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Investigation of the treatment process at Kungsberget's wastewater treatment plant under periods of irregular and low loads

Reningsprocessen på Kungsbergets avloppsreningsverk vid ojämn och låg belastning

Alexandra Bercoff

Abstract

Investigation of the treatment process at Kungsberget's wastewater treatment plant under periods of irregular and low loads

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At Kungsberget ski-resort in Gävleborg county all wastewater produced at the facility is treated on-site. The treatment takes place at their own wastewater treatment plant in a so-called Sequence Batch Reactor (SBR), which has been in operation for about a year before this study. Kungsberget AB is currently in charge of the facility but their goal is to hand responsibility over to Sandviken Energy AB. In order for this handover to occur Kungsberget has to produce three approved treatment results. This means that the concentrations of BOD_7 needs to lie under 0.3 mg/l and total phosphorous under 10 mg/l in the effluent water for three consecutive samples. The results show momentaneous values. These limits are stated in the permit Kungsberget received from the Environmental Protection Division. Kungsberget has had problems with high and fluctuating phosphorous concentrations and therefore the transfer has not yet taken place.

In this project several parameters have been analysed in order to obtain an overview of prevailing influent and effluent concentrations. Some of the parameters that have been analysed are; phosphorous, nitrogen, BOD_7, suspended solids and pH. A lot of time and effort has been put into elucidating operational routines at the wastewater treatment plant (WWTP) and gaining knowledge from available literature regarding different parameters' effect on treatment results.

Kungsberget has had problems adapting operating routines and reaching stable treatment results as the load is highly effected of seasonal fluctuation. This has not been taken into account earlier and the WWTP has been operated in the same manner all year around. Suggestions to how operating routines can be modified in to better meeting the needs have been produced and alternative treatment methods have been presented in the report. Two of the suggestions include biological phosphorous removal and adding carrier media to increase bacteria growth.

An aerobic solids retention time has been calculated in order to evaluate whether nitrifying bacteria have enough time for grow and maintain a stable population. The calculation was carried out by measuring suspended solids and aeration time and the result was a solids retention time of approximately 6 days.

Keywords: SBR, wastewater treatment, Kungsbergets ski-resort, oxygen supply, phosphorous, seasonal load, solids retention time (SRT).

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Referat

Reningsprocessen på Kungsbergets avloppsreningsverk vid ojämn och låg belastning.

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Kungsberget är en skidanläggning i Gävleborgs län som sköter sin egen avloppsvattenrening i ett reningsverk på området. Behandlingen sker i en så kallad Sequence Batch Reactor (SBR) som har varit i drift under cirka ett år före denna studie. Målet för Kungsberget AB som i dagsläget har hand om anläggningen är att överlämna ansvaret till Sandviken energi AB. Som krav för ett överlåtande har Sandviken Energi AB sagt att de vill se minst tre godkända reningsresultat i följd från anläggningen vilket innebär att utgående halter på BOD_7 samt totalfosfor ska ligga under 10 mg/l respektive 0,3 mg/l. Resultaten speglar momentanvärden. Dessa gränser är fastställda i tillståndet Kungsberget fått från länsstyrelsen i Gävleborg. Kungsberget har haft problem med höga och fluktuerande fosforhalter och därför har inte något överlåtande kunnat äga rum. I februari 2013 lyckades de dock få till tre godkända resultat.

I detta projekt har flera parametrar analyserats för att få en överblick av rådande koncentrationer på inkommande och utgående vatten. Parametrar som analyserats är bland annat fosfor, kväve, BOD_7, suspenderat material och pH. Fokus har även lagts på att klarlägga driftrutiner samt att anskaffa kunskap från befintlig litteratur om de nämnda parametrarnas inverkan på reningsresultaten.

Kungsberget har haft svårt att anpassa driften och uppnå stabila reningsresultat i och med att belastningen på avloppsreningsverket påverkas avsevärt mellan låg och högsäsong. Detta har inte tagits hänsyn till tidigare utan reningsverket har drivits på samma sätt sommar som vinter. Förslag till hur driftrutinerna kan utvecklas för att bättre möta de behov som finns har tagits fram och alternativa reningsmetoder presenteras i rapporten. Två av de förslag som tas upp är biologisk fosforrening och införande av bärarmaterial för att öka bakterietillväxten.

En aerob slamålder har beräknats för att göra en bedömning om denna är tillräcklig för nitrifierande bakteriers tillväxt och för att underhåll en stabil population. Resultatet, 6 dygn, erhölls genom att mäta halten suspenderat material samt tiden för luftning.

Nyckelord: SBR, avloppsvattenrening, Kungsberget skidanläggning, syretillförsel, fosfor, säsongsvarierad belastning, slamålder (SRT).

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Preface

This thesis is the last step in completing my degree within the Master Programme in Environmental and Water Engineering at Uppsala University. The project has been carried out at Sweco in Stockholm under the supervision of Stig Morling (Water and Wastewater, Environment, Sweco) to whom I am grateful for the guidance he has given me and the questions he has clarified. I am also grateful for the support from my academic supervisor Bengt Carlsson (Department of Information Technology, Uppsala University) who has helped me when Stig has not been available and also tried to provide me with necessary equipment to perform my work. A special thanks to Hans Peipke at Cerlic who lended me his demo solido sensor and MultiTracker.

Over and above this I would like to show my gratitude to the people in Kungsberget who have made this project possible. Lasse Bäckström has put time into guiding me around the WWTP and explaining how the plant is operated. He has also helped me from being stranded in Kungsberget when missing the last bus. Stefan Alanara has been helpful by both organising accommodation at the time of my visits and contributing with important information about the WWTP. Christofer Ericsson at Miljö och bioteknik Sverige AB has been helpful in answering questions regarding the SBR, thank you.

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Populärvetenskaplig sammanfattning

De flesta som har hört talas om Kungsberget förknippar det med skidåkning och mycket riktigt så är det en liten skidort i Gävleborgs län som varje säsong gästas av tusentals besökare och däribland en hel del skolklasser från stockholmsområdet. Det folk däremot inte tänker på är att alla dessa gäster med största sannolikhet besöker en toalett under sin vistelse och att avloppsvattnet då hamnar bara några hundra meter bort, på Kungsbergets reningsverk. Det är driften av reningsverket som denna rapport fokuserar på.

Reningsverket togs i drift för 2 år sedan då det befintliga reningsverket hade blivit för litet för att hantera belastningen som det ökade antalet besökare medförde. Valet av ny anläggning föll på en Sequence Batch Reactor, SBR, gjord att klara 100 m^3/dag. Anledningen till att en SBR anläggning utsågs som bästa alternativ var att det är förhållandevis lätt att anpassa varierande flöden i en SBR. Det har dock ändå visat sig finnas en del svårigheter med att driva anläggningen. En SBR fungerar som en aktiv slamprocess med skillnaden att alla reaktioner sker i samma tank. Det finns inga separata bassänger för luftning och sedimentering utan reningsprocessen är istället uppdelad i faser som regleras utifrån ett tidsschema. Faserna på anläggningen i Kungsberget utgörs av en påfyllnadsfas, en reaktionsfas (luftad och oluftad), en sedimenteringsfas och en dekanteringsfas.

Utmaningen med anläggningen har varit att anpassa driften så att inställningarna passar med rådande förhållanden. Exempel på parametrar som kan regleras och som har tittats närmare på är luftningstid, slamuttag och kemikaliedosering. Luftning är nödvändig för att nitrifikation ska äga rum men är kostsam och det är således inte önskvärt att lufta mer än nödvändigt. Luftning sker delvis under påfyllnadsfasen för att underhålla bakteriekulturen men även under en del av reaktionsfasen för att stimulera nitrifikation. Slamuttaget bestämmer slamåldern som är ett mått på genomsnittlig uppehållstid för en slampartikel i systemet. För att hålla en jämn slamålder krävs att slamuttaget balanseras upp med tillförsel av nytt slam. Om slamåldern blir för låg hämmas nitrifikationen då nitrifierarna har en långsam tillväxthastighet och behöver tid att etablera sig. Ett konstant slamuttagsöverskott kan leda till ’wash out’ som innebär att bakterierna utarmas ur reaktorn på grund av för stort slamuttag. Kemikaliedoseringen i Kungsberget styrs via en pump som regleras via strömtillförsel. På kontrollpanelen ställs tiden in för vilken pumpen ska förses med ström och dosera tanken med fällningskemikalier som i Kungsbergets fall är PAX 21. Pumpen doserar 14 l/h vilket gör det möjligt att beräkna önskad doseringsmängd utifrån tidsinställningen.

Enligt tillståndsbeskrivningen från länsstyrelsen finns det vissa reningskrav för att Kungsberget ska få driva sin verksamhet. För fosfor ligger gränsen på 0,3 mg/l och för BOD_7 ligger kravet på 10 mg/l. Under året som varit har halterna på utgående vatten varierat kraftigt och fosforhalterna har legat en bra bit över gränsnivån under längre perioder vilket är oacceptabelt. Det har därför under februari månad detta år lagts stort fokus på att få ner fosforhalten i utgående vatten. Utöver de formella kraven finns det även ett intresse i att erhålla tre godkända reningsresultat då det skulle innebära en möjlig överlåtelse av ansvaret för reningsverket till Sandviken energi AB. Då anläggningen togs i bruk fanns det en överenskommelse om att Sandviken energi AB skulle ta över anläggningen efter att tre godkända resultat kunnat påvisas. I mitten av februari 2013 nådde Kungsberget sitt mål, troligtvis mest på grund av en kraftig höjning av kemikalietillförseln. Kemikaliedoseringen hade tidigare legat runt 3 liter men ökades upp till 6,2 liter. Ett alternativ till att öka kemikaliedoseringen är att introducera biologisk fosforrening. Dock bör det tas i beaktande att biologisk fosforrening ställer krav både på temperatur, tillgång på kolkälla samt varierande anaeroba och aeroba förhållanden. Biologisk fosforrening fungerar på så vis att speciella bio-P bakterier tar upp ett överskott av fosfor som de ackumulerar och som slutligen hamnar i slammet. I första steget av processen tar bakterierna upp flyktiga fettsyror som de lagrar som energi. Detta måste ske under anaeroba förhållanden. För att bakterierna sedan ska kunna använda denna energi för att ta upp fosfor så krävs syre. Bio-P bakterierna har då ett försprång i tillväxt jämfört med andra bakterier eftersom de inte måste konkurrera om lättnedbrytbart kol.

Ett annat förslag är att reglera kemikaliedoseringen för att förhindra överdosering. On-line mätning av fosfor innan dekantering kan indikera behov av fällningskemikalier. Doseringen kan sedan ske innan skivfiltret som vattnet måste passera innan det släpps ut. För att detta ska vara genomförbart behöver en fosforanalysator installeras och vissa modifieringar utföras. Det är kostsamt och därför eventuellt inte ekonomiskt försvarbart. Alternativet till detta är att mäta halten suspenderat material (SS) i inkommande vatten och utnyttja denna vid doseringen av fällningskemikalier. Största andelen fosfor i avloppsvattnet är antingen partikulärt eller bunden till partiklar vilket gör att SS-halten är en bra indikation på fosforkoncentrationen. Då förhållandet mellan SS- och fosforkoncentration är relativt konstant är det enklare och billigare att installera en susphaltsgivare än en fosforanalysator.

BOD_7 halten har å andra sidan legat på en godkänd nivå i princip hela tiden med undantag från tiden efter uppstarten. BOD_7 analysen har en mätosäkerhet på 30 % vilket gör att värdena är relativt opålitliga. Ett förslag som presenteras för förbättrad rening är införande av bärarmaterial. Bärarmaterialet tillsätts i tanken för att öka tillväxtytan för biofilm som gör det möjligt för partiklar med dålig sedimenteringsförmåga att fästa på något och sedimentera istället för att följa med utgående vatten. Bärarna kan vara gjorda av plast, sten eller sand. Det är även möjligt att erhålla både nitrifikation och denitrifikation simultant då det i mitten av biofilmen råder anaeroba förhållanden medan det på ytan finns tillgång på syre under luftningen. Potentiellt kan även biologisk fosforrening gynnas av bärarmaterialet. Ett möjligt hinder är att bio-P bakterierna och denitrifierarna konkurrerar om organiskt material. Det kan även bli konkurrens om syret då både nitrifikation och fosforupptaget kräver syre. Fosforupptag och nitrifikation sker om vart annat på ytan och fosforupptag gynnas av att bärarmaterialet tvättas regelbundet så att en tunn biofilm erhålls.

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ABBREVIATIONS

ASBR	Anaerobic sequence batch reactor
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
SBBR	Sequencing batch biofilm reactor
SBR	Sequence batch reactor
SRT	Solid retention time
SS	Suspended solids
SV	Sludge volume
TOC	Total organic carbon
VFA	Volatile fatty acids
WWTP	Wastewater treatment plant

1 INTRODUCTION

The wastewater treatment plant in Kungsberget is run by a so-called sequence batch reactor, SBR, which was first taken into use in the beginning of 2012. Kungsberget is a ski-resort situated approximately 25 kilometers north-west of Sandviken in Gävleborg County. Only wastewater from the ski-resort is treated at the plant and the load therefore strictly depends on seasonal fluctuations which is a challenge when operating the plant. The flow varies between approximately 0-80 m^3/day, which is the reason to why an SBR seemed best suited when the procurement took place. It is considerably easier to manage varied flow in an SBR than at a conventional plant. No industrial water or storm water is lead to the waste water treatment plant (WWTP). Kungsberget fritidsanläggning AB are presently in charge of operating the WWTP but the idea has been for Sandviken municipality to take over the responsibility within a near future. Sandviken have said that they expect to see three acceptable treatment results before they are willing to take over the responsibility for operating the plant. This is what Kungsberget fritidsanläggning AB has been aiming for since the plant was first taken into operation but has not been able to achieve. They struggle with high and unstable phosphorous concentrations in the outgoing water which indicates that the plant needs further tuning.

1.1 OBJECTIVE

The main objective of this thesis is to analyse the treatment process at Kungsberget's WWTP, identify problems and what causes them. It is of interest to see how treatment results are affected when the plant is run well below its capacity which is currently the case. The goal is to trace connections between operating procedures and treatment results in order to propose ideas for an improved course of action.

1.2 DELIMITATIONS

Alternative settings will not be tested in practice at the plant but instead summarized as potential improvements at the end of the report.

1.3 KUNGSBERGET WASTEWATER TREATMENT PLANT

The treatment process involves physical, chemical and biological stages in which the chemical and biological phases are performed in an SBR. An SBR is operated like a "plug-flow" system meaning that specific volumes of water, batches, are treated one at a time. This differs from a conventional "mix-flow" system as there is no reflux of treated water mixed with untreated water. To remove phosphorous and suspended solids (SS) polyaluminium chloride hydroxide, PAX 21, is added at the top of the tank during the aerobic phase. PAX 21 is a commonly used flocculent agent. More information about PAX 21 can be found in section 3.5.1.

Before wastewater enters the plant it passes through a 60 m^3 tank located down by the main resort area. The tank is used for storing wastewater before it is pumped up through a coarse screen where large items are removed into a big plastic sac. After the coarse screen the water continues into a 25 m^3 surge tank where it stays until the tank is sufficiently full and emptied into the SBR. It is never completely emptied as there are pressure transmitters that sense the water level and empty the tank to a set limit. The SBR is not filled in one go but instead little by little as the surge tank fills up and empties. Figure 1 is a photo of the SBR in Kungsberget.

Figure 1 Kungsberget's SBR.

The 60 m^3 storage tank is a back-up in case there is a problem at the plant and it also gives an opportunity to control flow. The SBR has a capacity of treating up to 35 m^3 per batch and therefore the surge tank can be emptied several times before the SBR is ready to start processing (Miljö och bioteknik, 2011). The 5.5 m high SBR is insulated and has an outer diameter of 5 m. In Appendix I more specifications are found. In the reactor the biological and chemical treatment takes place. A thorough description of the processes occurring in an SBR is presented in the literature review. The following steps describe the process based on settings at Kungsberget's WWTP.

- Fill and mix
- React
    - Anoxic
    - Aerobic
- Settle
- Decant
- Idle

Table 1 gives an overview of the time assigned for each step in the process. For more details about settings see Appendix I.

Table 1 Time and order of each phase in the SBR at Kungsberget. More detail is presented in the text that follows.

Variable	**Time**	**Unit**
Fill	Varies with load	min
Anoxic	45	min
Aeration	15	min
Reaction (total)	225	min
Anoxic	45	min
Aerobic	180	min
Chemical dosage	12-26	min
Settle	100	min
Decant (maximum)	20	min
Idle		
Solids retention time (SRT)	20	days
Number of days between sludge withdrawal	1	days

Fill and mix

During the fill phase, the basin receives influent wastewater. The process is in a so called pause phase waiting to reach a water depth of 530 cm to start the reaction phase. The time this takes depends on the hydraulic load that is to say how much wastewater there is available. The SBR is filled little by little as the surge tank fills up and supplies it with more water. While in pause phase, a sequence of 15 min aeration every 45 min takes place. This is to maintain a healthy microbiology culture in the tank. The air bubbles also mix the water obtaining a uniform blend.

React

Once the reactor has reached the 530 cm limit the process moves into reaction phase starting with a 45 min anoxic phase followed by 180 min aeration. It is possible for the plant to go in to a high load mode if wastewater needs to be treated at a faster pace. The aerobic phase is then shortened to 120 min.

The flocculent agent, PAX 21, is added at the top of the tank during the aerobic phase. The amount added is regulated by setting the duration of which the chemical pump receives power. The pump itself operates at a rate of 14 l/h. In Kungsberget's case the time has been set between 12-26 min resulting in a 2.8-6.1 l dose.

50 min after the reaction phase has started a one litre sample is taken out by the operator and left to settle for 30 min. The sludge volume is noted to get an idea about sludge quality.

At the bottom of the tank 45 blower plates are placed in five rows with 9 blowers in each row. The blowers receive power from a Robuschi ES45/1P which has the capacity of blowing 183 m^3air/h. Each plate has a capacity of supplying 20 m^3 air/h. Figure 2 shows a photo of the blower plates.

Figure 2 Blower plates on the bottom of the SBR at Kungsberget’s WWTP.

Settle

After aeration has ceased 100 min of settling time begins.

Decant

This period involves withdrawal of treated water from 530 cm down to a set level depending on desired treatment volume. The decanting is controlled by pressure transmitters that send signals to a valve that closes when the right amount of water has been withdrawn from the reactor. Kungsberget has a so called fixed-arm decanter that leads the water out of the reactor and on to a disc-filter.

Idle

Sludge is pumped into a container during the aerobic reaction phase, which is later collected by Sita. Sita is a Swedish company that collect and handle all sorts of waste. The frequency of sludge wasting can be altered in order to attain a preferred solids retention time, SRT. The SRT in Kungsberget is currently set to 20 days. This means that 1/20 of the SBR content is removed once a day.

When the process is over the water is decanted and filtered through a disc-filter[1]. The disc-filter has a pore size that is designed to remove suspended material. After being treated the effluent is finally directed to Lillån which is a small stream close to the WWTP.

The consumption of energy for running the WWTP is slightly less than 2000 kWh/year.

Miljö och Bioteknik Sverige AB is the supplier behind Kungsberget’s SBR and they have delivered the facility based on specified requests. They guarantee the reactor to be able to achieve a certain level of purification. Table 2 specifies details concerning dimensioning load and table 3 states purification capacities. The supplier claims that the facility is capable of performing both phosphorous reduction and nitrification at a temperature down to 10 $^{\circ}$C.

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[1] Model: Hydrotech, Filtertype HSF1708-1F,Serial No 7480, Year 2011

Table 2 Dimensioned load for the SBR at Kungsberget stated by Miljö och Bioteknik Sverige AB.

Capacity specifications	**Amount**	**Unit**
Dimensioning wastewater	100	m^3/d
Maximum wastewater	150	m^3/d
Organic load	30	kg BOD/d
Phosphorous load	0.8	kg P/d

Table 3 Guaranteed purification capacity for the SBR in Kungsberget stated by Miljö och Bioteknik Sverige AB.

Purification specifications	**Reduction**	**Effluent limit**
BOD_7	90 %	< 10 mg/l
Phosphorous (P-tot)	95%	< 0.3 mg/l
Suspended solids (SS)	-	< 20 mg/l

More details regarding the settings at Kungsberget's WWTP and its physical dimensions are found in Appendix I.

1.3.1 Requirements

Kungsberget's Fritidsanläggningar AB received a permit in May 2012 allowing them to expand the current waste water treatment facility. The requirements set for effluent water by the Environmental Protection Division on the Environmental Testing Advisory Board at Naturvårdsverket were:

BOD_7	10 mg/l
Phosphorous (P-tot)	0.3 mg/l

The values represent mean values per quarter and if these limits are exceeded Kungsberget is required to report it within a week to the regulatory authority, in this case Sandviken municipality. When doing so they are also obliged to announce a plan as to how to prevent the incident from being repeated. The permit also requires effluent water to be lead to Jädraån instead of Lillån as has been the case earlier.

2 METHOD

In order to familiarize with the methods and devices used at Kungsberget's WWTP and to fully understand the problems behind inadequate treatment results different approaches were adopted. A literature study was carried out to gain deeper understanding of the processes taking place and how they are affected by different disturbances. Literature dealing with the complexity of different parameters interactions were studied and later related to the specific case study, Kungsberget. For practical reasons and in order to see how the plant is operated, Kungsberget was visited several times and a guided tour with a thorough review was performed. The operators were interviewed to understand their version of the situation and the supplier of the plant was questioned for specifications.

Over and above the literature study, practical work was carried out, such as sampling. On four occasions between February and April 2013 samples of raw water and effluent were taken for analyses of pH, alkalinity, phosphate, temperature and sludge volume. The results were added to a set of data obtained from Eurofins, an accredited laboratory that have analysed samples from Kungsberget since it was first taken into operation. The complete sets of data have been worked with in Excel to illustrate parameters fluctuation through time and in some cases trends and interactions. Graphs of special interest were added in the result section.

pH and alkalinity was analysed with an Aquacheck Truetest device in this study that operates at temperatures between 15 and 40 $^{\circ}$C and at alkalinity between 0 and 300 ppm. The reason to why this equipment was used is that all data withheld from the practical work during this study was put together with former data from samples carried out by the operators at Kungsberget in which Aquacheck Truetest was used. The trustworthiness can however be questioned as water temperatures drop below 15°C.

Phosphorous concentrations are measured by Eurofins laboratory almost every week and locally in Kungsberget on a daily basis. There is a 10 % measurement uncertainty when analysing phosphorous at the laboratory. The uncertainty when analysing locally is probably higher but has not been determined. The method used for analysing is according to Swedish standard and is referred to as SS-EN ISO 15681-2.

Phosphate concentrations in this study were withheld from a device from HACH[2]. The instrument is unable to compute values over 3.3 mg PO_4/l but has been used for the same reason as for pH mentioned above. A problem compiling data from Eurofins and local data is the fact that Eurofins measure total phosphorous concentration whilst the device in Kungsberget measures phosphate. There is no easy way of getting around this but what has been done is that the PO_4 values have to be multiplied by 0.326 to obtain a pure phosphorous concentration as a phosphate molecule contains 32.6 % phosphate. This method does not take organic phosphorous into consideration and therefor the correct value is somewhat higher and what is calculated. This should be kept in mind when studying figure 14, 15 and 16.

The main way of removing phosphorous is through flocculation however it is hard to analyse whether adding more flocculent has had a noticeable effect as samplings at Kungsberget before and after changing chemical dosages are inadequate as shown in

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[2] HACH pocket colorimeterII. Reagens HACH PhosVer3 (Ascorbic acid, potassium pyrosulfate, sodium molybdate).

table 5. The samples taken in connection with dosage changes have been analysed locally and not necessarily on the first batch after a change. Each batch composition differs and property dissimilarities are likely to differ more the longer analyses are postponed after a change. The connection between pH and phosphorous was analysed as pH affects the efficiency of the flocculent agent.

Temperature was measured with a mercury-in-glass thermometer during the anaerobic reaction phase in the tank. In order to analyse sludge volume a one litre sample was taken out during the aerobic reaction phase and left to settle for 50 min before the level to which sludge had settled was noted.

Nitrogen concentrations have only been analysed by Eurofins laboratory and the tests performed are limited. The only fraction analysed over and above the total amount of nitrogen is ammonium. There is a 10 % measurement uncertainty when analysing total nitrogen at the laboratory. The method used for analysing is according to Swedish standard and is referred to as SS-EN ISO 11905-1.

Carbon sources have been analysed at Eurofins laboratory as BOD, COD, TOC and SS.

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TOC	Total organic carbon
SS	Suspended solids

Each and every one of these have been analysed according to Swedish standard and the results all contain measurement uncertainties that are stated in table 9.

Table 4 Methods used and measurement uncertainty at Eurofins laboratory when analysing BOD, COD, TOC and SS.

	Swedish Standard	**Measurement uncertainty**
BOD	SS EN 1899 1-2	30 %
COD	Spectroquant	10 %
TOC	SS EN 1484	10 %
SS	SS EN 872-2	10 %

The amount of suspended solids was measured with a Solido sensor and MultiTracker from Cerlic. This was mainly done with the purpose of calculating a theoretical aerated SRT. The aerated SRT varies depending on how many batches are run during one day as the aeration time differs as a consequence of this. It is also of interest to know what percentage of a day is aerated as the SRT is calculated per day.

Equation 1 is commonly used for calculating SRT for continuous systems;

$$\theta = \frac{V \cdot SS_r}{Q_w \cdot SS_w + Q_{ef} \cdot SS_{ef}} \tag{1}$$

θ	Solids retention time (SRT)
V	Reactor volume
SS_r	Suspended solids in reactor
Q_w	Excess sludge flow
SS_w	Suspended solids in waste sludge
Q_{ef}	Effluent sludge flow
SS_{ef}	Suspended solids in effluent

As for SBR, equation 1 can be simplified. It is based on the assumption that SS_{ef} is zero so that the second term in the denominator is excluded. As wasting occurs during the mixing phase SS_r will equal SS_w in equation 1. This means that they cancel out. So, what is left is

$$\theta = \frac{V}{Q_w} = \frac{A \cdot h_{tot}}{A\frac{\Delta h_w}{\Delta t}} = \frac{h_{tot}}{\frac{\Delta h_w}{\Delta t}} \tag{2}$$

where $\frac{\Delta h_w}{\Delta t}$ is the change in water level after wasting measured as m/d and A is the area in m^2. h_{tot} is the total water depth.

Three criteria need to be satisfied in order for this simplified equation to be applicable:

1. Constant suspended solid concentration over time.
2. Balanced wasting and sludge growth.
3. Homogeneous suspended solid concentration is in the reactor.

These criteria are rather demanding and quite obviously cannot be completely fulfilled. However it may be possible to accept certain debauchery and still benefit from the results.

In this study SRT for three scenarios treating 1, 2 or 3 batches per day have been analysed. At the occasion of analysis the treatment cycle was made up as described in table 1. Total process time was 340 min in which 180 min were aerated.

On the next page the time of aeration during one day is stated for three different scenarios depending on the number of batches treated.

Scenario 1 - 1 batch in one day

Total time: 24 h, 1440 min
Process time: 340 min

- 180 min aeration
- 160 min *no* aeration

Mix and fill: 1100 min

- 275 min aeration
- 825 min *no* aeration

Total aeration: 180+275 = 455 min
Fraction of a day: 455/1440 = 0.316 = **31.6 %**

Scenario 2 - 2 batches in one day

Total time: 24 h, 1440 min
Process time: 680 min

- 360 min aeration
- 320 min *no* aeration

Mix and fill: 760 min

- 190 min aeration
- 570 min *no* aeration

Total aeration: 360+190 = 550 min
Fraction of a day: 550/1440 = 0.382 = **38.2 %**

Scenario 3 - 3 batches in one day

Total time: 24 h, 1440 min
Process time: 1020 min

- 540 min aeration
- 480 min *no* aeration

Mix and fill: 420 min

- 105 min aeration
- 315 min *no* aeration

Total aeration: 540+105 = 645 min
Fraction of a day: 645/1440 = 0.448 = **44.8 %**

3 LITERATURE REVIEW

In order to better understand how SBR works and to gain information about how the opearators at Kungsberget could potentially improve their operating routines a literature review has been performed. In the following sections different topics and aspects are brought up that will later be discussed together with the results obtained from Kungsberget. A brief background dealing with legal issues has been included to provide an idea of requirements within wastewater treatment.

3.1 SWEDISH LAW AND REGULATIONS

Looking back through time it may seem as if the total amount of effluent increased drastically up until the 1960s as more and more urban areas introduced wastewater plants. This is a modified truth since it only points out the fact that before introducing wastewater plants all untreated wastewater was pumped out into recipients uncontrolled. This changed when WWTP's came about and effluent data began to be recorded. Thus effluent was not really increasing but the amount recorded was and therefor it seemed as if the total amount of effluent soared when more wastewater plants were put into operation. Later, during the late 1960s and 1970s, modern WWTP's were built and old ones modified to separated phosphorous and organic matter from the raw water which reduced recipients' nutrition load tremendously. Further improvements were conducted during the mid 1980s when nitrogen removal was introduced (Naturvårdsverket, n.d).

At the time of writing Sweden's municipalities act as both a supervisory and an examining authority for all wastewater treatment plants up to 2000 pe. However, from the 1st of July 2011 the Sea and Water authority (Havs- och vattenmyndigheten) has the overall responsibility for plants handling up to 200 pe. As for anything bigger than 2000 pe the responsibility still lies on the Environmental protection agency (Naturvårdsverket). The Environmental protection agency have published a document containing advice on how to handle small-scale wastewater treatment that municipalities can use as a guideline when setting environmental and health requirements both for existing and new plants. Each WWTP is considered separately and requirements are set after the type of treatment performed and surrounding environmental condition.

The Urban Wastewater Treatment Directive (UWWTD, 91/271/EEC) put together by the European Union has been implemented into Swedish law and regulations concern all wastewater treatment, however, quantitative requirements mainly apply for large WWTP's, i.e. bigger than 2000 pe. UWWTD states that effluent nitrogen concentrations from WWTP's managing more than 100 000 pe may not exceed 10 mg/l and that the corresponding figure for WWTP's with 10 000-100 000 pe is 15 mg/l. An exception to this applies if a 70 percent nitrogen reduction of the raw water can be achieved. According to the Environmental protection agency the average level of nitrogen reduction 2010 in Sweden was around 60 percent. Concentration requirements for effluent oxygen consuming substances are national whilst nitrogen reduction requirements only apply for WWTP's with a coastal recipient south of Norrtälje municipality (Naturvårdsverket, n.d).

There has been a debate amongst scientists as to the value of reducing nitrogen effluent to the Baltic Sea considering the vast natural source from nitrogen fixating bacteria. Nitrogen fixation from the air is performed by cyanobacteria that benefit from generous phosphorous supplies, high temperature and poor water exchange. When nitrogen is limited they grant an advantage over non-fixating bacteria. If cyanobacteria are given growth advantages, nitrogen will be added to the sea from the air and even worse, poisonous cyano-blooms will be a fact. The processes are complicated and no outcome is certain leading to the controversial hypothesis that reducing nitrogen effluent in relation to phosphorous may not have an effect in the long run (Naturvårdsverket, n.d).

There are no legal requirements covering nitrogen reduction limits for WWTP's serving less than 2000 pe, however, requirements can be put up supported by paragraphs in the second chapter of The Swedish Environmental Code. In the second chapter it is mentioned that purification should be performed with an as good technology as possible and that environmental precaution is required when handling wastewater. Technology is constantly developing and therefore older WWTP's may have lower requirements than new ones. The two regulations mentioned are defined in paragraph 2 and 3 in the second chapter of The Swedish Environmental Code (Miljöbalken, 1998).

The law system places the responsibility of supervising and reporting each plant's environmental impact on the operator leaving them to take record of effluent concentrations, handle waste and chemicals etcetera. An idea behind this is to keep the operator up to date by regularly taking water samples and gaining better understanding and control of the plant by doing so.

3.2 SBR

The basis for today's SBR technology was first developed during the 1920s but then abandoned until late 1960s. Robert. L. Irvine is a legend within SBR systems and he named his variable-volume system the SBR in 1967 (Goronszy et al. 2001). It is fair to say that America was leading in the resumption of SBR technology and during the 1980s a number of full-scale SBR plants were built in the U.S. It should also be pointed out, however, that the mathematical models explaining the process presented in 1970 originated from early accepted equations and parameters found in activated sludge process theory (Morling, 2009).

3.2.1 Process

As explained briefly earlier SBR-technique is a plug-flow system that requires careful tuning to meet specific conditions of wastewater properties. Conditions may be affected by seasonal variations or other specific circumstances that need to be taken into account when designing a plant. It is noteworthy that no universal settings are applicable for all SBR-units but instead there are guidelines to help tune satisfactory parameters to account for prevailing conditions through trial and error. Conditions that affect the treatment processes are temperature, pH, in-flow volume, organic load and more. Obviously certain conditions are preferred but not always achievable. Fortunately there are methods to attain adequate purification without having to change, for example the temperature or any other property of the incoming water before treatment. Temperature is a specifically challenging variable in colder regions such as Scandinavia and studies have been carried out to improve wastewater treatment methods.

There are both simpler and more advanced SBR's and they are all regulated via a console that allows the operator to control the process. Aspects which can be altered in most facilities are;

- Blowers – desired time and duration of aeration.
- Mixing – desired time for mixing (not at Kungsberget).
- Sludge withdrawal – amount of sludge removed from the reactor. Sets solid retentions time.

- Chemical dosage – amount and type of flocculent agent added.

Not only is there a need to make decisions regarding the four points stated above but it is also significant to consider how they ought to interact with one another. Relevant questions to be asked are; should the mixing occur whilst the blowers are active? when is an appropriate time to add the chemicals.

It is possible to apply on-line control to an SBR-process allowing for immediate action to take place when concentrations are unsatisfactory and also for keeping constant record.

The time it takes for a batch of wastewater to be treated is closely related to incoming water concentrations as well as to the desired degree of purification. The pie chart in figure 3 is an example of what a 6 h cycle may look like.

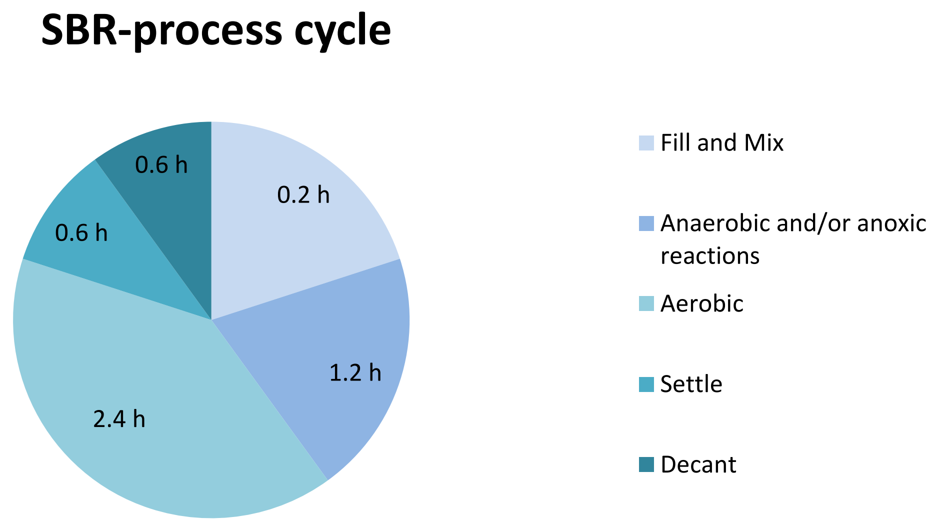

Figure 3 Conceptual model of a 6 h long SBR-process.

The SBR process is described in more or less the same manner in many different reports and other sources of literature. Therefore the summary below describing the SBR phases is a blend of facts taken from the following sources; ABL Environmental consultants limited, 2013, Veolia water Solutions & technology, 2013, and Poltak, 2005.

Fill and mix

There are several ways of filling the reactor depending on the users' intentions. The influent supplies micro-organisms in the active sludge with nutrition, creating an environment for biochemical reactions to take place. Most denitrification occurs during this phase when anoxic conditions prevail and whilst there still is plenty of readily biodegradable material. The amount of time spent on mixing and aerating can be altered. This phase can be regulated either through time or volume settings i.e. either by stating a duration-time for filling the tank or a by specifying a limit for the water level when decanting. There are three common ways of filling the tank but the methods are rather flexible for modification.

Static fill – Usually applied during the start-up phase of a SBR-system. Both mixers and blowers are turned off whilst the tank is being filled. It is also common to apply this method during periods with low flux and at plants that are not in need of nitrogen removal as it saves energy.

Mixed fill – Mixers are turned on to spread biomass in the influent. The blowers are inactivated resulting in anoxic conditions promoting denitrification. It is possible to introduce biological phosphorous removal by applying anaerobic conditions during this phase. More information about this is found in the section “Biological phosphorous removal” later on.

Aerated fill – As the name suggests air is added during the filling phase, however, the blowers need to be switched off at some point allowing for denitrification to occur. Mixing is also active during aerated fill, either mechanically or by the air being pumped in. When both oxic and anoxic phases arise it is possible for nitrification and denitrification to take place. As for oxygen it is central to keep a dissolved oxygen level below 0.2 mg/l in order to achieve anoxic conditions in the idle phase. Figure 4 presents a conceptual idea of an “aerated fill”.

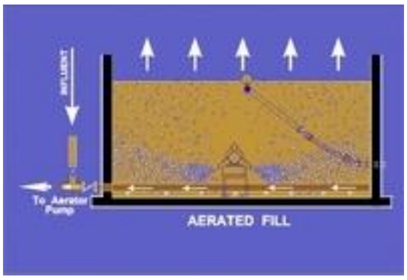

Figure 4 SBR-process during “aerated fill phase” (Source: Veolia water Solutions & technology, 2013, with permission).

Anaerobic and/or anoxic reaction

Although reactions occur in the fill and mix phase most reactions take place after the tank has been filled. Both mixers, if present, and aeration units are active. Denitrification needs anoxic/anaerobic conditions and a carbon source to take place. Therefore most denitrification occurs in the fill and mix stage before oxygen is added and when readily biodegradable carbon is still available. Throughout this phase most organic material is removed as a result of micro-organisms uptake for biomass growth. Figure 5 presents a conceptual idea of the “react phase”.

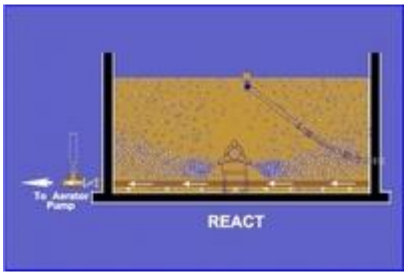

Figure 5 SBR-process during the “react phase” (Source: Veolia water Solutions & technology, 2013, with permission).

Settle

When the blowers are turned off and mixing has ceased there is time for the active sludge to settle. It is common for sludge to settle as a flocculent mass creating a sharp line between supernatant and sludge. The settling phase is crucial as it needs to be ensured that solids settle rapidly enough to prohibit sludge from escaping with effluent water during decanting. Figure 6 presents a conceptual idea of the “settle phase”.

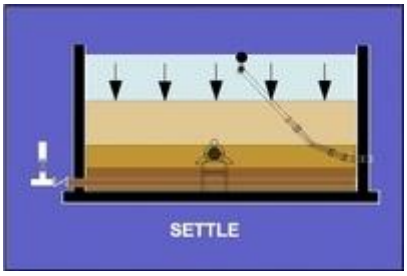

Figure 6 SBR-process during the “settle phase” (Source: Veolia water Solutions & technology, 2013, with permission).

Decant

A decanter is a device in the tank directing clear supernatant effluent to a recipient. As shown in figure 7 there is a tube leading water from the device and out through the tank wall. Once settling is complete the decanter receives a signal that opens a valve and a path for effluent water. There are two major types of decanters, floating and fixed-arm. Floating decanters are located just beneath the surface which prevents floating particles from escaping with outgoing water. The device is more expensive than a fixed arm decanter but in the case of flotation or foam forming, escaping particles are more easily avoided. Both floating and fixed arm decanters allow the operator to regulate fill and withdrawal volumes. The fixed arm decanter is always placed below the level that allows for maximal withdrawal which prevents the water level from sinking below the decanter. The volume is adjusted by pressure transmitters that sense the water level. As for floating decanters the procedure is pretty straight forward as there is never a risk of the decanter ending up above surface. Maximum use of the tank volume is sought after without again jeopardizing sludge escape, and the operator may therefore need to be cool headed at times when defining the vertical distance between the decanter and tank floor. If the decanter comes too close to the bottom it may disturb the sludge.

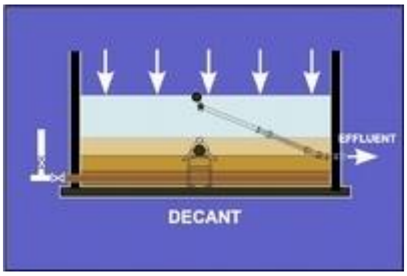

Figure 7 SBR-process during the ”decant phase” (Source: Veolia water Solutions & technology, 2013, with permission).

Idle

Sludge is taken out of the tank. The time and duration at which this occurs can be decided upon by the operator in order to set a suitable SRT. The withdrawal is referred to as ‘wasting’. Nitrifying bacteria determine the SRT as they grow slowly and therefore need a longer SRT than denitrifying bacteria. Figure 8 presents a conceptual idea of wasting.

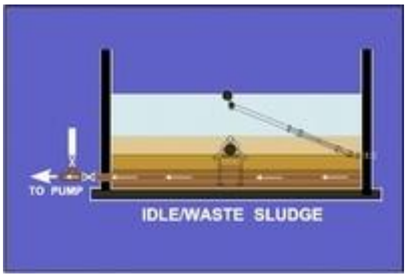

Figure 8 SBR-process during wasting (Source: Veolia water Solutions & technology, 2013, with permission).

To estimate the aerobic SRT it is necessary to find out for how long the reactor is aerated. It is important that a SRT is chosen to match the organic load. If the retention time is too short nitrification will be affected and if it is too long formation of filamentous organisms such as Microthrix parvicella may develop, causing bulking. A high retention time also causes sludge to undergo more endogenous decay which has an effect on particles ability to settle and the amount of sludge produced. It is central to keep the micro-organism culture balanced and tuning the plant may take time. The retention time must be calculated under a long period of time. To increase or decrease sludge withdrawal does not momentarily change the SRT as the past prevailing conditions form the bacteria culture rather than the current condition. To see the effect of changes in wasting it is necessary to wait at least three to four SRT cycles. By then 95 % of the sludge has been replaced which can be considered a stable condition (Stockholm vatten, 2013).

3.3 FLOCCULATION

Flocculation is a way of removing particles in wastewater. However, many particles are small and have too low densities to sediment on their own. The sedimentation principle is described by Stokes Law,

$$v = \frac{2}{9}\frac{r^2 g(p_{part} - p_{liquid})}{\eta} \qquad (3)$$

v	sedimentation velocity
r	particles radius
g	gravitational acceleration
p_{part}	particle density
p_{liquid}	liquid density
η	liquid dynamic viscosity

The problem with small particles can be solved by adding a flocculating agent. Flocculating agents cause two different processes to occur, one called charge neutralization and one called sweep coagulation.

When causing charge neutralisation the added chemical lump together negatively charged particles by using its positive charge to neutralize the repulsion. Positive ions in the flocculent attach to negatively charged particles surfaces making them neutral and allowing for Van der Waals forces to act between the particles pulling them together. When joined together their total weight increases causing them to sink (Hansen, 1997). There are several different flocculating agents and they all consist of a salt with an active positively charged part. It can easily be understood that higher charged ions are more effective than weaker charged ones as less ions are needed to neutralize. Practically all positive ions can be used as flocculants and it is simply a question of money and health consideration that brings the choice to aluminium and iron (Hansen, 1997). The other mechanism acting during flocculation is sweep coagulation. When metal ions react with water hydroxides are formed creating cloudlike formations. These “clouds” are excellent traps for small particles and soluble substances (Hansen, 1997). It is important to withhold quick mixing so both mechanisms mentioned can occur. If the flocculent is not mixed in quick enough it will react with the water directly producing hydroxides. This in turn leaves no possibility for the process of charged neutralization to take place (Hansen, 1997).

Besides mixing, factors such as pH and temperature play a role in flocculation and sedimentation. It should be ensured that the amount of chemical in the effluent is minimised. Flocculating agents have different optimum pH levels where they function as efficient as possible. Generally poly aluminium agents with a higher charge (e.g. PAX) work within a broader pH interval than the low charged ones (Svenskt vatten, 2010). This is mainly due to the fact that higher charged agents carry out neutralizations whilst lower charged agents cause sweep coagulation. Although they are active within a wide range they tend to function best at a high pH level (Hansen, 1997).

It should also be kept in mind that temperature plays an important role in how effective coagulation and flocculation occurs. Low temperatures affect metal hydroxides solubility and generally low temperatures have a negative effect as flocculation and particle reduction decreases with decreasing temperature (Aromaa, 2000).

3.4 PHOSPHOROUS IN WASTEWATER

Phosphorous is present in different forms in wastewater;

- Organically bound phosphorous
- Inorganic phosphorous
    - Polyphosphate
    - Orthophosphate

Polyphosphate is broken down to orthophosphate in wastewater and occurs in different forms depending on pH as shown in table 4 (Svenskt Vatten, 2010).

Table 5 State in which phosphorous occurs depending on pH (Svenskt Vatten, 2010).

pH	Name	State
< 2.1	Trihydrogen phosphate ion	H_3PO_4
2.1-7.2	Dihydrogen phosphate ion	$H_2PO_4^-$
7.2-12.3	Hydrogen phosphate ion	HPO_4^{2-}
>12.3	Phosphate ion	PO_4^{3-}

3.4.1 Chemical flocculation

Within wastewater treatment it is sought after to remove both particle-bound phosphate and soluble forms of phosphorous. The soluble substances need to be precipitated as salt. As indicated in section 2.3 phosphorous mainly exists as orthophosphate in wastewater. When orthophosphate reacts with either aluminium or iron an insoluble salt is formed. Theoretically a trivalent metal ion can bind one phosphate ion$(+3-3=0)$. The charge per atom is less for aluminium polarised agents such as PAX 21as the ions are joined together. However the complex as a whole has a larger charge (Hansen, 1997). This leads to the hypothesis that aluminium polymerized agents should be less effective in removing dissolved phosphate. Aluminium polymerized agents are instead better at removing particles. Poly aluminium compounds have a higher charge and the neutralization process can therefor occur quicker than if, for example, aluminium sulphate was used (Svenskt Vatten, 2010).

Poly aluminium chloride, figure 9, is an acidic solution that can contain up to 15 positive charges per aluminium ion and does not affect pH to the same extent as its sister compounds with a lower charge (Svenskt vatten, 2010).

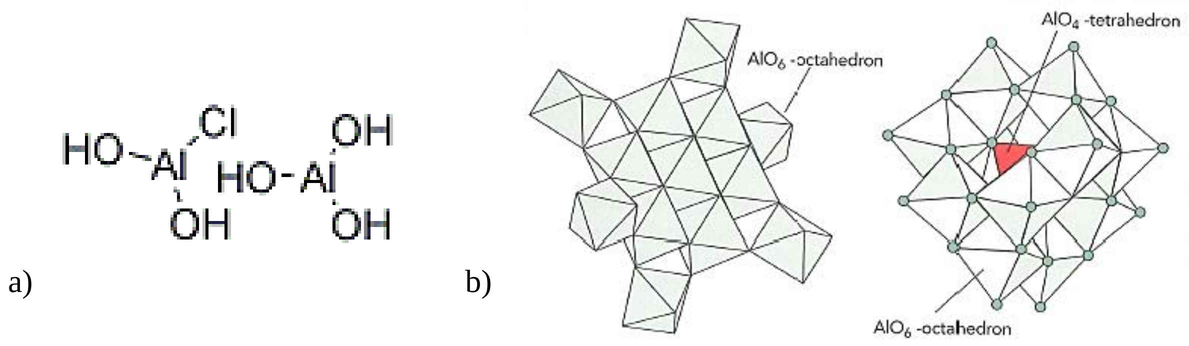

Figure 9 a) Poly aluminium chloride, Pax 21. $Al_2ClH_5O_5$ (Source: modified from Chemnet) b) Molecular structure for two Al-13 ions (Svenskt vatten, 2010, with permission)

Poly aluminium chloride, PAX 21, is favourable within treatment of cold water as flocculation time is not affected in the same way by cold temperatures as it is when iron chloride or aluminium sulphate is used. Chloride ions are released when PAX 21 dissolves in water. They pass through the treatment process without reacting. The aluminium ions on the other hand react with phosphate ions, hydroxides and particles. The exact composition of the resulting flocculent is unknown but equation 4 and 5 describe the reactions that take place (Svenskt Vatten, 2010).

Aluminium phosphate flocculation

$$Al^{3+} + HPO_4^{2-} \leftrightarrow AlPO_4 + H^+ \tag{4}$$

Aluminium hydroxide flocculation

$$Al^{3+} + 3H_2O \leftrightarrow Al(OH)_3 + 3H^+ \tag{5}$$

The aluminium hydroxide, $Al(OH)_3$, produced has a gelatinous and flocculating structure. The addition of hydrogen atoms lower pH and if it sinks below 5 the lack of hydroxides inhibit the process and production of $Al(OH)_3$. The result of this is ceasing flocculation. If, on the other hand, pH increases above 8, reactions between hydroxide and aluminium hydroxide take place producing aluminate ions as seen in equation 6. If pH continues to increase, aluminate, $Al(OH)_4{}^-$, will dissolve and aluminium concentrations rise (Svenskt vatten, 2010).

$$Al(OH)_3 + OH^- \leftrightarrow Al(OH)_4{}^- \tag{6}$$

3.4.2 Biological phosphorous removal

An alternative to using chemicals for phosphorous removal is so called biological phosphorous removal. It is not as commonly practiced in Sweden as in the United States and South Africa and one possible answer to this may be Sweden's strict regulations regarding phosphorous levels in effluent water. To achieve biological phosphorous removal, anaerobic conditions are required. In fact, biological phosphorous removal occurs in the active sludge process even though it is not the main purpose of the process. One reason is micro-organism assimilation. Depending on how much organic material is broken down, phosphorous levels are reduced by 20-50 %. Wastewater has a BOD_7:P quota of approximately 100:3 which means that micro-organisms that require a 100:1 quota experience phosphorous excess and therefore assimilation is not enough to remove sufficient amounts of phosphorous (Svenskt vatten, 2010).

In biological phosphorous removal special bacteria known as bio-P or PAO (Polyphosphate accumulating organisms) are active. They have the great ability of taking up more phosphorous than needed for growth and store it in their cell structure. The process of biological phosphorous removal starts with an increased concentration of phosphorous. Bio-P bacteria are, during anaerobic conditions, able to use energy from stored cellular polyphosphate to take up organic carbon, more specifically, volatile fatty acids (VFAs). This process is energy consuming but the fatty acids are stored as energy for later purposes. The energy used to transform VFAs to energy is withheld from hydrolysis of stored polyphosphates to phosphate. The phosphate is transported out of the cell leading to increased phosphorous concentration. When the process moves on to an aerobic phase the bio-P bacteria have an advantage as they do not have to compete for biodegradable carbon. They are then able to use stored energy gained in the anaerobic phase for growth and phosphorous uptake. The phosphate concentration in the water decreases to a lower level than the initial and there is a net loss of phosphorous in the water. The bio-P bacteria settle in the sludge which is separated from the clear water. Figure 10 shows the biological phosphorous removal process. Bio-P organisms contain three internal storage products relevant for excess phosphorous removal, polyphosphate, polyhydroxy-alkanoates (mainly PHB) and glycogen. Glycogen is turned into PHB using ATP from the hydrolysis of polyphosphate as energy source. During this process $NADH_2$ is released. Figure 10 explains what happens during aerobic metabolism. The stored PHB is oxidized creating NADH that is used to produce ATP. ATP is in turn used for growth and polyphosphate and glycogen uptake (Van Haandel, Van Der Lubbe, 2007).

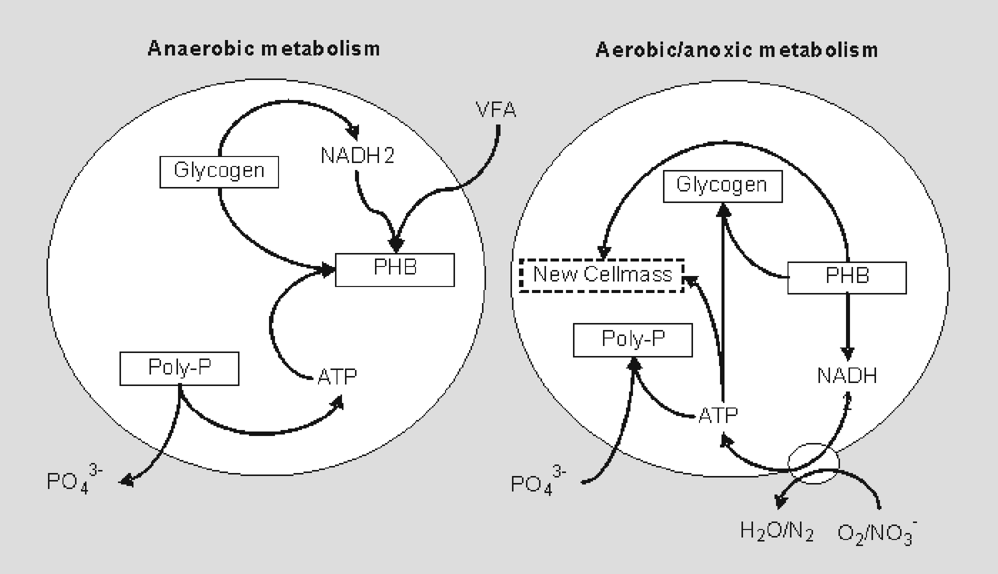

Figure 10. The anaerobic and aerobic phases of biological phosphorous removal. Source: Inspired by Smolders et al. (1994)

Based on the results from an experiment carried out at Dokka’s wastewater plant in Gällivare the conclusion could be drawn that biological phosphorous removal is only possible in SBR’s down to a temperature of 4-5 °C. Below this temperature soluble phosphorous instead increases. The report from this study also states that the phosphorous level fluctuates more at small-scale SBR-facilities with biological phosphorous removal than with conventional precipitation removal systems (Marklund; Morling, 1994).

3.5 NITROGEN IN WASTEWATER

Most of the nitrogen that ends up at a wastewater plant originates from urea. The organic-nitrogen is often converted into ammonium when transported through pipes to the WWTP. Organic nitrogen is seldom analysed but is assumed to represent 30 % of the total amount of nitrogen. The other 70% of the influent is said to be NH_4-N. As for oxidized nitrogen it is assumed to be non-present in raw wastewater (Morling, 2009).

In the discharged water the organic nitrogen is inert which means either it is impossible to transfer biologically or else it is an end result from the biological treatment. This fraction is often assumed to be 1 mg/l if the total nitrogen influent concentration is below 50 mg/l. Nitrogen is also removed as gas, mainly N_2, but small fractions of N_2O can also be formed which effects the climate negatively as it is a greenhouse gas. The last way for nitrogen to leave the plant is through sludge withdrawal. The sludge mainly contains organic nitrogen (Morling, 2009).

One of the active sludge process main goals is to remove nitrogen from raw wastewater. This is done through two biological steps, nitrification and denitrification. One could argue that there are in fact three steps if ammonification is included. Ammonification is the process of converting organic-nitrogen into ammonium but as mentioned earlier, this often occurs while the water is transported through pipes to the plant. Organic nitrogen can also be converted into ammonia depending on pH and temperature (The water planet company, 2013). As wastewater usually is neutral, pH 7, nitrogen is in the form of ammonium rather than ammonia (Svenskt vatten, 2010).

Nitrification
Nitrification is the process of converting ammonium to nitrate, equation 7 a,b,c.

Oxidation of ammonium ions to nitrite ions by *Nitrosomonas, Nitrosospiras* and *Nitrosococcus*.

$$NH_4{}^+ + 1.5O_2 \leftrightarrow NO_2^- + H_2O + 2H^+ \tag{7a}$$

Oxidation of nitrite to nitrate by *Nitrobacter, Nitrospira, Nitrospina* and *Nitrococcus*.

$$NO_2^- + 0{,}5O_2 \leftrightarrow NO_3^- \tag{7b}$$

Full reaction

$$NH_4{}^+ + 2O_2 \leftrightarrow NO_3^- + H_2O + 2H^+ \tag{7c}$$

A total of 4.6 g oxygen is consumed per gram nitrogen oxidized. Nitrification is an acidifying reaction which is understood by studying reaction 7a. 0.14 g hydrogen ions are released for every oxidized gram of nitrogen (Svenskt vatten, 2010). The optimum pH for *Nitrosomonas* and *Nitrobacter* lies between 7.5 and 8.5 but most treatment plants are able to effectively nitrify within a pH of 6.5 to 7.0. Nitrification stops when pH drops below 6.0. The nitrification reaction consumes 7.1 mg/l of alkalinity as $CaCO_3$ for each mg/l of ammonia oxidized (The water planet company, 2013). Monitoring pH is, for reasons described above, important in order to maintain a high performing SBR. In some cases chemicals may need to be added to raise alkalinity. Measuring alkalinity continuously using a probe increases the chance of detecting a sudden drop of alkalinity.

The nitrifying bacteria are not dependent of organic material as they gain energy from oxidizing ammonium or nitrite and use carbon dioxide for growth. The uptake of carbon dioxide for biomass production is energy consuming which slows down their growth rate. Thus the nitrifying bacteria growth rate sets sludge retention time. The retention time may be no shorter than what makes it possible for the nitrifying bacteria growth rate to compensate for sludge withdrawal (Svenskt vatten, 2010).

Temperature also effects nitrification and the process will cease if the temperature exceeds 40 °C. Optimum lies between 30-35ºC and if the temperatures drop below 10 °C reactions will proceed but at a lower rate. If effluent water contains more NH_3 than 2-3 mg/l it is a sign of non-functioning nitrification (The water planet company, 2013).

Denitrification

Denitrification is the process of converting nitrate to nitrogen gas. The process occurs in several steps where nitrate is reduced by accepting electrons produced during oxidation of organic matter;

$$NO_3^-(aq) \rightarrow NO_2^-(aq) \rightarrow NO(g) \rightarrow N_2O(g) \rightarrow N_2(g) \tag{8}$$

$+$V $+$ III $+$ II 0 Oxidation number

It has not been defined whether NO is a mandatory intermediate (Ingesson, 1996)

Equation 9 is the complete reaction formula for denitrification.

$$4NO_3^- + 5C(organic\ carbon) + 4H^+ \leftrightarrow 2N_2 + 5CO_2 + H_2O \tag{9}$$

The reaction is carried out by heterotroph bacteria that gain energy and carbon for growth by breaking down organic material. Denitrification therefore requires a carbon source and anoxic or anaerobic conditions to proceed, ideally a dissolved oxygen level above 0.2 mg/l (The water planet company, 2013).The intended final nitrogen product is nitrogen gas which is harmless, although sometimes nitrous oxide, N_2O, is formed which is a greenhouse gas.

As equation 9 indicates, the reaction is buffering, consuming 0.07 g hydrogen ions per gram reduced nitrogen. Optimum pH values for denitrification are between 7.0 and 8.5 (Svenskt vatten, 2010)

Denitrifying organisms are more resistant towards toxic substances than their fellow nitrifying organisms and recover quicker from a toxic occurrence (The water planet company, 2013).

Temperature also plays an important role for denitrifying organism. Their growth rate increases with temperature within the range 5-30 ºC. Equation 9 also shows the need for carbon in the denitrification process. Theoretically 2.86 g COD is needed to remove 1g nitrogen in the form of nitrogen gas. Taking cell synthesis into account approximately 4g COD is needed in reality (Nikolic, 2006: Sundin, 2006). One option of satisfying the demand is to add an external source of carbon. The type of carbon added influences growth rate in which methanol and acetic acid are preferred over endogenous carbon (The water planet company, 2013).

Presently there are no nitrogen purification requirements for wastewater treatment plants in Sweden but the future seems to be putting an end to that. Although there are no set limits to what level a plant may let out all plants still practice nitrogen removal of some sort. Nitrogen removal is energy consuming as it requires oxygen and therefore the largest expense for a WWTP by far.

3.6 BOD/COD/TOC/SS

Removing organic matter from the raw water is an important part of wastewater treatment. The main reason for removing organic matter is to avoid an oxygen consuming load reaching the recipient. There are several ways of measuring organic material.

Biochemical oxygen demand (BOD) – the amount of dissolved oxygen aerobic biological organisms require in order to break down organic material present in a given water sample at a certain temperature over a specific time period. BOD is measured as mg/l.

Chemical oxygen demand (COD) – a test used to measure the amount of organic compounds in water that have not been oxidized. It is expressed in milligrams per liter and indicates the mass of oxygen consumed per litre of solution.

Total organic carbon (TOC) – a measure of organic carbons.

Suspended solids (SS) – the SS-concentration refers to all small solid particles in a solution.

BOD specifies the amount of available organic carbon bacteria can oxidize and benefit from. It is a good indicator to how much ‘food’ there is available for micro-organisms and therefore gives a hint to how much oxygen needs to be added for optimum decomposition.

Information about the ability of a substance to be broken down can be withheld by examining the COD:BOD quota. For a single substance the quota is unambiguous but for a mix it is more difficult to draw conclusions. The quota is a biodegradability index and can give a hint to whether most of the organic content is readily biodegradable or not (Svenskt vatten, 2009). The drawback with this quota is its inability to say anything about the decomposition process. Substances degrade at different paces and the index therefore only gives information about degradability within set time limits. Easily biodegradable BOD is sometimes referred to as *soft* BOD in respect to *hard* BOD which consists of large molecules that are harder to degrade. The index is helpful mainly if the quota is close to one, 100% biodegradable, or if the oxidization process of organic material is uniform, i.e. has a uniform decomposition rate. It is, because of this, easier to predict biodegradability in homogenous wastewater (Naturvårdsverket, 1989). A simple rule is, if the COD:BOD_5 ratio does not exceed 2:1, biodegradability is fine, but if there is more COD in respect to BOD, there are a lot of poorly biodegradable substances present (Winkler, 2012).

It should be remembered that nitrification also is an oxidizing process, consuming oxygen. Nitrification may show elevated levels of biodegradation although no organic matter is broken down. The COD:BOD quota will then show a misleadingly high value as COD testing does not have a corresponding chemical nitrogen reduction as BOD (Naturvårdsverket, 1989).

Another common quota is the food/micro-organism quota (f/m) which is a parameter that can be used to control wasting. It is an alternative to sludge retention time and may at times be more intuitively understood. The f/m ratio, equation 10, is the quota of BOD_5 divided by MLSS (Mixed Liquor Suspended Solids) measured as weight.

$$f/m = \frac{BOD_5\ Q}{MLSS\ V} \tag{10}$$

BOD_5	Biochemical oxygen demand in the reactor $[g/l]$
Q	Flow of BOD_5 $[(m^3/l)]$
$MLSS$	Total mixed liquor suspended solids in the reactor $[g/l]$
V	Reactor volume $[(m^3)]$

If the f/m ratio is high there is a lot of food in respect to micro-organisms and the growth rate is high, resulting in high BOD removal. The opposite is true for a low ratio where the micro-organisms are competing over food. Normally a high oxygen uptake is associated with a high f/m ratio and "young" sludge. A low oxygen uptake on the other hand is associated with a low f/m ratio and older sludge saying that if a higher oxygen uptake is desired more sludge should be withdrawn. Oxygen uptake can be measured with a test called Oxygen Uptake Rate (OUR). The test is carried out by a device measuring mg O_2/h/g of MLSS. A high BOD- removal may be considered favourable but nevertheless it has its price. If oxygen concentrations are not high enough to meet the needs, poor sludge settlement may occur. Usually the f/m values range from 0.5-1.0, however, a value between 0.2 – 0.5 is what is aimed for. A value under 0.1 is considered low (Spencer Davis, 2005).

A rule of thumb is that 1.5-2.0 kg O_2 is needed for every kilo of BOD. It should be insured that the aeration system has an oxygenation capacity to supply sufficient amounts of oxygen at different temperatures. If a concentration of about 1.5-2.0 mg O_2/l can be maintained, oxygen will not be limiting for bacteria flocks. Dispersed bacteria are not limited until oxygen levels drop below 0.6 mg/l. When levels drop below this level, filamentous bacteria have an advantage as they can withstand low oxygen concentrations better. This can cause filamentous bulking (Spencer Davis, 2005).

3.7 SLUDGE QUALITY

At this point it has been made clear that sludge quality has a huge impact on the water treatment process. It all comes down to promoting a favourable bacterial culture and maintaining it. Micro-organisms need the right nutrition, temperature, pH etcetera. Nutrition wise they need a composition of carbon, nitrogen and phosphorous in the right proportions to reach maximum growth rate and avoid filamentous bulking. A favourable ratio lies between 100 BOD: 5 N: 1P and 100 BOD: 10 N: 1 P (Winkler, 2012). If there is a lack of N or P filamentous bacteria will start to dominate (Spencer Davis, 2005).

Flocks are desired as they settle easier than dispersed bacteria. When wastewater enters the tank molecules and colloidal particles are trapped and adsorbed onto flocks. Bacteria attach on to both outer and inner surfaces of the flock and a single flock is able to adsorb millions of bacteria. Bacteria sited inside the flock sometimes struggle with lack of oxygen supply. There is an oxygen concentration gradient ranging from high to low, from the wastewater and in to the flock. To ensure continued growth inside big flocks a minimum concentration of 0.6 mg O_2/l is required in the core. This corresponds to 1.2-2.0 mg O_2/l in the mixed fluid. If this is not maintained the inside threats to be inhabited by facultative anaerobic bacteria. The outer layer of a flock is regularly colonized by protozoa, rotifers and other microorganisms that rank higher than bacteria in regards to trophic level. These organisms consume bacteria and small particles. Many different bacteria co-exist and the composition varies a lot, sometimes even on a daily basis. It is the ability to assimilate current nutrition sources that determine bacteria composition. Bacteria secrete different enzymes that allow them to be more or less successful in digesting certain types of substrate and therefore dominating bacteria are a result of the current range of substrate. Microorganisms are fantastic in adapting to new conditions. Sometimes even toxic chemicals, such as phenol, can be used as food resource after a few days of adapting necessary enzymes (Spencer Davis, 2005).

Different conditions favour different types of microorganisms making it somewhat possible for the operator to control the composition. According to the operating instructions provided by Water care AS (the Norwegian company that delivered the SBR to Kungsberget via the reseller Miljö och Bioteknik AB) the optimal pH to maintain what they call a “correct” microorganism population lays between 7 and 7.5.

3.8 SBBR AND ASBR

There are modified versions of SBR that can be applied to further improve treatment efficiency. A technology known as SBBR (Sequencing Batch Biofilm Reactor) is recommended for managing high COD and BOD concentrations (Li et al, 2003). The process is similar to SBR except for the addition of carrier media to the reactor. Microorganisms attach to the media creating a biofilm on the surface which can be rock, sand or plastic. An illustration of a plastic element is shown in figure 11. Adding carrier media has the advantage that microbe cultures with poor settling ability that would otherwise have been washed out instead can attach to biofilm with high cell density (Dong-Seog et al., 2008).

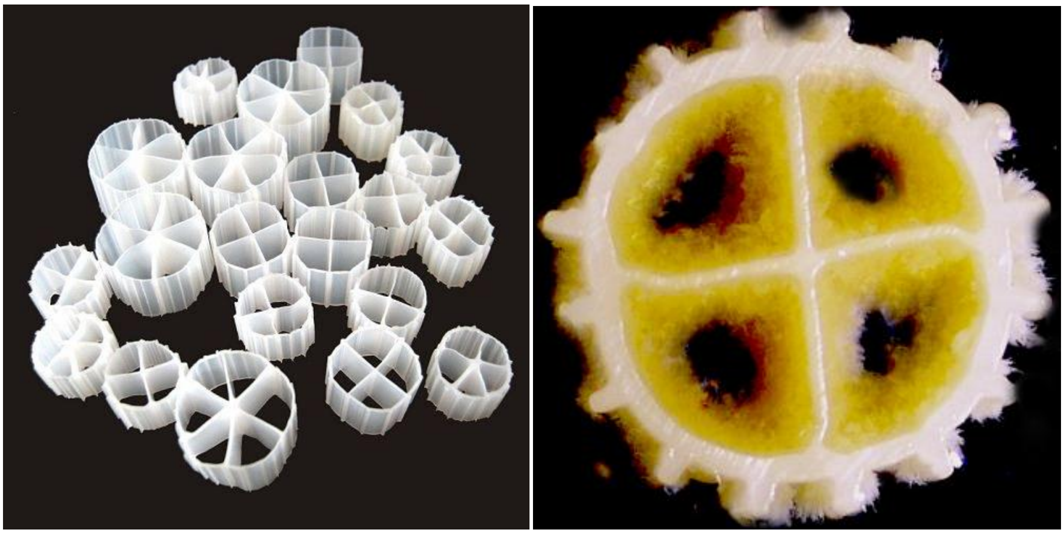

Figure 11 Plastic carrier media. The left photo shows a pile of unused elements and the right photo shows an element with a biofilm of microorganisms (Sources: Epic modular process systems and Tongxiang Small Boss Special Plastic Products, with permission).

Another positive side of SBBR is the carrier's feasibility to support PAO's (Polyphosphate-accumulating organisms) and therefore manage both nitrogen and phosphorous removal. The anoxic conditions that arise in the centre also make it possible for denitrification to take place. This means that nitrification and denitrification can occur simultaneously during aeration (Ding et al, 2011). Oxygen deficit may arise when both nitrification and phosphorous uptake take place as both processes require oxygen. In addition to oxygen, denitrifiers and PAO's also compete for organic substrate. These two factors may inhibit phosphorous removal in the biofilm but this should have little effect, looking at a holistic perspective, if the carriers are washed frequently and a thin biofilm is maintained. It has been suggested that nitrification and phosphorous uptake takes place alternately on the outer oxic layer and that this is a result of oxygen deficiency for nitrifiers and heterotrophic bacteria such as PAO's that compete for oxygen. This suggests that SBBR is successful in nitrogen removal as SND (simultaneous nitrification and denitrification) occurs but perhaps less successful in phosphorous removal as it is limited by nitrification (Dong-Seog et al., 2008).

In ASBR (Anaerobic Sequence Batch Reactor) the reaction phase is completely anaerobic. It is a great advantage that no oxygen is needed as it makes it more energy efficient than a conventional SBR. Anaerobic granular biomass or excess wastewater is usually seeded into the reactor and left to acclimatize with prevailing wastewater conditions. The granular biomass decreases in size and usually takes a spherical shape as bacteria start to digest the material. Bacteria inside the granular biomass need a way to continuously receive new substrate which makes it fortunate that the gas produced in the decomposition process creates small openings that allow for substrate to reach the inside (Li et al., 2005).

4 RESULTS

Data for the parameters discussed in section 3.4-3.7 were analysed and are presented in section 4.1-4.4 below. Most data has been obtained from Eurofins laboratory but for some parameters complementary analyses have been carried out at the plant. This applies for pH, phosphorous and temperature. Over and above the different parameters, water flow has been measured and is shown in figure 12. It should be noted that the fixed months on the time axis mark the middle of the month. This means that a month starts halfway between the previous month and itself and carries on half way to the following month.

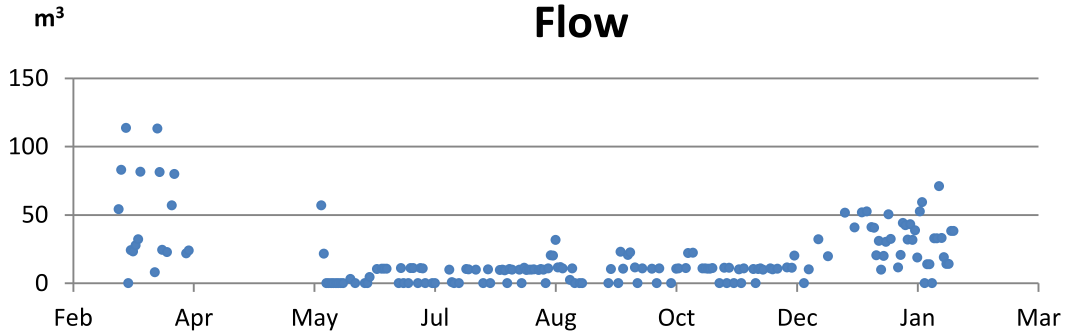

Figure 12 Flow of treated water from March 2012 to February 2013. The graph is missing values from some sporadic dates and also lacks data from April 2012.

In figure 12 it is clear that the load is higher during winter than during summer. There is a recurrent zero load during the summer which is never the case during the winter. Seasonal flow can be expected but nevertheless it is interesting to see how flow varies on a monthly basis. During the summer months flow is lower but more even.

4.1 PHOSPHOROUS IN WASTEWATER

As mentioned in section 2 it is hard to analyze whether adding more flocculent has had a noticeable effect as samplings at Kungsberget before and after changing chemical dosages are inadequate. The operator has noted some of the dates for when changes were performed. In table 6 changes are shown from August 2012 to February 2013, before the 3rd of August a six minute dosage applied.

Table 6 Dosage changes carried out. The phosphorous concentration refers to unfiltered P-tot concentration. Question marks note the uncertainty in changes carried out between 3.12.2012 – 18.1.2013 and 8.2.2013-26.2.2013.

Date	Dosage change (time, min)	New dosage (time, min)	Before change (mg P /l)	After change (mg P/l)
2012-08-03	+ 1 min	7 min	2.3	2.0
2012-08-09	+ 1 min	8 min	2.8	3.3
2012-08-16	+ 2 min	10 min	3.3	3.3
2012-08-27	+ 2 min	12 min	2.67	1.4
2012-09-20	+ 1 min	13 min	3.32	1.67
2012-12-03	+ 2 min	15 min	1.21	0.54
???	???	4 min	???	???
2013-01-18	+ 2 min	6 min	3.3	1.91
2013-02-04	+ 6 min	12 min	3.3	3.3
2013-02-06	+ 2 min	14 min	3.3	3.3
2013-02-08	+2 min	16 min	3.3	3.3
???	???	???	???	???
2013-02-26	+10 min	26 min	???	0.17

No tests were analysed at a laboratory between the 25th of January and the 11th of February limiting the possibility of interpreting the situation. The instrument used in Kungsberget is unable to compute values over 3.3 mg PO_4/l and it is therefore not possible to state the contribution from the flocculant to the changes in January and February as the device shows 3.3 mg PO_4/l both before and after increased dosage. Concentrations were high, above 3.3 mg PO_4/l, during January and the first part of February and therefore serious action had to be taken to trim the SBR into improving reduction. The operator began to study the facility more thoroughly and increased the flocculent agent dose to 6.1 litres (26 min). Unfortunately there are no records of exact changes in chemical dosage between the 8th and 26th of February but when studying figure 13 a huge drop in phosphorous concentration is seen during the latter half of February.

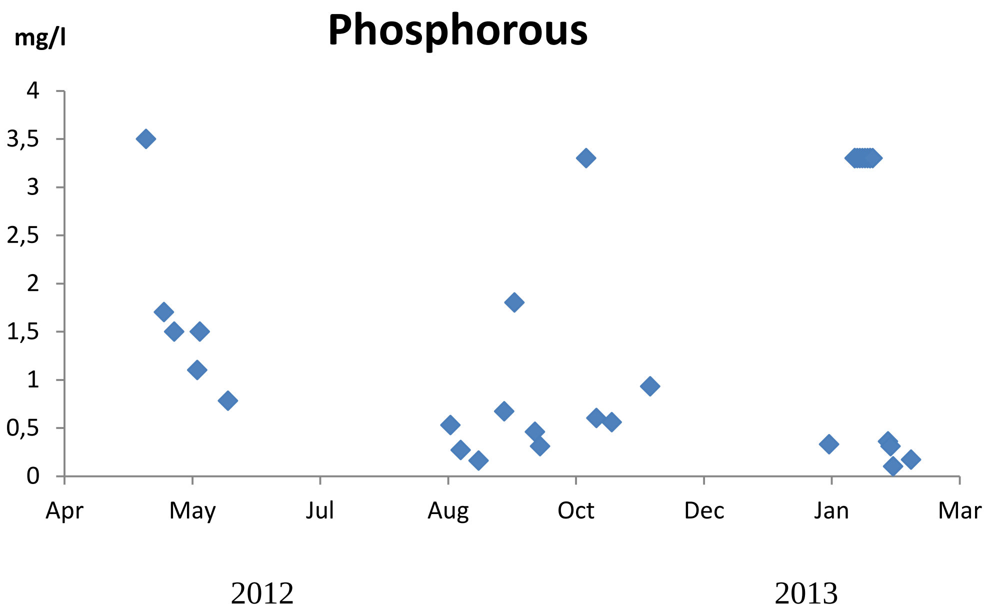

Figure 13 Results from Eurofins and locally analysed samples of total phosphorous concentration.

The concentrations in figure 13 vary at a large scale and have according to local measurements been on a level above 3.3 mg PO_4/l between the 4th and 11th of February and also in a sample taken in April and October. The analyses performed locally have not been filtered and the total phosphorous concentrations may therefore be higher than what is represented in figure 14, 15 and 16. The set limit for effluent concentrations is, as mentioned in section 3.4, 0.3 mg P/l. Two values below this limit were obtained in late February but before that, requirements have only been met twice since May 2012, figure 13. The supplier claims the reactor to be capable of reducing total phosphorous concentrations to <0.3 mg P/l.

Figure 14 shows phosphorous concentration and pH in a diagram.

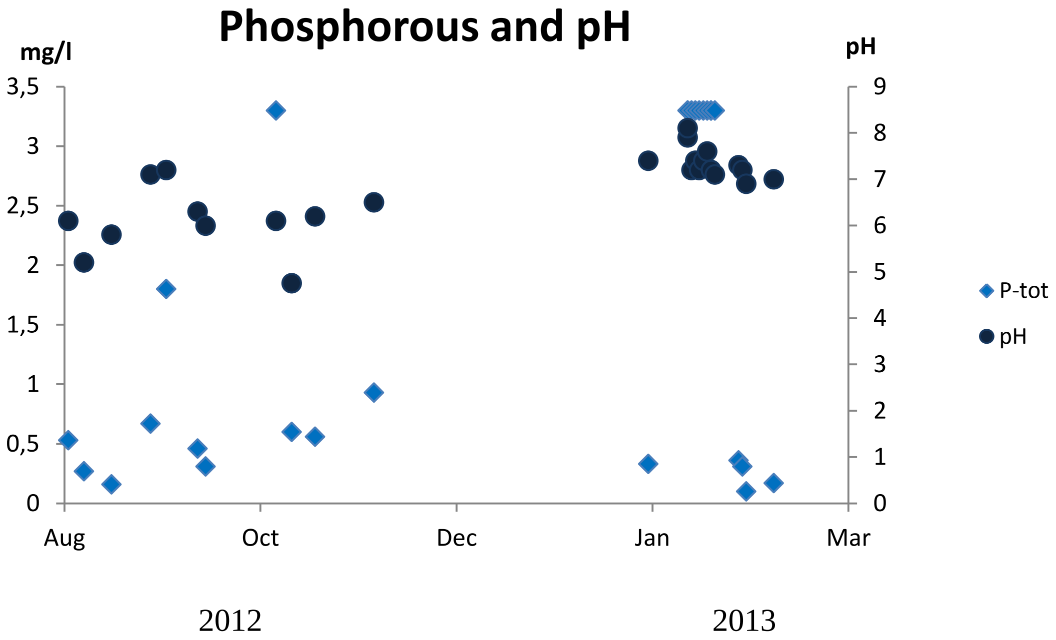

Figure 14 Results from Eurofin and locally analysed samples of total phosphorous concentration and pH.

It is hard to tell whether there is a connection between phosphorous and pH just by examining figure 14. In order to establish this, other factors have to remain unchanged to make sure there are no other influences that affect either pH or phosphorous. A slight connection can however be sensed in figure 14 even if it is not significant. A pattern of increasing concentrations following increased pH can be noted during September and October, yet not perfectly clear. However, the effluent concentration in February changed drastically without a major change in pH.

Even if effluent concentrations have failed to satisfy required limits in the past the degree of reduction has still been fairly high. Figure 15 shows in- and outflow from June 2012 to February 2013 and table 6 shows the level of reduction.

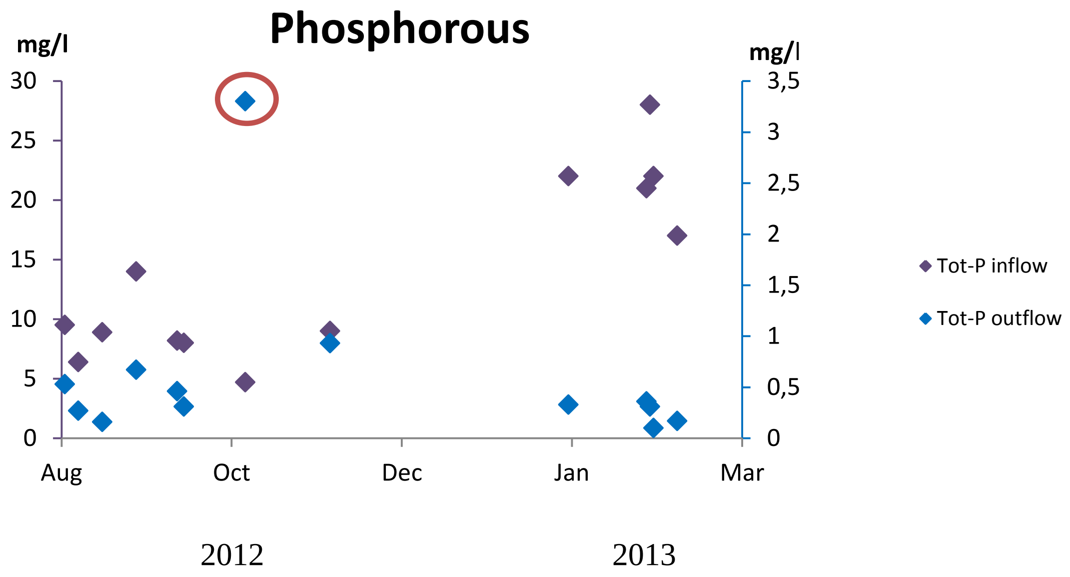

Figure 15 In- and outflow concentrations. The inflow concentrations are on the primary y-axis and the outflow concentrations on the secondary y-axis. The circled point is a suspected sampling error.

Table 7 Level of phosphorous reduction. Value in bold may be a sampling error.

Date	In concentration	Effluent concentration	Reduction
2012-08-30	9.5	0.53	0.94
2012-09-03	6.4	0.27	0.96
2012-08-10	8.9	0.16	0.98
2012-09-20	14	0.67	0.95
2012-10-02	8.2	0.46	0.94
2012-10-04	8.0	0.31	0.96
2012-10-22	4.7	**3.30**	**0.30**
2012-11-16	9.0	0.93	0.9
2013-01-25	22	0.33	0.99
2013-02-17	21	0.36	0.98
2013-02-18	28	0.31	0.99
2013-02-19	22	0.10	0.995
2013-02-26	17	0.17	0.99

The average level of total phosphorous reduction has been over 95% since the end of August (disregarding 2012.10.22) and since January 2013 an improved reduction level can be sensed.

4.2 NITROGEN IN WASTEWATER

According to figure 16 the total effluent nitrogen concentrations seem to follow a negative trend from April 2012 to January 2013. The N-tot concentrations vary from

120 mg/l to 25 mg/l with a mean value around 65 mg N/l. The NH_4-N varies from 13-40 mg NH_4^+/l with a mean value around 21 mg NH_4^+/l.

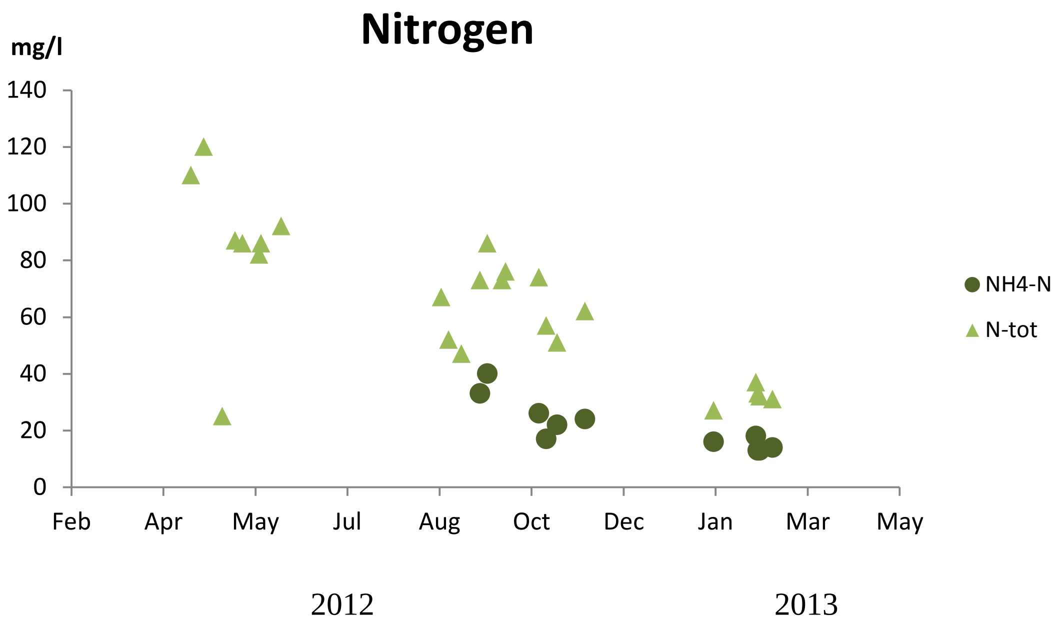

Figure 16 Results from Eurofins of total nitrogen and ammonium effluent water concentrations.

The reduction level of nitrogen has been somewhat difficult to follow as data at times has shown higher effluent than influent values which most likely is an indication of measuring errors. However, examining the four results from February 2013 in table 7 an average reduction level of 79 % can be concluded which is satisfactory.

Table 7. Inflow and outflow concentrations of total Nitrogen in mg/l.

Date	Inflow	Effluent	Reduction
2013-02-17	180	37	0.79
2013-02-18	160	33	0.79
2013-02-19	180	32	0.82
2013-02-26	130	31	0.76

It is hard to analyse how the sub processes of nitrogen removal, nitrification and denitrification progress as there is little or no data on organic nitrogen, ammonium, nitrate and nitrite. Nitrification can somewhat be analysed through data obtained for ammonium by looking at the NH_4-N/N-tot quota, figure 17. Stig Morling (Morling 2013, pers. communication) has previously produced values for Kungsberget that show effluent nitrogen concentration quotas depending on nitrification and denitrification. These are summarised in table 8.

Table 8 Template nitrogen concentrations based on earlier measurements at Kungsberget. Concentrations are given in mg/l after nitrification and denitrification based on a 70 mg N-tot/l incoming raw water concentration. (Morling, 2013, pers. communication)

Fraction	**Influent**	**After nitrification**	**After denitrification**
N-tot	70	70	10
Organic Nitrogen	2	2	2
NH_4-N	68	0-28	2
NO_3-N	0	40-68	6
Assimilated Nitrogen		*10-20*	*10-20*

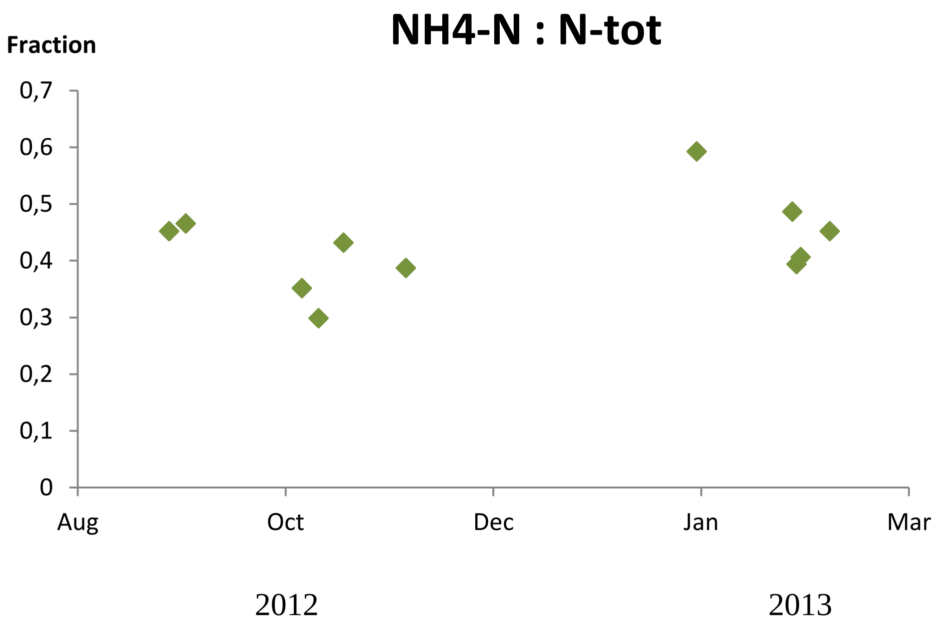

Figure 17 Ammoniums fraction of the total nitrogen effluent concentration

There are four samples from the latter half of February where both nitrate and ammonium have been analysed. The results are summarized in table 9.

Table 9 Concentration in effluent water of total nitrogen, ammonium, nitrate and organic nitrogen in mg/l from February 2013. The NH_4/N-tot fraction and NO_3/N-tot fraction have been calculated from obtained data in the table.

	2013-02-17	**2013-02-18**	**2013-02-19**	**2013-02-26**
Total nitrogen (N)	37	33	32	31
NH_4-N	18	13	13	14
NO_3-N	16	18	18	19
Organic nitrogen*	3	2	1	**-2**
NH_4/N-tot	0.49	0.39	0.41	0.45
NO_3/N-tot	0.43	0.55	0.56	0.61

*Organic nitrogen has not been measured but is instead assumed to be the remaining fraction when ammonium and nitrate has been withdrawn from the total amount of nitrogen.

Relating figure 17 and table 8 with the information given in table 9 indicates that both nitrification and denitrification occurs to some extent at Kungsberget. If nitrification occurs the NH_4^+/N-tot ratio should lie between 0 and 0.4. As seen in figure 17 the fraction has seldom been within this range, however, the latest values analysed, table 9, show a NH_4/N-tot ratio around 0.45 and a NO_3/N-tot ratio of approximately 0.55. This indicates that nitrification and denitrification are taking place.

There is a 10 % measurement uncertainty when measuring total nitrogen which is one explanation to why there is a negative value for organic nitrogen the 26th of February 2013. Total nitrogen concentration may vary between 27.9 and 34.1 mg/l which means that if it is in fact 34.1 mg/l, the organic nitrogen concentration is 1.1 mg/l which is more reasonable than -2 mg/l.

The theoretical value for denitrification in regards to COD:N is 2.86 as discussed in section 3.5. This means that 2.86 g COD is required to convert 1 g of nitrate nitrogen into nitrogen gas. It was also mentioned that 4 g COD is a more realistic value when considering cell synthesis. In figure 18 the influent COD:N relationship at Kungsberget between 3rd of May 2012 to 26th of February 2013 is shown.

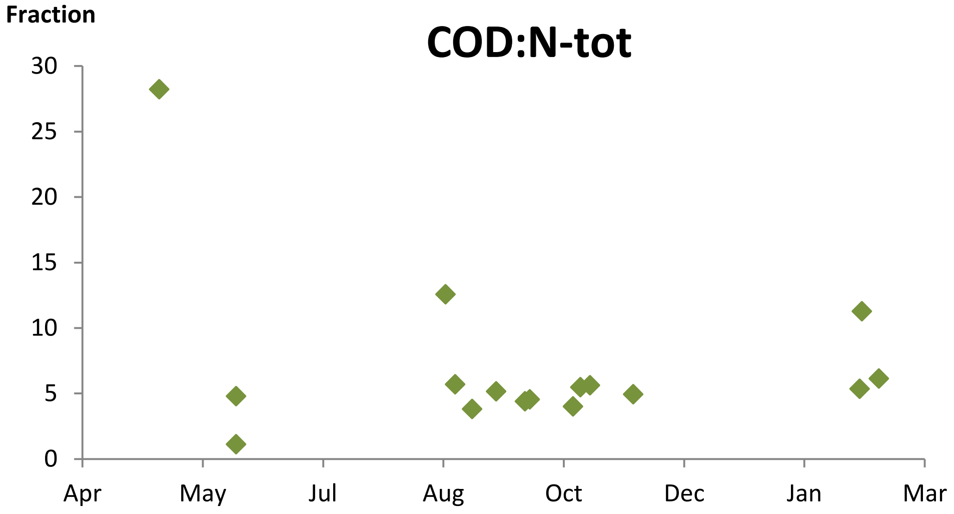

Figure 18 COD:N-tot relationship in influent raw water.

Most values in fig 18 lay around 5. This means that for every gram of nitrogen, 5 g COD is available for denitrification.

4.3 BOD/COD/TOC/SS

The results from the BOD_7 analyses are shown in figure 19. It can be wise to consider the 30% measurement uncertainty when examining the results. According to the permit from the Environmental Protection Division the BOD_7 concentration is not allowed to exceed 10 mg/l.

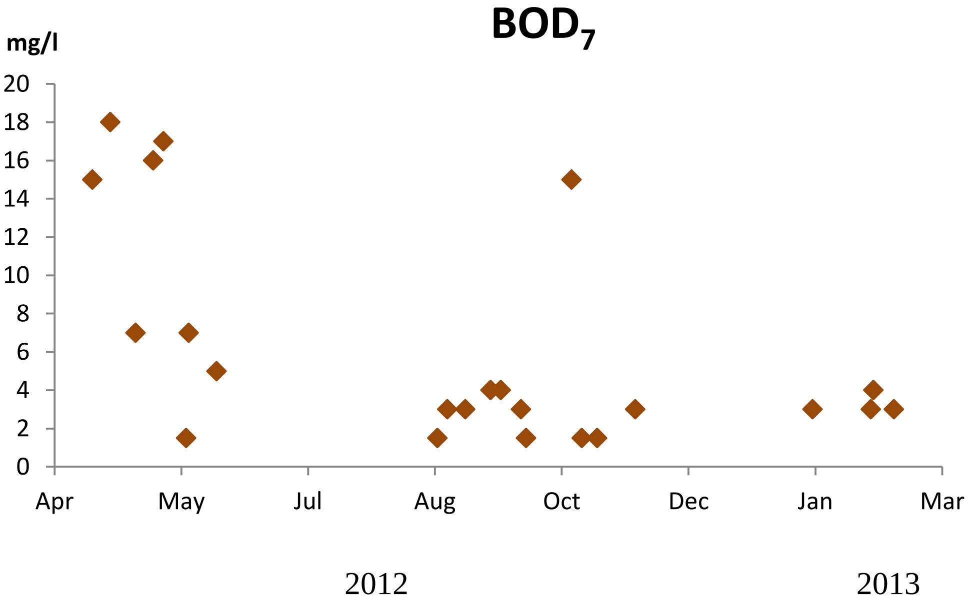

Figure 19 Results from Eurofins of BOD_7 concentration in effluent.

Most values lie under 10 mg/l. The level of reduction does not drop below 0.97 between 16th of April 2012 and 26th of February 2013, which is considerably high and can be seen in Appendix 1.

In figure 20 COD concentrations at Kungsberget are shown. There are no specifications from the Environmental Protection Division regarding limits for COD.

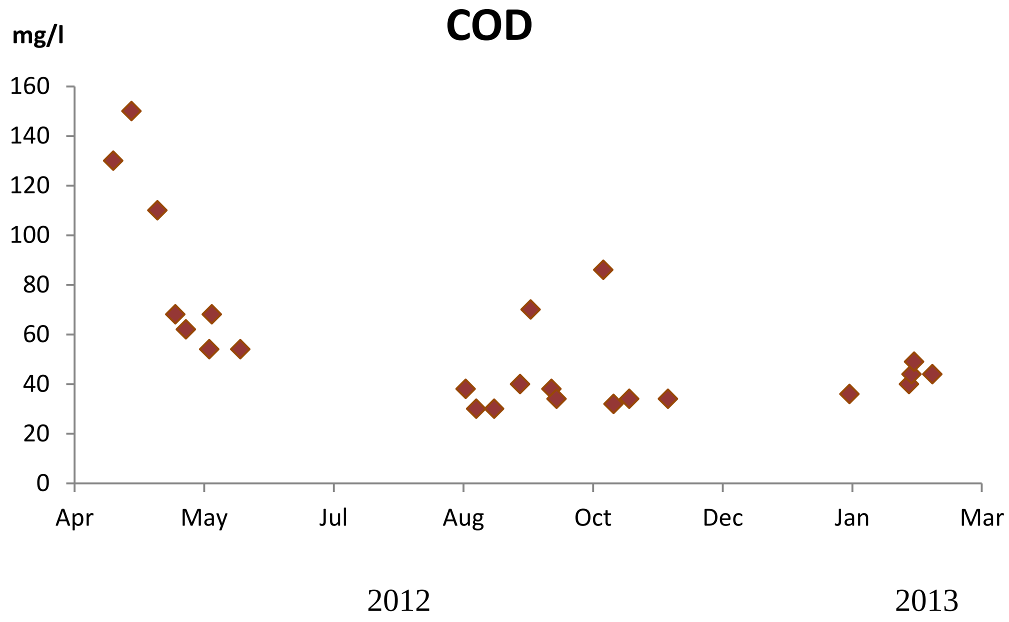

Figure 20 Results from Eurofins of COD concentration in effluent.

The level of reduction does not go under 0.84 between the 16th of April 2012 and the 26th of February 2013 which is shown in Appendix 1.

The relationship between BOD_5 and COD was described in section 3.6. It was stated that a 2:1 quota for COD:BOD_5 is considered acceptable whilst anything above that indicates the presence of poorly biodegradable substances. As the results obtained from Eurofins are all in BOD_7 a converting factor was used to convert BOD_7 to BOD_5.

$BOD_7 = 1{,}17 * BOD_5$ (Morling, 2013, pers. communication)

The situation in Kungsberget concerning COD:BOD is illustrated in figure 21.

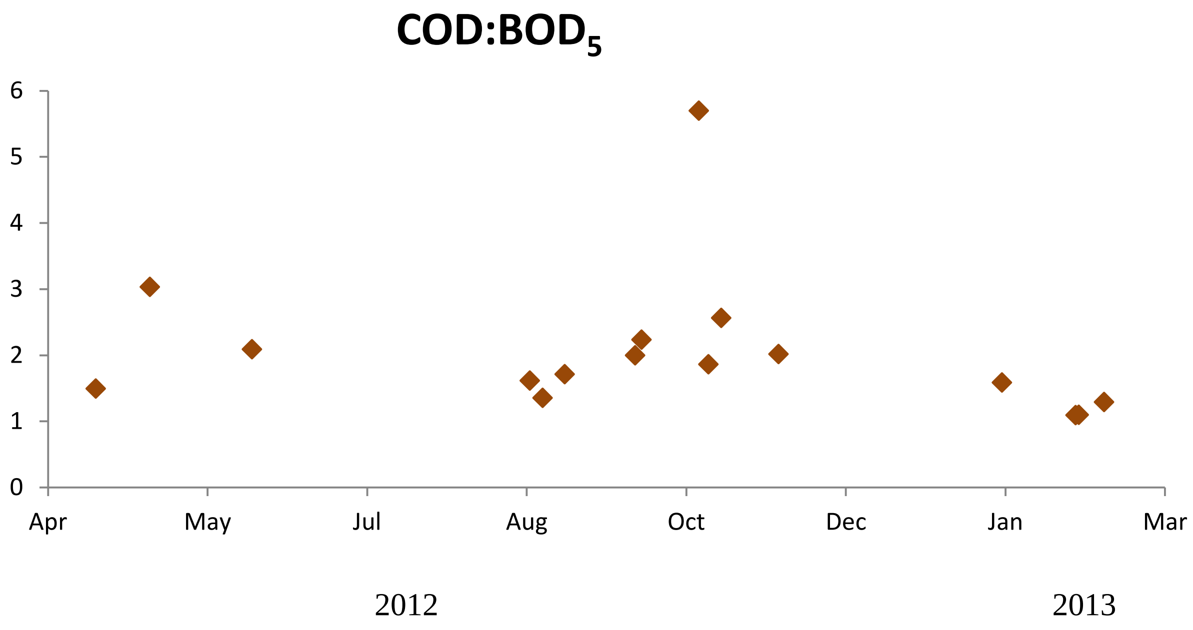

Figure 21 Results from Eurofin of the COD:BOD$_5$ quota.

In figure 21 it is clear that a fair amount of values lay below 2 showing that the degree of biodegradability in incoming water is fine. The fact that both COD and BOD$_7$ are highly reduced indicates that material is biodegradable. Again the result from 22/10-2012 stands out and can be considered an outlier.

In figure 22 TOC at Kungsberget is shown between April 2012 and January 2013. There are no specifications from the Environmental Protection Division regarding limits for TOC. It is less common to analyse TOC than BOD and COD at WWTPs.

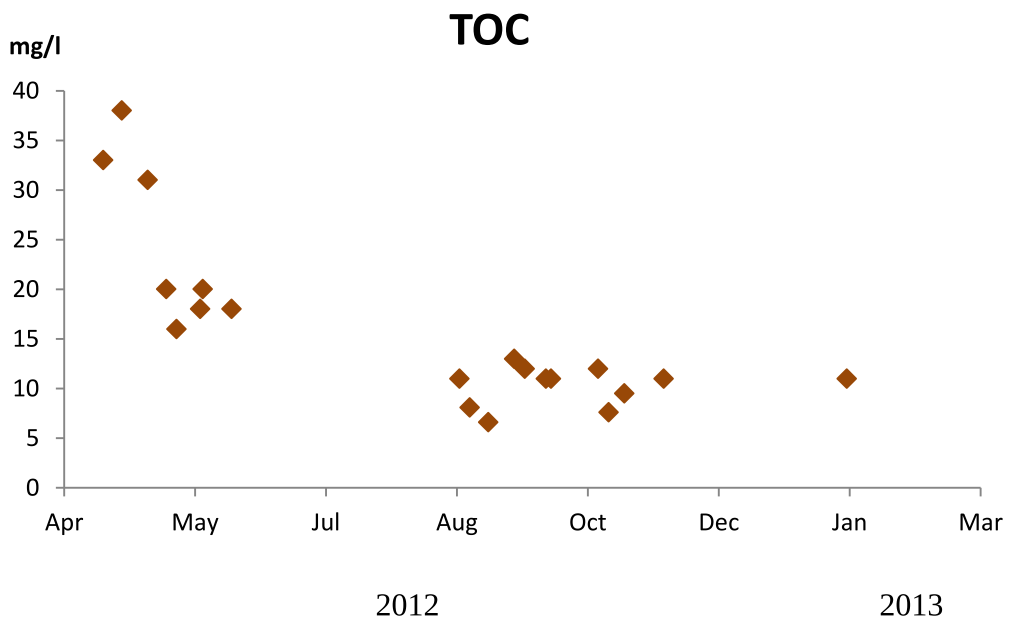

Figure 22 Results from Eurofin of TOC concentration in effluent.

A fairly stable level seems to have established itself from late August ranging between 6.6-13.0 mg/l from 30/8-2012 to 25/1-2013. A level below 15 mg/l can be considered acceptable (Morling, 2013, pers. communication).

In figure 23 concentrations of suspended solids at Kungsberget between 16th of April 2012 and 26th of February 2013 are shown. There are no specifications from the Environmental Protection Division regarding limits for suspended solids.

Figure 23 Results from Eurofins of concentration suspended solids in effluent.

A low effluent concentration is shown for the 4 samples taken in February. The five samples between 25th of January and 26th of February 2013 have a mean value of 3 mg/l whilst the values between the 30th of August and 1st of November 2012 have a mean value of 11 mg/l, disregarding 24/9 which is considered an outlier, 37 mg/l. A level below 20 mg/l is guaranteed by the supplier, table 3. The effluent concentrations may therefore be considered to be more than satisfactory. Comparing the reduction level for four values mentioned from 2012 with four values from 2013 an improvement is evident. The reduction level has changed from 0.87 to 0.99 which is shown in Appendix 1.

4.4 SOLIDS RETENTION TIME

The 1 litre sludge samples taken for the analyses of sludge volume were all taken during the first half of February and the sludge volume (SV) ranged between 330 and 400 ml. According to the operators at Kungsberget WWTP the sludge volume usually lies slightly below 300 ml.

In order to calculate solids retention time the concentration of suspended solids has been measured. Flow is based on volumes withdrawn during one day. Volume is calculated by recording water level changes during decanting and wasting and multiplying it by the tank bottom area. The inner diameter is approximately 4.76 m, radius 2.38 m. The volume is calculated as

$$V = 2.38^2 * \pi * \Delta\, h \tag{11}$$

$\Delta\, h$ is the difference in water level between when the tank is full and after decantering.

The simple way of calculating solid retention time was described in equation 2 and will be referred to as method 1. The water level in the only batch run the 20th of May 2013 reached 5.38 m before going into reaction phase and dropped to 5.11 m after wasting had taken place, $\frac{\Delta h_w}{\Delta t}$ 0.27 m/d. The calculation is done with equation 2 in section 2,

$$\theta = \frac{Total\ water\ depth\ in\ reactor\ (m)}{water\ level\ reduction\ after\ wasting\ (m/d)} = \frac{h_{tot}}{\frac{\Delta h_w}{\Delta t}} = \frac{5.38\ m}{0.27\ (m/d)} = 20d$$

This is consistent with the value displayed on the control panel. As the equation is based on the assumption of zero SS effluent concentration the result is not affected by the number of batches treated in a day.

The common way of calculating sludge retention time in continuous systems was described in equation 1 and will be referred to as method 2. The SS-concentrations needed in the equation have been measured and are shown in table 10.

$$\theta = \frac{A \cdot h_r \cdot SS_r}{A(\Delta h_w \cdot SS_w + \Delta h_{ef} \cdot SS_{ef})} = \frac{h_r \cdot SS_r}{\Delta h_w \cdot SS_w + \Delta h_{ef} \cdot SS_{ef}}$$

A	Bottom area of the tank
h_r	Water level when the tank is filled
Δh_w	Difference in water level after wasting
Δh_{ef}	Difference in water level after decanting

Table 10 Measured concentrations of suspended solids 20/5-2013.

$\boldsymbol{\theta}$	**Solids retention time**	**Value**	**Unit**
$\boldsymbol{SS_r}$	Suspended solids in reactor	2.5	kg/ m^3
$\boldsymbol{SS_w}^*$	Suspended solids in waste sludge	2.5	kg/ m^3
$\boldsymbol{SS_{ef}}$	Suspended solids in effluent	0.1	kg/ m^3

*SS_w equals SS_r as sludge is withdrawn during the mixing phase.

SS_{ef} is considerably high and excluding it, as in equation 2, therefore results in a rough approximation. In table 11 withdrawal (wasting + decanting) is presented based on the number of batches. Calculations are based on 0.71 m/d wasting irrespective to the number of batches treated in a day. If more than one batch is treated the 0.71 m that is withdrawn during wasting in the first batch is instead withdrawn as effluent.

Table 11 Changes in water level due to wasting and decanting based on 1, 2 or 3 treated batches in a day.

Number of batches	**Wasting $\Delta h_w / \Delta t$ [m/d]**	**Decanting $\Delta h_{ef} / \Delta t$ [m/d]**	**Total decanting [m/d]**
1	0.27	0.71	0.98
2	0.27	0.27+2*0.71	1.69
3	0.27	0.27+3*0.71	2.4

Equation 1 gives θ_1, θ_2, θ_3, for 1, 2 and 3 batches as

$\theta_1 = 18.03\ d$

$\theta_2 = 15.94\ d$

$\theta_3 = 14.70\ d$

After estimating a theoretical solid retentions time the three scenarios described in the method section can be evaluated in order to withhold an aerated sludge retention time.

Scenario 1
In scenario 1 the daily time for aeration is 31.6 % which means the aerated solid retention time is

Method 1
$20d * 0.316 = 6.3\ d$

Method 2
$18.03 * 0.316 = 5.70\ d$

Scenario 2
In scenario 2 the daily time for aeration is 38.2 % which means the aerated solid retention time is

Method 1
$20d * 0.382 = 7.6\ d$

Method 2
$15.94 * 0.382 = 6.09\ d$

Scenario 3
In scenario 3 the daily time for aeration is 44.8 % which means the aerated solid retention time is

Method 1
$20d * 0.448 = 9.0\ d$

Method 2

$14.70 * 0.448 = 6.59\ d$

All three scenarios show an aerated sludge retention time that is considerably lower than 20 days which is what the control panel shows.

5 DISCUSSION

Several different parameters have been analysed and operating methods have been described and are to be discussed. The parameters mentioned in the result section will be brought up and potential changes and improvements suggested.

It can be interesting to look at common influent concentrations in table 12 before interpreting the results from Kungsberget. The values in table 12 have been published by the Environmental protection agency and are valid for WWTPs serving between 200-2000 pe.

Table 12 Common influent concentrations according to the Environmental protection agency (Naturvårdsverket, 2007).

	Common influent concentrations (mg/l)	**Kungsberget (mg/l)**
BOD_7	100-250	40-1400
P-tot	5-12	6-28
N-tot	20-40	50-180
SS	100-250	50-630
COD	250-600	110-1800

Kungsberget’s concentrations are in some cases far higher than the ones stated by the Environmental protection agency but this is not necessarily alarming. Kungsberget has a varied load which makes it hard to state ‘common’ values and it is therefore unfair to compare Kungsberget’s results with other common values, still it gives an idea and reference to work with. Firstly Naturvårdsverket’s values are based on conditions in small communities and not as in Kungsberget’s case, a ski-resort, which leads to fundamental differences. At Kungsberget most pipes are lead inside which minimizes inflowing groundwater. The influent therefore is more concentrated than what can be considered ‘normal’. Low leakage levels are of course positive as they minimize the amount of water that needs to be treated and also stops wastewater from being mixed with cold melt water during spring when the snow melts. It can also be interesting to compare quotas to see if ratios are similar. The BOD_7/P-tot quota is 100:5 according to Naturvårdsverket and at Kungsberget it varies between100:15 and100:2. This means that the phosphorous level sometimes is a lot higher in regards to BOD_7 than what is common and places greater strains on reduction.

5.1 PHOSPHOROUS IN WASTEWATER

The issue with which Kungsberget have most been struggling is that of high phosphorous concentration, and will therefore be attended to first. Phosphorous concentrations have been highly varied making the problem hard to address. The main way of removing phosphorous is through flocculation and attempts have been made to lower concentrations by increasing chemical dosage. However, as mentioned earlier, there is a solution that does not entail adding more chemicals, biological phosphorous removal. To achieve biological phosphorous removal on a large scale certain conditions are needed and the question is if the method is applicable in this case. The high BOD_7/P-tot quota shows there is a lack of VFA's (volatile fatty acids) to remove enough phosphorous. This can be solved by adding an external carbon source but the idea is unappealing as one of the positive aspects of biological phosphorous removal is that it saves money due to reduced chemical expenses. Reduced expenses would be cut out if money had to be put on VFA's instead. Temperature may most certainly be an issue as it may drop during persistent cold periods. Even if the tank is isolated and the water temperature can be held at 10-15 °C during the winter season when outside temperatures drop below zero it can be difficult to maintain an adequate purification level. It should be remembered that 10 °C is not optimal for bio-P bacteria even if the process, according to the study carried out at Dokka WWTP, can be performed down to 4-5 °C. A positive aspect is that winter time is the high season meaning higher load and less storage time which gives the water less chance to cool off. The air pumped in is a source of heat and also helps to stop the temperature from dropping. One possible solution to the cold temperature problem is to add heated air at times when temperatures get critical. This would of course be energy consuming and would have to be weighed against the option of adding more chemicals. To examine the bio-P activity analyses would have to be carried out at different stages of the treatment cycle. The first step in the reaction phase is anaerobic and is the stage in which phosphorous concentrations increase due to released phosphate from bio-P bacteria. It would be necessary to measure phosphorous levels before the treatment cycle, after anaerobic conditions, after aerobic conditions and finally after the settlement phase, to see how the content varies throughout the process.

The fact that Kungsberget have not been able to reduce phosphorous to an adequate level speaks against introducing bio-P as biological processes are less reliable. However, biological phosphorous removal would not have to rule out chemicals completely but could instead minimize usage. One option is to add a flocculent before the disc-filter to lower concentrations further if needed. On-line control could help indicate phosphorous levels before decanting and regulate possible chemical dosage before the disc-filter as an alternative to adding chemicals to the tank. If this is to be done filters with smaller pore size need to be fitted to stop flocks from escaping. Installing a phosphorous analyzer may be costly but very convenient in order to keep track of concentrations. The majority of phosphorous in wastewater is either solid or bound to particles which make the suspended solid concentration a good indicator of the amount of phosphorous at hand. The relationship between phosphorous and suspended solids (SS) is more or less constant which means it is possible to measure SS instead of phosphorous and yet obtain an idea of the phosphorous concentration. An important aspect to this is that SS- concentration sensors are remarkably cheaper than phosphorous analyzers and therefore makes this an attractive alternative. If biological phosphorous removal is not adapted the present situation with chemical flocculation needs to be improved. There are no data showing the direct effect of increasing chemical dosage but table 5 shows that phosphorous concentrations are reduced as a result of increased chemical dosage in some cases. In other cases no changes have been established when more chemicals are added. The reason for this is unknown but one possible explanation is that chemicals are not mixed in quick enough when dosage time exceeds 12 min. To obtain an effective flocculation, chemicals need to be mixed in as quickly as possible. Chemicals are added at the top of the tank which may hinder a uniform spread. One option is to dose chemicals at two or more locations simultaneously to speed up spreading. Another option is to install mixers that facilitate spreading.

5.2 NITROGEN IN WASTEWATER

There are no requirements for nitrogen at this point in time but stricter regulations can be expected in the future. Effluent nitrogen concentrations have slowly gone down since the facility was brought into use. Comparing Naturvårdsverket's value for common influent concentrations, 20-40 mg/l, with Kungsbergets, 50-180 mg/l, it is clear that Kungsberget has a more concentrated load to deal with. This again, as explained above, is partly due to low dilution as a result of minimal leakage. The fact that Kungsberget mainly have daily visitors who produce wastewater through visiting the toilet rather than consuming water through cooking or showering also contributes to the wastewater being more concentrated. In order to reduce nitrogen further, more work needs to be put into studying nitrification and denitrification in detail to spot possible bottlenecks. At the moment there is no way of knowing if further reduction is possible and if it is what potentially may be stopping processes. To do a thorough investigation, sampling needs to be taken at various stages throughout the treatment process. One possible sampling scheme is described in table 13.

Table 13 Sampling scheme for analysing nitrogen removal during wastewater treatment at Kungsbergets WWTP.

Occasion	**Parameter**	**Purpose**
Influent **(Before water enters the tank)**	Total nitrogen Organic nitrogen NH_4^+ NO_3^-	Get reference values.
Before the anaerobic reaction phase. **(After mix and fill)**	Total nitrogen Organic nitrogen NH_4^+ NO_3^-	See to what extent ammonification, nitrification and denitrification occur during mix and fill.[1]
Before the aerobic phase. **(After anaerobic phase)**	Total nitrogen NH_4^+ NO_3^-	See if denitrification is proceeding.[2]
Before Settlement **(After aerobic phase)**	Total nitrogen NO_3^-	See if nitrification is proceeding.[3]
Effluent **(Before decanting)**	Total nitrogen Organic nitrogen NH_4^+ NO_3^-	Get an overview of the total degree of reduction.[4]

[1] Is it true that most of the denitrification occurs during mix and fill? Here it is possible to analyse whether the right amount of oxygen is added during this phase. Maybe it would be possible to lower aeration time and achieve more denitrification without jeopardizing the bacteria culture.

[2] If nitrate levels have been reduced and the total nitrogen concentration has gone down, denitrification has been successful. If instead, nitrate levels have not been reduced as much as expected it can be wise to measure ammonium concentrations to see that nitrification has not occurred and contributed to more nitrate. This is of course unlikely as nitrification needs oxygen to proceed. If there is not a sufficient amount of carbon denitrification is inhibited and it may therefore be wise to measure BOD to find out whether this is preventing the reaction from taking place.

[3] Compare nitrate level with the level before aeration to see if nitrification has been successful. Also measure total nitrogen concentration in the unlikely event of denitrification during aerated conditions.

[4] Analyse how much nitrogen has been removed in total and draw conclusions about the processes from different nitrogen fractions. If there is a high concentration of organic nitrogen it indicates that further reduction is possible but that ammonification is not working. If nitrate concentrations are high it could be a sign of non-functioning denitrification and if they are low, non-functioning ammonification or nitrification may instead be the problem.

There are a lot of aspects to take into consideration at Kungsberget that have not been attended to earlier. The fact that wastewater travels short distances before entering the plant gives less time for ammonification to take place and therefore more ammonification needs to occur at the WWTP before nitrification/denitrification can proceed. This is most likely not a problem as time is given both in the storage tank and during the fill and mix stage but ammonium levels should nevertheless be measured.

The influent COD:N-tot relationship in figure 18 is sufficient for denitrification but as there are no measurements from after the fill and mix phase it is impossible to know whether there is enough carbon left to continue denitrification during the anaerobic reaction phase.

Nitrifiers are most sensitive and if temperatures drop below 10 degrees a bottleneck situation will most definitely arise. Keeping constant track of temperature gives the opportunity to trace potential unexplainable changes in the results. Maybe decreased reduction levels can be prohibited by extending reaction time. Another possibility is to set up a solution where heat is provided to the reactor from the small thermal power plant next door. pH is also an important parameter to keep an eye on in regards to nitrification. If nitrification is working fine it may lower pH to a level that is self-inhibiting. This can also be prohibited through continuous measurements of alkalinity by on-line measuring and adding substances to raise alkalinity if needed.

Analysing nitrogen gives a hint to whether a sufficient amount of oxygen is added. During low season water resides in the tank for longer before entering a treatment cycle. This means that there is more time for processes to occur during the mix and fill phase. It has earlier been suggested that most denitrification arises during this phase and it is therefore reasonable to presume that if water is left too long, carbon sources will run out before treatment starts. If NO_3^- is measured during mix and fill it would give an idea to how much ammonium is being nitrified and if nitrate concentrations are high maybe aeration time during the mix and fill phase can be reduced. In regards to limiting oxygen consumption it is also wise to measure nitrate concentrations after the anaerobic phase. If there still is nitrate available that has not been denitrified one possible reason may be the lack of organic matter. A decision ought to be made to whether more carbon should be added to reduce nitrogen further or if instead aeration time can be cut down to save energy that is otherwise wasted on converting ammonium to nitrate that later is let out to the recipient anyway. As mentioned in section 3.6 BOD has a very high level of reduction which strengthens the hypotheses that there may be a lack of organic matter. The best way of controlling oxygen levels is through on-line control and it should therefore be considered. It may even be so that reduced aeration time during mix and fill could promote bio-P bacteria that are dependent on anaerobic conditions to take up VFA’s. Longer periods of anaerobic conditions would give bio-P bacteria more time to grow. Unfortunately there is no data over oxygen levels so it isn’t possible to analyse whether there is a connection between oxygen and phosphorous levels.

5.3 BOD/COD/TOC/SS

BOD_7 meet the effluent concentration requirements of 10 mg/l for the most part and notably during February 2013. It impresses that BOD_7 levels are reduced to such an extent even though influent concentrations are way above what the Environmental protection agency states as ‘common’. In figure 21 where the COD:BOD relationship was illustrated it was somewhat made clear that incoming carbon sources are fairly biodegradable. The amount of suspended solids is also fairly low which is positive. The fact that removal of organic matter has been successful will facilitate a possible future introduction of UV or chlorination treatment. The future will most likely bring stricter regulations and in that case Kungsberget has an advantage. High levels of organic particles hampers both UV and chlorination treatment. In the case with UV, existing particles in the water block rays from reaching bacteria and viruses which impairs disinfection. As for chlorination there is a risk of chlorinated organic particles being generated which may be both carcinogenic and harmful to the environment. Kungsberget are on the right track.

5.4 FLOW AND OPERATIONAL ROUTINES

Seasonal loading cannot be ignored when defining operating routines as it has been in the past. Modifications should be done at least twice a year to adjust to prevailing conditions. The two main changes that can be altered operationally are sludge retention time and aeration. During low season a SRT is needed to prevent wash-out. It is not possible to say exactly how many days are appropriate for sludge retention during high and low season but this can be tried out. Over and above seasonal fluctuations Kungsberget experience weekly variation with visitor-peeks during weekends. This is not optimal but could to some extent be regulated via storage to achieve a more stable flow. It was illustrated in figure 12 that the summer time flow is more stable than the winter flow. It all comes down to the fact that it is more difficult to keep an even flow when more water needs to be treated. The 60 litre tank the raw water passes through before ending up in the storage tank is mainly there as a back-up if the SBR facility for some reason is out of order or needs maintenance but could also to some degree be used to even out flow. Practicing storage and controlling flow is also a way to handle potential chock situations in raw water composition and quantity. The blend becomes more uniform if water is allowed to mix thoroughly before entering the tank preventing peak loads. Aeration time also needs to be tested manually to achieve appropriate settings. As mentioned earlier it may be possible to reduce aeration time during low season. Another solution to the challenge with varying loads is installing another smaller tank that can be used during low season. This way it would be easier to maintain a bacteria culture even during low flow and the tank would also be convenient as a back-up solution. A swap from the bigger to the smaller tank could easily be carried out by leading water to the smaller tank instead of the big one and inoculating bacteria. Tentatively the seasonal swaps should be done in connection to the opening and closing of the lift system as visitors mainly come to ski. A third though regarding seasonal challenges is investigating if there are people with summer houses in the area with outhouses or separating toilets that they wish to empty. Adding more faecal and urine when the flow is low would help maintain a stable bacteria culture throughout the year.

The main challenge is to keep up a good bacteria culture and possibly this can be eased by introducing carrier media. Carrier media would provide a larger area for bacteria to grow on and aid during times when substrate is limited. Bacteria that would otherwise perhaps have been washed out could be given a chance to grow. The potential of carrier media increasing phosphorous by favouring bio-P bacteria supports the idea.

5.5 SOLID RETENTION TIME

At Kungsberget wasting occurs during the aerobic phase which can be questioned. At that point the solution is uniform and not as concentrated as after settling has taken place. To avoid handling unnecessary amounts of water it is more convenient withdrawing sludge after the decanting is done. One reason to why wasting is carried out during the aerobic phase may be the fact that it simplifies calculations of sludge retention time. If sludge is withdrawn during aeration the suspended solid concentration is more likely to be homogeneous in the tank which is one of the three criteria that needs to be fulfilled if the simplified sludge retention time equation is to be used (equation 2). The result from equation 2 show that the sludge retention time matches the retention time displayed on the control panel, 20 days. This equation is based on the assumption that SS-effluent concentration is zero and that the number of batches treated is therefore irrelevant for the sludge retention time which is not the case in Kungsberget. Neither does it represent the aerated SRT. The three scenarios analysed in section 4.4 shows that SRT increases with the number of batches treated during a day and that the aerated sludge retention time is considerably lower than 20 days. Aerated SRT ranges between approximately 5.7 and 6.6 days which is not necessarily enough to satisfy nitrifying bacteria. Sludge withdrawal is controlled by setting a SRT that does not take aeration into consideration which is important to have in mind as nitrifying bacteria depend on the aerated SRT.

According to Svenskt vatten (2010) sludge volume needs to be below 300 ml to be categorized or interpreted. In the case with Kungsberget the level ranges from 330 to 400 ml and the samples therefore need to be diluted before analysed.

5.6 LIABILITY

Measuring errors are not to be forgotten when analysing data and drawing conclusions. BOD is the parameter with the highest level of uncertainty, 30%, and yet there are set requirements stating that the effluent level should be below 10 mg BOD_7/l. In practice this means that the measured concentration can reach up to 13 mg BOD_7/l before exceeding limits. As for phosphorous the uncertainty is 10 % which means that measured effluent concentrations up to 0.33 mg/l are acceptable. It should also be remembered that these uncertainty percentages only include analysing errors at laboratory and not errors connected to the time of sampling. There are two main operators at Kungsberget that share the sampling duty and none of them have received any training in how the sampling should be carried out. It is therefore possible that the samples are somewhat contaminated and that they may not only be performed in an incorrect manner but also differently depending on who is sampling. This source of error should be added to the uncertainty presented from the laboratory, however, it is hard to estimate how much sampling errors contribute. Another issue connected to this is routines. To minimize errors it is wise to follow routines. If it is not possible to have the same person taking samples it can at least be seen to that sampling is performed in the same way and at the same time every day or at every occasion. Samples also need to be taken regularly to spot changes and track down trends.

6 CONCLUSIONS

The treatment process at Kungsberget's WWTP works relatively well apart from the past problems with high phosphorous concentrations. Both the phosphorous and BOD reduction is high and even if nitrification seems to be somewhat limited the nitrogen reduction overall is still satisfactory. The current solid retention time may be limiting nitrification.

After having investigated Kungsberget's wastewater plant a number of possible actions have emerged to improve the treatment process,

- A suitable solid retention time needs to be tried out for summer and winter conditions. The current SRT may be limiting nitrification. It is also suggested that the aerated SRT is taken into account in the future when defining sludge withdrawal.
- Measuring oxygen levels is recommended to get an idea of the concentration in order to adapt aeration time more effective.
- The 60 m^3 tank can be used more efficiently to even out fluctuating flow.
- Phosphorous and BOD reduction is high even if not always sufficient.
- Introduction of carrier media would most likely improve treatment results.

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8 APPENDIX 1

8.1 DIMENSIONING

Data withheld for designing the plant and tuning process parameters in the biological and chemical stages.

Variable	**Dimension**	**Unit**
Hydraulic load		
Dimensioning daily flow	100	m^3/d
Maximum daily flow	125	m^3/d
Maximum inlet pumping volume	33	m^3/batch
Treatment		
Inflow pumping	40	min
Reaction	180-240	min
Sedimentation	90-120	min
Outflow	40	min
Data SBR-unit		
Number of batches per day	3	times
Air added per time unit	150	Nm^3/h
Sludge		
Sludge concentration in reactor	4.0	kg SS/m^3
Sludge load	0.12	kg BOD_5/kg SS
Solid retentions time	12	days
Sludge production	130	kg SS/d

8.2 BOD

Date	2012-04-16	2012-06-04	2012-08-30	2012-09-03	2012-09-10	2012-09-20	2012-10-02	2012-10-04	2012-10-22
BOD_7 effluent	15	5	1,5	3	3	4	3	1.5	15
BOD_7 inflow	630	180	180	120	180		120	130	36
Red	**0.976**	**0.972**	**0.991**	**0.975**	**0.983**		**0.975**	**0.988**	**0.583**

Cont.

Date	2012-10-25	2012-11-01	2012-11-16	2013-01-25	2013-02-17	2013-02-18	2013-02-26
BOD_7 effluent	1.5	1.5	3	3	3	4	3
BOD_7 inflow	170	120	140	490	750	1400	590
Red	**0.991**	**0.988**	**0.979**	**0.994**	**0.996**	**0.997**	**0.995**

8.3 COD/SS

Date	2012-04-16	2012-06-04	2012-08-30	2012-09-03	2012-09-10	2012-09-20	2012-10-02	2012-10-04	2012-10-22	2012-10-25
COD effluent	130	54	38	30	30	40	38	34	86	32
COD inflow	1100	440	340	190	360	430	280	340	240	370
Red	**0.882**	**0.877**	**0.888**	**0.842**	**0.917**	**0.907**	**0.864**	**0.900**	**0.642**	**0.914**

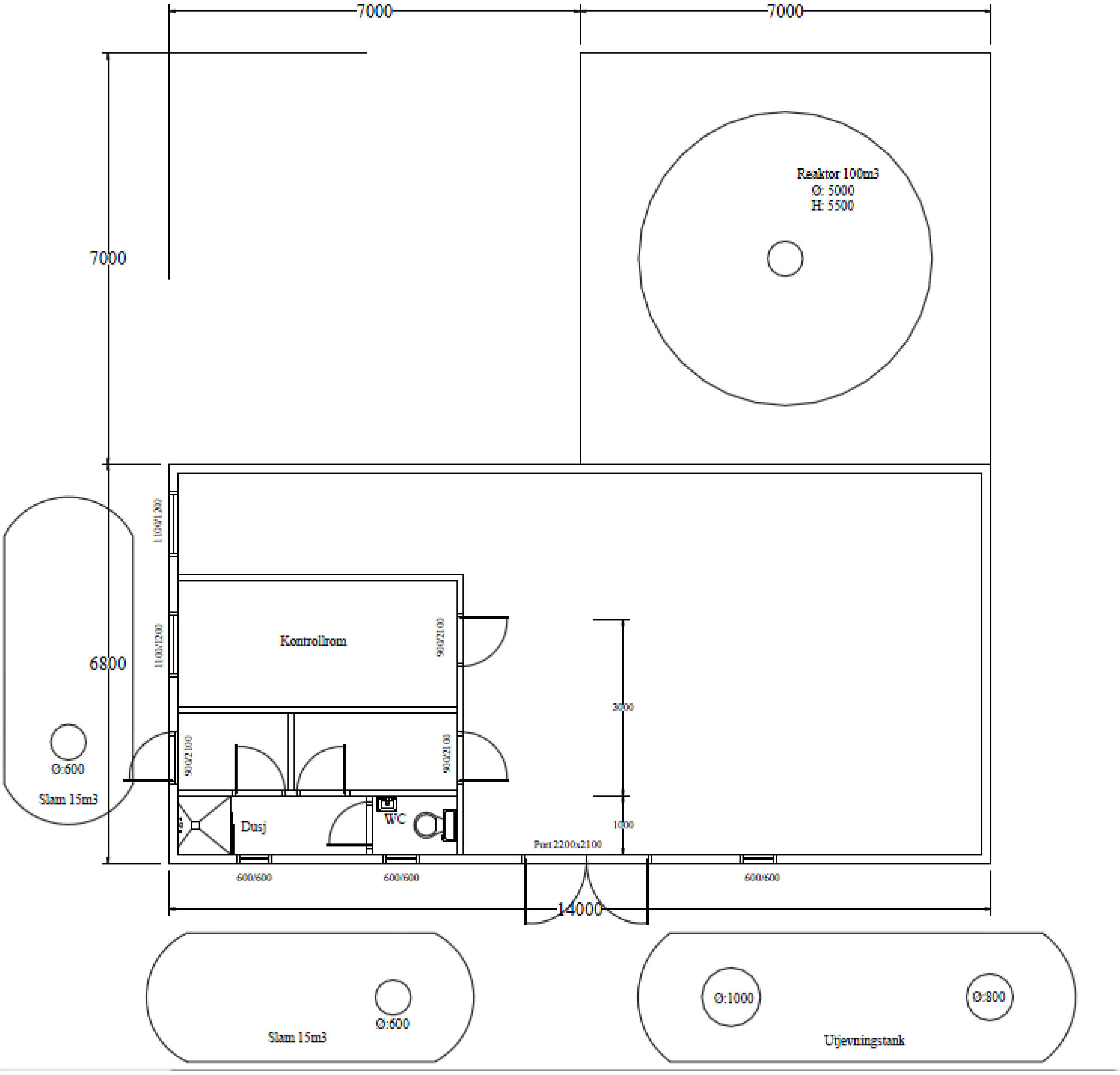
Cont.

Date	2012-11-01	2012-11-16	2013-01-25	2013-02-17	2013-02-18	2013-02-19	2013-02-26
COD effluent	34	34	36	40	44	49	44
COD inflow	360	330	910	960	1800	1100	890
Red	**0.906**	**0.897**	**0.960**	**0.958**	**0.976**	**0.955**	**0.951**

Date	2012-08-30	2012-09-03	2012-10-02	2012-10-04	2013-02-17	2013-02-18	2013-02-19	2013-02-26
SS effluent	13	7.6	13	9.4	2.8	2.8	3.1	3.6
SS inflow	110	160	64	58	630	480	320	190
Red	**0.882**	**0.953**	**0.797**	**0.838**	**0.996**	**0.994**	**0.990**	**0.981**

8.4 DESIGN OF KUNGSBERGET'S WWTP

Drawing used with permission from Kungsberget's WWTP.



8.5 FLOW DIAGRAM OF KUNGSBERGET'S WWTP