9,3	8,8	14,3	25,8	1,8	6453	0,8	0,1
02-16	10	8,1	10,9	0,1	50,5	6065,9	1,6	40577,4	0,0	0,0	3,5	23,9	11,6	6586,5	6,9	0,003	9,6	9,7	14,2	26,3	1,8	6582	0,6	0,0
02-17	11	8,6	11,4	0,1	50,5	6391,2	2,4	40204,2	0,0	0,0	4,0	26,2	11,3	6907,9	7,0	0,002	5,4	11,0	15,2	23,1	1,9	6903	0,5	0,0
02-18	12	8,7	11,6	0,1	50,5	6592,9	4,8	47314,5	0,0	0,0	6,9	30,5	11,7	7000,9	7,0	0,018	64,1	13,5	17,0	21,3	2,0	7053	1,3	0,1
02-19	13	9,6	12,8	0,1	50,5	5710,1	3,4	47778,2	0,0	0,0	4,7	30,1	11,8	6211,7	7,0	0,000	0,0	12,9	17,1	24,5	1,7	6200	1,0	0,0
02-20	14	8,5	11,1	0,1	50,5	5562,5	2,0	46856,6	0,0	0,0	3,6	26,9	11,9	6103,2	7,0	0,000	0,0	10,5	16,4	22,6	1,7	6091	1,1	0,0
02-21	15	7,2	10,0	0,1	61,7	5805,9	2,1	42416,3	0,1	186,4	2,9	22,1	11,9	6389,0	7,0	0,014	50,1	9,3	12,8	21,8	1,8	6498	1,0	0,1
02-22	16	6,6	9,5	0,1	70,1	6816,2	1,5	34748,7	0,0	0,0	3,2	22,8	10,5	7105,1	6,9	0,004	12,8	8,1	14,8	36,5	2,0	7148	0,8	0,0
02-23	17	7,6	10,9	0,1	70,1	6622,4	3,7	36750,9	0,0	0,0	5,8	29,2	11,3	7155,4	7,0	0,000	1,3	11,3	17,9	26,8	2,0	7143	1,0	0,0
02-24	18	7,2	10,4	0,1	70,1	7262,5	3,2	32532,0	0,0	0,0	4,3	22,9	11,1	7439,7	7,0	0,050	179,8	10,4	12,5	27,2	2,1	7608	0,8	0,0
02-25	19	5,9	8,5	0,1	70,1	8010,8	2,5	25220,8	0,1	302,8	2,8	18,0	9,4	7886,2	6,9	0,236	851,1	8,4	9,6	33,7	2,4	8727	0,7	0,1
02-26	20	5,4	8,4	0,1	70,1	7522,5	3,5	27873,4	0,3	991,3	4,6	20,3	10,0	8022,3	7,0	0,182	656,6	8,9	11,4	45,7	2,4	8671	0,6	0,3
02-27	21	5,8	8,6	0,1	70,1	7884,0	3,7	30999,4	0,0	0,0	6,4	22,0	10,7	8069,0	7,1	0,003	9,5	9,5	12,5	46,8	2,2	8071	0,7	0,0
02-28	22	4,7	7,4	0,1	70,1	7617,9	5,0	36272,0	0,0	0,0	8,1	23,1	11,3	7946,0	7,1	0,000	0,0	9,7	13,4	43,8	2,2	7933	0,2	0,1
03-01	23	4,5	8,0	0,1	70,1	6465,6	4,6	34794,8	0,0	0,0	6,8	27,0	11,4	6886,9	7,1	0,001	3,2	9,1	17,9	33,7	1,9	6878	1,0	0,1
03-02	24	6,1	10,1	0,1	70,1	5844,9	3,6	33452,0	0,0	0,0	5,3	27,8	11,3	6309,1	7,1	0,000	0,0	9,6	18,2	25,5	1,7	6298	0,8	0,0
03-03	25	6,5	10,8	0,1	70,1	5699,8	2,8	33368,7	0,0	0,0	4,5	28,0	11,4	6194,9	7,0	0,000	0,0	9,2	18,8	28,9	1,7	6186	0,8	0,0
03-04	26	7,1	11,6	0,1	70,1	5484,3	2,8	30591,9	0,0	0,0	4,9	26,8	11,5	5842,0	7,0	0,000	0,0	9,9	16,9	28,4	1,7	5990	0,8	0,0
03-05	27	7,3	12,1	0,1	70,1	5398,1	2,9	30578,0	0,0	0,0	4,5	25,7	11,5	5902,8	7,0	0,000	0,0	10,1	15,6	23,8	1,6	5894	0,7	0,0
03-06	28	6,9	11,8	0,1	70,1	5378,5	2,4	34116,0	0,0	0,0	4,4	26,5	11,7	5891,4	7,0	0,000	0,0	9,3	17,2	24,5	1,6	5881	0,9	0,0
03-07	29	6,5	11,6	0,1	70,1	5234,4	4,9	37229,2	0,0	0,0	4,1	27,5	12,2	5801,6	7,0	0,000	0,0	11,4	16,1	25,3	1,6	5790	1,2	0,0
03-08	30	7,7	13,1	0,1	70,1	5203,7	2,6	33753,0	0,0	0,0	4,7	29,9	12,0	5721,9	7,0	0,000	0,0	10,4	19,5	20,1	1,6	5760	0,9	0,0
03-09	31	8,1	13,3	0,1	70,1	5278,0	3,1	32498,5	0,0	16,1	5,1	32,3	12,1	5837,8	7,0	0,000	0,0	11,2	21,1	21,5	1,6	5823	0,9	0,0
03-10	32	7,8	12,9	0,1	70,1	5502,7	4,5	31735,6	0,0	0,0	6,1	32,7	12,1	5907,2	7,0	0,000	0,0	12,3	20,3	34,4	1,6	5895	0,8	0,0
03-11	33	7,6	12,6	0,1	70,1	5180,6	3,6	34846,5	0,0	0,0	4,9	30,0	11,8	5779,4	7,0	0,000	0,0	11,3	18,7	28,8	1,6	5766	1,0	0,1
03-12	34	7,5	12,1	0,1	70,1	5192,3	2,5	35265,0	0,0	0,0	4,0	24,6	11,9	5757,3	7,0	0,000	0,0	10,0	14,7	17,0	1,6	5748	1,0	0,1
03-13	35	6,9	11,7	0,1	70,1	5162,4	2,0	36549,8	0,0	0,0	4,0	24,7	12,1	5746,9	7,0	0,000	0,0	8,9	15,8	20,1	1,6	5737	1,0	0,1
03-14	36	7,1	11,4	23,1	46,9	5070,0	2,0	37353,9	0,0	0,0	3,5	23,8	12,4	5644,0	7,0	0,000	0,0	9,1	14,7	22,7	1,6	5637	1,0	0,1
03-15	37	8,6	11,9	35,0	35,0	5070,0	1,8	35319,5	0,0	0,0	3,4	23,5	12,3	5584,0	6,9	0,000	0,0	10,4	13,1	20,4	1,6	5586	0,9	0,1
03-16	38	9,2	12,4	35,0	35,0	5029,7	1,8	35466,8	0,0	0,0	3,2	23,3	12,1	5528,8	6,9	0,000	0,0	11,0	12,4	25,4	1,5	5525	0,9	0,1
03-17	39	9,8	13,4	35,0	35,0	4976,4	1,8	36697,1	0,0	0,0	3,3	23,5	12,2	5532,8	6,9	0,000	0,0	11,6	11,9	22,4	1,5	5530	0,9	0,0
03-18	40	8,9	12,0	35,0	35,0	4949,5	2,1	36293,1	0,0	7,8	3,6	23,8	12,5	5591,7	6,9	0,000	0,0	11,0	12,8	23,5	1,6	5592	0,9	0,0
03-19	41	7,8	10,0	35,0	35,0	5319,9	1,9	35550,9	0,0	0,0	3,7	22,6	12,1	5730,1	7,0	0,000	0,0	9,7	12,9	35,4	1,6	5737	0,8	0,0
03-20	42	6,0	8,9	35,0	35,0	5143,7	1,7	36608,5	0,0	0,0	3,4	23,5	12,3	5610,2	7,0	0,000	0,0	7,8	15,7	24,7	1,6	5611	0,9	0,0
03-21	43	5,9	8,4	35,0	35,0	5187,8	1,5	38133,2	0,0	7,7	3,0	24,6	12,7	5736,3	7,0	0,000	0,0	7,4	17,2	30,3	1,6	5737	1,0	0,0
03-22	44	6,6	8,8	35,0	35,0	4976,0	1,5	37413,4	0,0	0,0	3,0	25,3	12,4	5578,5	7,0	0,000	0,0	8,0	17,3	13,5	1,5	5578	1,3	0,0
03-23	45	5,3	7,5	35,0	35,0	4915,1	1,4	38155,4	0,0	0,0	2,8	26,9	12,4	5563,9	7,1	0,000	0,4	6,7	20,2	13,8	1,5	5558	1,3	0,1
03-24	46	6,0	8,3	35,0	35,0	4879,5	1,4	35981,0	0,0	0,0	2,8	26,7	12,1	5522,3	7,0	0,000	0,0	7,4	19,2	16,0	1,5	5514	0,9	0,0
03-25	47	5,8	8,1	35,0	35,0	4839,6	1,7	36402,5	0,0	0,0	2,8	26,2	12,4	5476,8	7,0	0,000	0,0	7,5	18,6	13,8	1,5	5474	1,0	0,0
03-26	48	4,8	7,1	35,0	35,0	4888,8	1,8	37282,1	0,0	0,0	3,1	25,3	12,6	5553,6	7,0	0,000	0,0	6,7	18,7	12,5	1,5	5548	1,0	0,0
03-27	49	4,6	6,8	35,0	35,0	4903,0	1,7	39051,5	0,0	0,0	3,1	25,3	12,0	5593,1	7,0	0,000	0,0	6,3	19,0	14,2	1,6	5591	1,0	0,0
03-28	50	4,7	7,0	41,3	28,8	4902,0	1,6	40131,8	0,0	0,0	2,6	24,8	13,0	5530,0	7,0	0,000	0,0	6,4	18,4	13,1	1,5	5525	1,0	0,0
03-29	51	5,6	7,8	46,7	23,3	4781,7	1,8	36945,9	0,0	0,0	2,7	24,9	12,3	5457,5	7,0	0,000	0,0	7,4	17,5	13,2	1,5	5445	1,0	0,0
03-30	52	6,8	9,1	46,7	23,3	4789,0	2,1	37467,2	0,0	0,0	2,8	27,1	12,6	5408,1	7,0	0,000	0,8	8,9	18,2	14,4	1,5	5438	0,9	0,0
03-31	53	7,2	9,6	46,7	23,3	4771,3	2,2	36971,0	0,0	0,0	2,8	28,0	12,2	5394,6	7,0	0,000	0,0	9,4	18,6	13,0	1,5	5401	1,0	0,0
04-01	54	6,8	8,8	46,7	23,3	4685,9	2,2	36222,4	0,0	0,0	4,0	27,1	12,1	5354,3	7,0	0,000	0,0	9,0	18,1	12,5	1,5	5346	1,0	0,0
04-02	55	5,3	7,1	46,7	23,3	4679,8	2,7	37576,3	0,0	0,0	5,6	26,5	12,3	5310,5	7,0	0,000	0,0	8,0	18,6	14,3	1,5	5302	1,0	0,0
04-03	56	4,6	6,5	46,7	23,3	4746,0	2,4	41105,8	0,0	0,0	5,8	26,1	12,4	5404,6	7,0	0,000	0,0	7,0	19,1	12,7	1,5	5401	1,1	0,0
04-04	57	4,6	6,6	46,7	23,3	5120,2	2,5	40713,2	0,0	0,0	4,1	23,4	12,7	5708,2	7,0	0,002	6,6	7,1	16,3	17,6	1,6	5712	1,0	0,0
04-05	58	5,8	2,7	46,7	23,3	6136,1	2,8	37288,2	0,0	0,0	3,6	24,9	12,3	6640,1	6,9	0,000	0,7	8,6	16,4	31,1	1,8	6631	1,0	0,0
04-06	59	6,6	0,5	46,7	23,3	5150,9	2,6	39484,5	0,0	0,0	3,1	31,2	12,1	5794,3	7,0	0,000	0,0	9,3	22,0	20,4	1,6	5793	1,0	0,0
04-07	60	7,6	0,5	46,7	23,3	5440,7	2,4	40728,9	0,0	0,0	2,9	30,2	12,1	5968,2	7,0	0,062	223,9	10,0	20,2	20,5	1,7	6177	1,0	0,0
04-08	61	4,9	0,5	46,7	23,3	6214,2	2,2	22594,6	0,2	540,9	2,6	18,1	10,4	6805,4	6,9	0,029	104,3	7,1	11,0	38,6	1,9	6903	0,6	0,0
04-09	62	6,3	0,5	46,7	23,3	6161,8	2,4	25666,0	0,0	107,3	3,3	20,4	10,5	6604,4	6,9	0,007	23,8	8,7	11,7	45,9	1,8	6621	0,6	0,0
04-10	63	5,7	0,5	46,7	23,3	7687,8	4,5	33732,2	0,0	0,0	4,3	21,2	11,1	7471,3	7,1	0,230	829,7	10,2	11,1	25,6	2,3	8290	0,9	0,0
04-11	64	6,0	0,5	46,7	23,3	5516,3	5,6	46670,9	0,0	56,6	5,0	23,2	12,1	7753,6	7,1	0,195	701,4	11,6	11,6	36,9	2,3	8447	1,2	0,0
04-12	65	4,8	3,9	46,7	23,3	6233,6	2,4	38428,4	0,0	0,0	3,1	23,4	12,1	6737,3	7,1	0,009	31,7	7,3	16,1	24,9	1,9	6774	1,0	0,0
04-13	66	4,5	6,0	46,7	23,3	5370,2	2,1	34441,6	0,0	0,0	3,1	26,2	12,0	5962,4	7,1	0,000	0,0	6,6	19,6	22,1	1,7	5956	0,8	0,0
04-14	67	7,2	7,7	46,7	23,3	5474,8	3,1	34996,9	0,0	44,6	4,4	26,1	12,1	6152,2	7,0	0,000	0,0	10,4	15,7	15,8	1,7	6145	1,2	0,0
04-15	68	4,4	5,7	46,7	23,3	5229,9	1,8	36191,2	0,0	0,0	2,4	25,4	12,0	5735,7	7,1	0,000	0,0	6,2	19,2	21,4	1,6	5726	1,0	0,0
04-16	69	2,5	4,1	46,7	23,3	4763,1	0,9	33243,1	0,0	0,0	1,8	25,3	12,1	5355,2	7,1	0,000	0,0	3,3	21,9	27,2	1,5	5347	1,0	0,0
04-17	70	2,9	4,7	46,7	23,3	5195,5	1,0	37058,0	0,0	0,0	2,3	26,7	12,6	5861,1	7,1	0,000	0,0	4,0	22,7	17,5	1,6	5852	1,2	0,0
04-18	71	2,7	5,1	46,7	23,3	5129,4	1,0	39693,0	0,0	0,0	2,4	28,6	12,7	5679,9	7,1	0,000	0,0	3,6	25,0	25,3	1,6	5671	1,3	0,0
04-19	72	2,7	5,0	35,6	34,4	5269,7	1,2	40925,1	0,0	0,0	2,5	27,6	13,1	5809,4	7,1	0,000	0,0	3,9	23,8	35,1	1,6	5804	1,4	0,0
04-20	73	2,6	5,7	23,3	46,7	5080,0	1,3	39577,1	0,0	0,0	2,5	28,4	13,0	5650,2	7,1	0,000	0,0	4,0	24,4	20,5	1,6	5642	1,3	0,0
04-21	74	3,4	6,5	23,3	46,7	4992,9	1,4	40155,2	0,0	0,0	2,9	30,9	11,8	5583,3	7,1	0,000	0,0	4,8	26,1	21,4	1,6	5581	1,4	0,0
04-22	75	3,7	6,8	23,3	46,7	4872,1	1,3	40959,1	0,0	0,0	2,6	19,7	12,5	5510,6	7,1	0,000	0,0	5,0	14,7	17,3	1,5	5497	1,4	0,0
04-23	76	3,5	6,7	23,3	46,7	4917,7	1,1	42776,9	0,0	0,0	2,7	11,5	12,9	5552,5	7,1	0,000	0,0	4,6	6,9	17,4	1,5	5553	1,4	0,0
04-24	77	3,5	6,7	23,3	46,7	4989,8	0,9	45262,4	0,0	0,0	2,8	27,7	13,5	5580,5	7,1	0,000	0,0	4,3	23,3	24,0	1,5	5573	1,4	0,0
04-25	78	3,4	6,4	23,3	46,7	4920,7	0,7	45361,7	0,0	0,0	2,4	29,6	13,7	5499,8	7,1	0,000	0,0	4,2	25,4	29,1	1,5	5491	1,4	0,0
04-26	79	3,9	7,2	23,3	46,7	4797,4	1,0	46210,0	0,0	0,0	2,8	29,0	13,6	5392,0	7,1	0,000	0,0	4,9	24,0	17,5	1,5	5385	1,4	0,0
04-27	80	4,3	7,5	23,3	46,7	4723,1	0,5	43716,7	0,0	0,0	3,9	28,5	13,9	5382,5	7,1	0,000	0,0	4,8	23,7	19,7	1,5	5378	1,2	0,0
04-28	81	4,2	7,1	23,3	46,7	4604,9	0,4	44206,5	0,0	0,0	3,9	29,4	12,3	5309,4	7,1	0,000	0,0	4,6	24,8	16,6	1,5	5301	1,3	0,0
04-29	82	3,0	6,1	23,3	46,7	4611,6	0,4	42483,6	0,0	0,0	2,0	29,8	13,5	5279,9	7,1	0,000	0,0	3,4	26,3	17,3	1,5	5274	1,2	0,0
04-30	83	3,5	6,4	23,3	46,7	4540,1	0,2	43486,5	0,0	0,0	1,9	30,2	13,6	5226,1	7,1	0,000	0,0	3,7	26,5	14,3	1,5	5221	1,4	0,0
05-01	84	2,6	5,2	23,3	46,7	4577,0	0,1	46918,2	0,0	0,0	2,4	30,8	14,1	5317,2	7,1	0,000	0,0	2,7	28,1	16,1	1,5	5306	1,4	0,0
05-02	85	1,9	5,0	8,9	61,2	5191,5	0,1	47839,8	0,0	19,9	2,8	30,5	14,6	5317,3	7,1	0,000	0,0	2,0	28,5	19,7	1,5	5308	1,7	0,0
05-03	86	1,3	4,7	0,1	70,1	4472,3	0,5	44907,8	0,0	0,0	1,4	31,2	14,1	5170,1	7,2	0,000	0,0	1,9	29,3	17,0	1,4	5164	2,0	0,0
05-04	87	1,2	4,8	0,1	66,6	4424,5	1,0	42555,8	0,0	0,0	1,9	33,3	13,5	5058,8	7,2	0,000	0,0	2,2	31,1	21,8	1,4	5052	2,0	0,0
05-05	88	1,4	5,1	0,1	70,1	4581,2	0,8	43593,0	0,0	0,0	2,0	33,7	14,5	5147,0	7,2	0,000	0,0	2,2	31,6	26,4	1,4	5143	2,0	0,0
05-06	89	1,5	5,3	0,1	70,1	4563,6	0,7	43647,6	0,0	0,0	1,9	33,9	14,6	5160,2	7,2	0,000	0,0	2,1	31,7	31,6	1,4	5157	1,9	0,0
05-07	90	1,6	4,9	0,1	70,1	4827,4	0,5	44778,0	0,0	0,0	1,9	31,7	14,5	5353,2	7,2	0,000	0,0	2,1	29,6	25,8	1,5	5339	2,0	0,0
05-08	91	1,6	4,8	0,1	70,1	4762,6	0,4	45104,5	0,0	0,0	2,0	31,9	14,8	5317,8	7,2	0,000	0,0	1,9	30,0	32,8	1,5	5305	1,7	0,0
05-09	92	1,2	4,8	0,1	70,1	4665,8	0,4	47360,9	0,0	0,0	1,7	31,6	15,2	5238,5	7,2	0,000	0,0	1,7	30,0	30,1	1,5	5227	1,8	0,0
05-10	93	1,6	5,6	0,1	70,1	4505,1	0,5	49740,8	0,0	0,0	1,8	31,8	14,9	5164,1	7,2	0,000	0,0	2,1	29,6	22,0	1,4	5155	2,0	0,0
05-11	94	2,3	6,6	0,1	70,1	5386,3	0,6	47467,5	0,0	0,0	2,3	28,2	15,1	5856,8	7,2	0,000	0,0	2,9	25,4	26,8	1,6	5834	1,7	0,0
05-12	95	2,6	6,7	0,1	70,1	5113,7	0,6	43412,0	0,0	15,3	2,2	27,8	14,9	5672,9	7,1	0,000	0,0	3,2	24,6	36,2	1,6	5660	1,7	0,0
05-13	96	1,1	7,2	0,1	70,1	4886,5	0,4	47159,1	0,0	0,0	1,9	31,8	15,0	5334,0	7,2	0,000	0,0	1,6	30,2	27,1	1,5	5320	1,9	0,0
05-14	97	0,1	6,0	0,1	70,1	4980,5	0,2	47799,1	0,0	0,0	2,0	29,8	15,0	5494,9	7,2	0,000	0,0	0,3	29,6	23,3	1,5	5479	1,8	0,0

Test period	BOD7 in	BOD7 ut	TSS in	TSS ut
	mg/l	mg/l	mg/l	mg/l
1	95,0	1,1	155,1	2,7
2	147,3	2,5	258,5	1,8
3	144,9	3,6	219,9	5,7
4	151,8	2,5	247,9	2,8
5	145,4	2,9	294,9	4,4
6	196,4	3,9	112,9	3,6

Appendix B - Emission permit

KONCESSIONSNÄMNDEN	BESLUT	Nr 138/92 1(68)
FÖR MILJÖSKYDD	1992-09-28	Dnr 192-1096-90
Avd 4	Stockholm	Aktbil 55
		Dnr 192-1097-90
		Aktbil 40
		Dnr 192-1098-90
		Aktbil 39

SÖKANDE

Stockholm Vatten Aktiebolag
ombud: stadsadvokat Stig Bragnum, Stockholms stadskansli, juridiska avdelningen, Strömsborg, 105 35 STOCKHOLM

SAKEN

Ansökan om tillstånd till utsläpp av avloppsvatten i Saltsjön, Stockholms och Nacka kommuner, Stockholms län (verksamhetskod 92.01)

KONCESSIONSNÄMNDENS BESLUT

Koncessionsnämnden lämnar Stockholm Vatten Aktiebolag tillstånd enligt miljöskyddslagen att i Saltsjön släppa ut avloppsvatten från tätbebyggelse som är ansluten till Henriksdals, Bromma och Louddens reningsverk.

Koncessionsnämnden skjuter enligt 21 § miljöskyddslagen upp prövningen av vilka villkor som skall gälla beträffande dels begränsningsvärden för avloppsvattnets innehåll av föroreningar, dels skyddsåtgärder som avser ledningsnätet och dels skyddsåtgärder som avser ämnen som i icke obetydlig grad kan störa processerna i reningsverket, äventyra slammets kvalitet som jordförbättringsmedel eller som i utloppsvattnet når eller kan nå akuttoxiska nivåer eller på annat sätt ge negativa effekter i recipienten.