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Long Term Performance of an Urban Decentralised Greywater Treatment System in Oslo, Norway

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Abstract

Source separation of wastewater keeps the nutrient-rich fraction from the toilet (blackwater) separated from the remaining main volume (greywater). This separation optimises the recycling of both nutrients and water. A pilot system for decentralised greywater treatment was constructed in 2001 in a courtyard at Klosterenga (KL) in Oslo, Norway, which serves an apartment building of 100 persons. The system consists of a septic tank followed by pre-treatment vertical flow aerobic biofilters and a sub-surface horizontal flow constructed wetland. The scope of this thesis was to investigate the long-term treatment performance of the system.

Water samples from the influent (i.e. septic tank effluent) and effluent were analysed with regards to: phosphorus, orthophosphate, nitrogen, nitrate, ammonia, pH, conductivity and indicator bacteria. The average phosphorus effluent was 0,27 mg P/l, which is substantially below the 1 mg P/l guideline. The BOD treatment efficiency was as high as 98 % and resulted in an average effluent of less than 5 mg O/l. Average total nitrogen effluent concentration was 2,2 mg N/l and thus achieves drinking water quality with respect to nitrogen. All parameters fulfilled discharge limits from the time of construction until today. There were no significant change in the effluent from 2001-2013 compared to 2014, except for pH and phosphorus. This is also as expected when the filter material is functioning as intended, and it was calculated that the wetland filter would have a total service time of 45 years with regards to phosphorus removal. The highest registered amount of bacteria in the effluent was 19 E. coli per 100 ml which means that the water fulfils the Norwegian requirements for good bathing water quality (<100 per 100ml), and that the effluent can be re-used for irrigation of edible crops.

When the KL system was compared to the average effluent concentrations of other large-scale constructed wetlands systems, it performed better with regards to all of the parameters, and it also had higher treatment efficiencies with regards to BOD and nitrogen. An investigation of the plans and policies regarding wastewater in Oslo revealed that expanding the use of systems as KL can contribute to achieve the current goals, and that the KL system is becoming increasingly relevant. An economic estimate indicates that treating greywater in systems such as KL would be 65% cheaper than using the centralised system of Oslo municipality. For KL and the centralised system the final recipient is in a state where nutrient loading should be reduced, and a substantial (70-95 %) reduction of this loading, per person, can be achieved by source separation and treating the greywater at KL.

The system at KL shows how decentralised sanitation solutions can offer cross-sectorial benefits, and thus can contribute to making urban areas more sustainable. The constructed wetland system not only treats wastewater, it contributes to urban greening, increased environmental awareness, reduced pollution, recycling of resources – and it can be easily integrated with existing centralised infrastructure. Overall the system demonstrates that successful greywater treatment by constructed wetlands is possible in urban settings where space is limited, and that a high effluent quality can be achieved, even after more than a decade of operation.

Preface

This thesis is submitted as a part of the requirements for the degree Master of Science in Water- and Environmental Technology (Master i Teknologi, Vann- og Miljøteknikk) at the Department of Mathematical Science and Technology, Faculty of Environmental Science and Technology, at the Norwegian University of Life Sciences. The thesis has been written with a supervisor from the Department of Environmental Sciences.

The process of this thesis has been valuable experience, with many new insights gained. Despite the hard work it has also been a pleasure to be allowed to investigate such an interesting topic that combines three fields I am passionate about: urban solutions, cyclic thinking and sanitation. This thesis has also been a practice in priorities and allocation of time. Technical problems delayed the process many times and the final data were retrieved approximately only a month before deadline – but when all the results where there the pieces finally fell into place. Topics as economy, total environmental consequences and politics are also dealt with, because it was relevant, interesting and contributed to the bigger picture. However, as my time and competence was limited, this thesis creates first and foremost an overview over these aspects, and can serve as inspiration for further investigations. At least it truly does so for me.

I would like to thank my supervisor, Petter D. Jenssen, for being an excellent source of inspiration and for giving valuable input throughout the process.

Also thank to Tor Nilsen and Martin at Gamle Oslo Servicesentral for information and technical help in the field, Landscape architects at Grindaker and Askild H. Nilsen for information on the system, Karen Refsgård for help with the economic considerations, Faustine D. Mironga for support and guidance in the lab, Tine W. Fjeldstad and Lukas van der Horst for proofreading some of the text, and my family and friends for supporting me.

Finally, I would like to thank Gamle Oslo Servicesentral for sponsoring the lab equipment for analysing the water samples,

Ås. 15th of August 2014

Marie Rødsten Sagen

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Abbreviations

BOD	Biochemical Oxygen Demand
KL	Klosterenga
LWA	Lightweight Aggregate
WWTP	Waste Water Treatment Plant

Only in paragraph 4.4.2:

OCS	Oslo Municipality centralised wastewater system
KLD	Klosterenga decentralised greywater system

1 Introduction

The list of environmental challenges humanity are facing is long: climate change, biodiversity loss, and depletion of water, minerals and land (Agudelo-Vera et al. 2012; UNEP 2007). Often the cause of these challenges is the human linear systems that create too high a concentration of something in the wrong place, as nutrients in a lake or CO_2 in the atmosphere. The challenges call for a change of mindset, and a need to create sustainable solutions. Humans have to work together with nature, to learn from its complex systems and – instead of linear – apply cyclic, integrated approaches (Agudelo-Vera et al. 2012; Esrey 2001; UNEP 2007).

Because of population growth, combined with increasing urbanization, more that 50 % of the world's population today live in cities (WHO 2013). The numbers are steadily increasing, and with an estimate of 70 % of the world's population living in urban areas in 2050 (WHO 2013), solutions for cities are needed for a sustainable future (Nichols & Kockelman 2014). As cities consist of densities of people, it is important to use this density as an advantage. When people act together in densities, energy and resources can be saved, for example through shared housing and public transportation (Nichols & Kockelman 2014).

Wastewater is an especially important and interesting part of cities, not only because of its irreplaceable functionality, but also since it is an area with urgent need of innovation. The wastewater sector has more or less remained unchanged for decades, partially because it is invisible infrastructure and partially because it is an area with many taboos. At the same time, the wastewater sector has great potentials for saving both water and energy, in addition to the potential to recycle valuable nutrients (Cordell et al. 2009; Esrey 2001; Langergraber & Muellegger 2005).

Human feces and urine contains large amounts of phosphorus and nitrogen, the same main nutrients as in fertilizers (Benetto et al. 2009). The paradox is that while the world's reserves of phosphorus are about to run out, large amounts of energy and resources are used both in the production of fertilizers, and to treat nitrogen and phosphorus as pollutants in wastewater treatment plants (Cordell et al. 2009). The traditional centralized wastewater treatment plants also demands great and complex piped wastewater distribution systems, which are both expensive and difficult to maintain (Esrey 2001). This paradox calls for developing solutions where an increasing degree of nutrients from human excreta is recycled. (Cordell et al. 2009; Esrey 2001; Langergraber & Muellegger 2005). Today's water-based, centralized sewage systems mixes *blackwater* (water that comes out of toilets) with *greywater* (water from the remaining household). To optimise recycling the nutrients should be as concentrated as possible, and it is therefore desirable to source separate wastewater; that is handle the black- and greywater separately from the source (Esrey 2001).

A pilot decentralized greywater treatment system in a courtyard in Klosterenga (KL), Oslo, treats water from a 100 person apartment complex by a pre-treatment vertical flow aerobic biofilter followed by a subsurface horizontal flow constructed wetland. The system was one of the first of this size and for this density of people, but similar systems has also been constructed in Norway, Germany and Malaysia (Jenssen & Vråle 2003; OtterWasser GmbH 2009).

KL was built in 2001 and the system has shown highly satisfactory effluent values, meeting the European standards of swimming water (Jenssen et al. 2003), but has not been properly investigated since 2008 (Vråle 2008).

The scope of this thesis is to:

1. Study the long term treatment performance of the constructed wetland with regards to: phosphorus, nitrogen, organic matter and indicator bacteria.

2. Compare the results to other large-scale constructed wetlands treating greywater.

3. View the experience at Klosterenga in connection to current plans and policies for the wastewater situation in Oslo.

2 Theory: Constructed Wetlands and Decentralized Greywater Treatment in Urban Areas

This chapter is a summary of a literature study of the theory on greywater, constructed wetlands for wastewater treatment and generally on decentralized greywater treatment in urban areas.

2.1 Greywater

In a household, the wastewater from all other sources that the toilet is called *greywater*. In some countries greywater also excludes water originating from kitchens. An estimate of different fractions of wastewater and their use in a typical Norwegian household is shown in Figure 1.

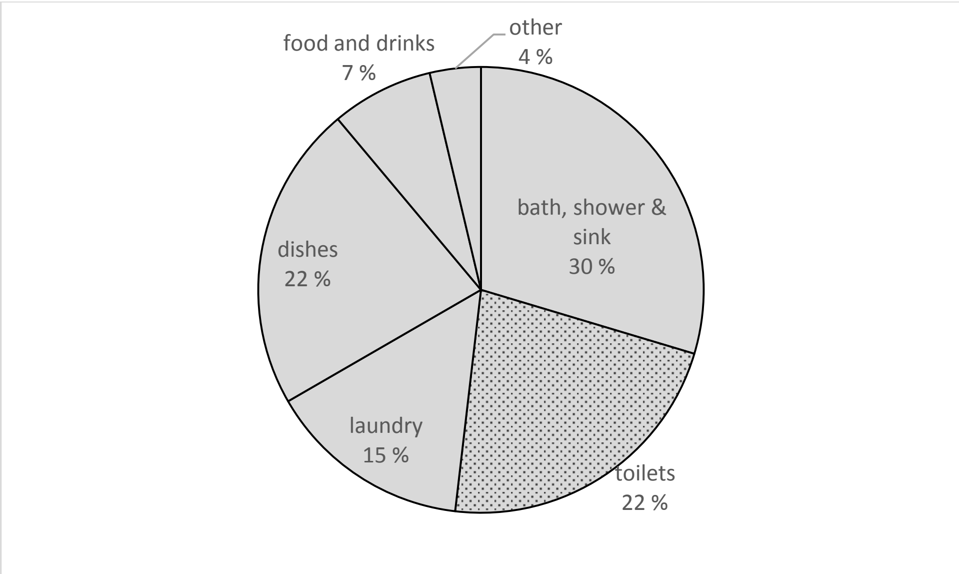

Figure 1, Norwegian estimated wastewater production for a household, and distribution by source. (Ødegaard et al. 2012)

Total water consumption per person per day in Norway is estimated to be 135 l (Ødegaard et al. 2012). Other sources also report Norwegian consumption to be 130-150 l/p/d (Norsk Vann 2009), and 95-115 l/p/d (Yri et al. 2007). A Swedish investigations estimates 100 l/p/day (Vinneras et al. 2006). According to the figure, the grey water production (88 %) therefore is estimated to 105 l/p/d, this is well in accordance with the literature and is the value that will be used throughout this paper.

Greywater composition and concentrations highly depend on the habits of the members of the households. Lifestyle, consumer choices, age distribution and water use tendencies are all factors that affect the the greywater quality and quantity (Donner et al. 2010). Dilution also matters, as higher water consumption will lead to lower concentrations. If kitchen water is included or not is also a determining factor. The most important pollutant parameters of wastewater, which are also the constituents measured in conventional treatment plants, are: Biochemical Oxygen Demand (BOD), bacteria and the nutrients phosphorus and nitrogen. Often orthophosphate and ammonia and nitrogen is aslo included. These parameters are also the ones that it will be focuses on in this thesis.

When describing the organic matter fraction in wastewater throughout this thesis, BOD values are BOD5 values, if nothing else is noted. In raw wastewater it is estimated that 70-80 % of the phosphorus is orthophosphate, and that most of the nitrogen is on the form of ammonia (Storhaug 2011). Greywater contains relatively few nutrients but up to 50 % of the organic matter. (Jenssen & Vråle 2003). The concentrations of bacteria are low, but mostly too high to meet the swimming water quality standards. The main purpose of greywater treatment systems are therefore to treat BOD and pathogens, while reducing nutrients is of minor concern (Jenssen & Vråle 2003).

Screening of greywater has shown that in addition to the pollutants normally tested for, almost 200 xenobiotic organic compounds and compound groups are also present in greywater, some of these are also suspected to be endocrine disruptors (Donner et al. 2010). It is still unknown to what extent this a problem, and to what degree these pollutants are treated, in both conventional and decentralized wastewater systems.

Data for expected greywater concentrations from households are of great variations, especially when it comes to phosphorus. Jenssen and Vråle (2003) describes that of the total amount in wastewater greywater has 10 % of the nitrogen and 26 % of the phosphorus. While Vinnerås and Jönsson (2002) reports that greywater has approx. 8 % of the nitrogen, 15 % of the phosphorus, and the major part of the heavy metals. As most other numbers throughout the literature are from Sweden or other counties, and in Norway only phosphate-free detergents are allowed to be used, these numbers were not considered representative. Ødegaard et al. (2012) describes that a 58 % estimate of the phosphorus can be found in the greywater, but this number seems very high and is most likely also based on a Swedish source. A value of 20 % will be used throughout this is a concentration that reflects Norwegian conditions with mainly phosphate free detergents (Jenssen 2005). For nitrogen an average of the data (8 %-10 %) is used, which means 9 % of the total nitrogen can be expected to be found in the greywater.

An experiement in a Swedish housing area showed that the concentration of BOD varied from 90 to 360 mg O/l (Vinneras et al. 2006). A slightly lower number for BOD was estimated in a research project in Norway where the expected concentration was 197 mg O/l. For phosphorus and nitrogen the numbers were 2,5 mg P/l and 9,5 mg N/l, respectively. The data, including the range for each parameter, can be seen in Table 1.

Table 1, Estimated greywater concentrations in Norway. (Yri et al. 2007)

Parameter	**Concentration**
Total phosphorus	2,5 (2,7 – 2,3) mg/l
BOD	197 (218 – 180)mg /l
Total nitrogen	9,5 (10,5 – 8,7) mg/l
Thermotolerant coliform bacteria (TKB)	100 000 / 100 ml

Expected specific mass concentrations of phosphorus and nitrogen from Jenssen and Vråle (2003) can be seen in Table 2. Bergen and Kaia are data from Norway and samples are taken from septictank effluent (STE). Vinnerås is data from Sweden. The Norwegian data is much lower than the Swedish. One possible reason for this is that a 5-10 % reduction of nutrients is expected in septic tanks. Another, probably more important reason is again that in Norway phosphate-free detergents are used.

Table 2, Greywater mass (g/p/year) and concentrations (mg/l), for phosohorus and nitrogen. (Jenssen & Vråle 2003)

	Phosphorus		Nitrogen	
	g/p/year	mg/l	g/p and year	mg/l
*Bergen**	58	1.07	406	7.1
*Kaja**	56	0.97	470	8.2
Vinnerås	190	5	500	13.2

To further illustrate the varying concentrations of greywater see Table 3 where influent data from various countries are collected. Note that some of the data are including urine and some are excluding laundry machine.

Table 3, Greywater concentrations, all numbers in mg/l, from Rasmussen et al. (1996), a: excluding laundry machine, b: including urine, c: BOD7, d: P-free detergents

	Olson et al.	Brandes (a)	Kristiansen & Skaarer	Siegrist & Boyle	Bahlo & Wach	Schönborn & Züst (b)	Naturgårdsverket	Rasmussen et al.
BOD5	205	149	130 (c)	178	289	142	187 (c)	116 (c)
Tot N		11,5	19				6,7	42,2
NH4		1,7	11,5		2,6	95,7		36,1
Tot P	18,1	1.4 (d)	1.3 (0.42 (d))	4,4	4,1	9,5	4	3,97

As a summary, with especially weight on the Norwegian data from Yri et al. (2007), the expected concentration of total nitrogen would be around 9-10 mg N/l, expected total phosphorus concentration around 2-3 mg P/l, and expected BOD concentrations around 200-250 mg/l.

2.2 Greywater treatment and Discharge Limits

The required treatment of greywater, depends on the discharge. If the water is going to be released to lakes and rivers it needs more treatment, often secondary treatment, than if it will be released to the ocean. For irrigation and groundwater recharge usually the same standards as for lakes and rivers apply. If the water is intended for reuse, the type of usage will decide the required quality, but often a tertiary treatment is necessary including a step for bacteria removal (Jenssen & Vråle 2003). A wide range of treatment systems to treat greywater exist on the market. These systems has different design and sophistication, different capacity and provides different effluent qualities (Donner et al. 2010).

The Norwegian law on pollution (forurensningsloven) states that the requirement for wastewater effluent from urban areas with more than 100.000 inhabitatnts is a concentration of BOD < 25 mg/l, total phorphorus < 1 mg/l and total nitrogen <10 mg/l. The law on pollution furthermore demands a

70-90 % reduction of BOD, 80 % of phosphorus and 70-80 % of nitrogen if there is a sensitive area and there are user interests in the recipient. According to conditions, either the discharge limit or the treatment efficiency, or both shall be used. Sensitive areas are non-freshwater areas situated on the southern coast, between the border to Sweden and Norway's most southern point (Grense Jakobselv to Lindesnes). The Norwegian law on pollution has few details on greywater, but it is specified that greywater often has reduced requirements due to their lower concentrations of nutrients (Lovdata 2007). For small treatment plants in rural areas in Norway the requirements for phosphorus when discharging into lakes and rivers is also 1 mg P/l (Jenssen & Vråle 2003).

When it comes to bacteria the EU bathing water standards demands less than 1000 E.coli colony forming units per 100 ml for inland water and, less than 500 for coastal waters (EU 2006). In Norway the guidelines are slightly different, requiring a minimum quality of less than 1000 Thermotolerant Bacteria counts (TBC) per 100 ml. Additionally the Norwegian guidelines will define the water quality "less good" if there are between 1000 and 100 TBC and "good" if there is less than 100 TBC. Mostly E.coli is measured to represent TBC as this is a large and common group of the TBC, that is easy to detect (Folkehelseinstituttet 1994), so this this will also be the indicator used in this thesis. See Figure 2 for distinguishing between Total coliforms, Thermotolerant coliforms/bacteria and E. coli.

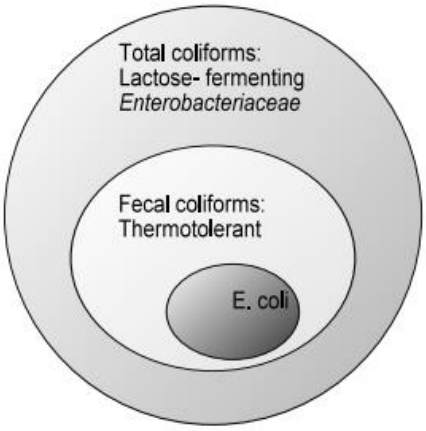

Figure 2, Overview of the difference between Total coliforms, Thermotolerant bacteria and E. coli. (Techniques in Environmental Health Sciences 2008)

2.3 Constructed Wetlands for Wastewater Treatment

2.3.1 What is Constructed Wetlands for Wastewater Treatment?

Natural wetlands has a naturally a high concentration of microbiota, and therefore has a high capacity for cleaning water (Moshiri 1993). Wetlands can therefore be constructed with the purpose of wastewater treatment, as a filter media covered with wetland plants, to take advantage of this ability. The main advantages of using constructed wetlands instead of conventional wastewater treatmnet are:

- the costs of construction and maintenance are low
- the energy consumption is low
- as the technology is simple, relatively untrained personel can be used to run the system
- the system are more flexible and adaptable to changes, than conventional treatment systems. (Jenssen et al. 2006; Moshiri 1993)

But conventional systems normally require less space per person than constructed wetlands, and conventional systems are easier to control (Moshiri 1993).

As in conventional wastewater treatment plants (WWTP) BOD is removed biologically from the wastewater in constructed wetland. Nitrogen is also removed biologically by aerobic nitrification prior to anaerobic denitrification. Phosphorus is removed chemically from the wastewater by binding to calcium, iron, aluminium or clay minerals in the filter material. The removal is mainly by precipitation of calcium- aluminium and iron-phosphates, where the dominant species of these is decided by the pH (Jenssen & Krogstad 2003). Bacteria and viruses can be removed by a number of various ways: sedimentation, filtration, oxidation, adsorption to organic matter, antibiosis, predation by Protista, attack by lytic bacteria and viruses, and by natural die-off (Moshiri 1993; Vymazal et al. 2003).

Constructed wetlands can be optimised by using a multi-stage system, and thus less space will be required. Research has shown that it is not cost effective to achieve both nitrification and denitrification in the same constructed wetland system, and separating the process in multiple stages is a way to solve this. Wetlands can be built with surface or subsurface flow, and with horizontal or vertical flow - some filters even has vertical up-flow. It has been reported that constructed wetland will be more efficient if the shape of the system has a 1:1 ratio that is circular or quadrat shape, and the wastewater should be distributed on a wide as possible area (Moshiri 1993). Higgins (2003) describes the four ways of how wetlands can be *engineered*, that is optimising the constructed wetland by monitoring, manipulating or controlling the process conditions:

1) *Modify the design*, by for example adding oxygen by submerged or diffuser piping and thus increasing ammonia nitrification rates. Other examples is to use a filter material with properties that adsorbs, volatilize or precipitates pollutants from the wastewater. Phosphorus removal is often the target here and research showed that 99% phosphorus removal was possible by using special substrates.
2) *Adding things to the process*, either chemicals or mixing the water with streams to increase heat for industrial water.
3) *Manipulate the vegetation*. Plants can be damaged and even killed by the wastewater if they are not sufficiently stress-resistant. Harvesting of the plants to remove the nutrients taken up in these (usually 10-15 % of the nitrogen and 40-60 % of the phosphorus) is also an option. Some plants also perform bioremedation and thus heavy metals and organic pollutants from the wastewater.
4) *Operate the system in an advanced manner*. The rate of the water feeding is an example of this, as lower feed rates will give longer retention time sand thus compensate for colder weather. Recycling of some streams is also an option to give the nitrate rich effluent conditions rich with carbon.

The operation costs of engineered wetlands are usually higher compared to other constructed wetlands, but can be used in many cases if the regular constructed wetland is not sufficient, for example industrial wastewater. An important point is also that engineered wetlands can be made more compact and have higher pollutant removal rates (Higgins 2003).

2.3.2 Norwegian Guidelines for Constructed Wetlands for Wastewater Treatment

All the wetlands described in the Norwegian guidelines are horizontal with subsurface flow. The guidelines are for wastewater in general and not for greywater. However, as the guidelines point out themselves, the systems could be made identical, only with a smaller area demand as the influent is less polluted (NKF & NORVAR 2001). The expected treatment efficiency and effluent concentrations can be seen in Table 4. Subsurface flow wetlands covered with grass on top instead of wetland vegetation are also called constructed wetlands in Norway, and the same definition will be used in this report (NKF & NORVAR 2001). When designing constructed wetlands for wastewater treatment the distance to groundwater should always be taken into account, as well as the conditions of the recipient.

Table 4, Treatment efficiency and effluent concentrations from the Norwegian guidelines on constructed wetlands, Note that the numbers are for wastewater and not greywater

	Treatment efficiency	Effluent concentrations
Total P	>90	< 1 mg/l
BOD7	>90	< 20 mg/l
Nitrification	50-99	
Total N	>50	<30 mg/l
Thermo tolerant bacteria	>99	<1000 TKB/100ml

The guidelines identifies three parts of the functioning wetland. The two first, the septic tank and the biofilter, are both pre-treatement before the wetland. The septic tank is the first step in most decentralized systems, and should be dimensioned with three chambers according to norwegian guidelines. Septic tanks are used for not only reducing organic matter and suspended solids but also to equalize the variations of greywater flow during the day (Elmitwalli & Otterpohl 2011)

The tank for pumping the water from the septic tank to the biofilter should be available for inspection and include a water level sensor that can report if the water level is too high. The filtermaterial in the biofilter is relatively coarse (2-5mm) and periodically loading of water is recommended, preferably 18-48 loads per day. With a nozzle the hydraulic load can be up to 20 cm/day for wastewater and 30cm/day for greywater, the recommended minimum height is 0.6 meters (NKF & NORVAR, 2001).

The constructed wetland itself should be minimum 1 meter deep and usually an impermeable membrane of plastic is used as sealing of the bottom and the edges. The sealing around the edges should be minimum 0,3 meters higher than the filter. If wetlands plants are not used, a 10-20 cm layer of coarse grained material for insulation should be used, before covered by grass. Ponding should never occur. The length and width of the filter is determined by the hydraulic conductivity of the filter media, where this conductivity is multiplied by 3 as input to darcys law to correct for temperature change and roots in the media. The slope of the bottom of the filter should be 0.5-1 %. The filter material should have a d_{60}/d_{10}<5, which usually is ensured by having 60 % of the material finer than 0,5-8 mm, 10 % of the material is 0.3-2mm, while maximum 0.5% of the material is finer than 0.1 mm. This normally gives a hydraulic conductivity of 100m/day. Normally the filter media is specifically designed for phosphorus sorption, allowing for binding capacity measured in the lab as 1-10 kg phosphorus bound per ton filter material. The binding capacity is documented best for the Lighweight aggregate (LWA) Filtralite-P, with the value that can be used for dimensioning being 1.5-2kg/m3. Other media like shellsand, podsol or other sands that are rich in aluminium, iron or calcium, can also be used and these might have lower phosphorus capacity but at the same time they have higher density and thus will decrease the required area for the filter. Normally 8-10 m3 per person is used for dimensioning, and for greywater this number can be reduced to 3-5 m3 per person. The minimum retention time in the wetland is 7 days. At the end of the filter it is required to have a manhole for sampling and inspection, including an option to regulate the water level in the wetland. Normally the water level is reduced with 10-20 cm at wither time to reduce the risk of frost (NKF & NORVAR, 2001). Constructed wetlands can also be used in other combinations, but then mainly used as a polishing step. And intensive pre-treatment, for example by biological/chemical methods, can significantly reduce the required space for the filter media (NKF & NORVAR, 2001).

Constructed wetlands for wastewater treatment has existed in Norway since 1991 (Mæhlum 1998, according to Mæhlum and Jenssen (2003). The combination of biofilter and constructed wetland, both with LWA, is not only the most common way to construct wetlands for wastewater treatment in Norway, the technique is also pioneered here (Jenssen et al. 2003). More on how the biofilter and the wetland and filter media works will be described in the following paragraphs. Focus will be on the Norwegian developed solutions but other solutions and experiences will be mentioned if relevant.

2.3.3 Biofilter

The biofilter has large surface area to support biofilm growth and a nozzle to equally distribute the wastewater on a large area. These two factors, together with the aeration is enhancing the BOD reduction. This prevents clogging in the wetland and thus the area needed for the wetland is smaller, which means the total system can be made more compact. If we assume 100 liters of greywater produced per person per day, 1 m2 surface area can treat water for approximately 10 people. With this loading rate (115 cm/d) a 70% BOD reduction, and a 2-5 log reduction of indicator bacteria can be obtained (Jenssen et al. 2003). There are four main influences on the nitrification: oxygen supply, temperature, pH and loading rate (Laber et al. 2003). Aerobic pre-treatment filters can remove up to 40 % of the total nitrogen, because of denitrification in anaerobe microzones (Kraft 2002, according to Jenssen et al. 2006). The nitrification prior to the Nitrogen-removal is the often limiting factor to Nitrogen-removal (Mæhlum & Jenssen 2003).

When constructed wetlands are used together with biofilters most of the treatment of BOD and nitrogen is carried out in the biofilter. While most of the phosphorus and microorganisms are removed in the construced wetland. See Figure 3. The treatment efficiency of BOD is somewhat lower for constructed wetlands compared to other nature based solutions since the plants in the filter media will always produce some organic material.(Jenssen et al. 2006). The lines between conventional and nature based solutions are being erased as natured based systems are becoming more engineered by using pumps and other technical components – and dividing the treatment into steps as with the biofilter pre-treatment (Heistad et al, 2001; Jenssen et al, 2006, according to Jenssen et al. 2006).

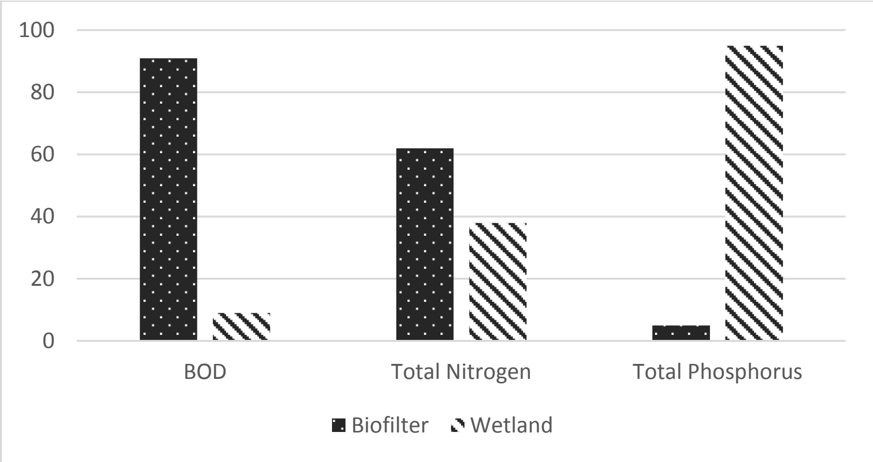

Figure 3, Relative treatment efficiency (%) for Biofilters compared to constructed wetlands. Graph based on numbers from Jenssen et al. (2006)

2.3.4 Wetland and Filter Material

The LWA Filtralite is a filter material commonly used in Norway for constructed wetlands. Filtralite is an expanded clay aggregate with high hydraulic conductivity and high phosphorus removal capacity, in addition to good insulation properties. The material is produced by heating clay or shale to temperatures above 1000 C. To enhance phosphorus removal capacity, as is done with Filtralie-P, the clay is added dolomite before heating. By adding dolomite the pH of the water passing through the material will slightly increase, but this is effect is mainly observed in the first years of the system (Jenssen & Krogstad 2003). Filtralite-P has shown very good treatment results and high phosphorus sorption capacity. Problems with the material could be the price and that the first year or two calcium leaching can clog outlets and also reduce the phosphorus binding capacity (ÁdÁm et al. 2007). Filtralite-P media has generally a very high capacity for not only binding phosphorus but also for reducing bacteria, and preliminary investigations has shown that Filtralite-P has potential for virus reduction. Investigations with filterbeds with Filtralite-P focusing of viruses has shown no somatic viruses in the effluent (Jenssen et al. 2010). Another advantage with the Filtralite-P material is that it can be utilised as a fertiliser in agriculture, when saturated with phosphorus. Not only is this saturated filter media a rich source of phosphorus, it also meets the Norwegian regulation guidelines for concentration of heavy metals , bacteria and parasites (Jenssen et al. 2010).

Phosphorus sorption is a very complicated process, and the scientific understanding is still limited. Therefore the phosphorus sorption capacity is difficult to predict, and Jenssen and Krogstad (2003) showed that a sorption capacity half of what was found in a short term batch experiment can be expected. Research has shown that in constructed wetlands with Filtralite-P material the Calcium compounds are the main removal mechanism, but that also a considerable amount can be adsorbed to the aluminium compounds. Over long time the pH of the wetland is falling and approaching that of the wastewater, which means Al and Fe compounds become more dominant with time (Jenssen & Krogstad 2003). Constructed wetlands with LWA has been tested against wetlands that consist of sand material, and shown to perform up to 25% higher removal of Total Nitrogen (Zhu 1998, according to Jenssen & Krogstad 2003). A possible explanation to this is the better developed root-zone in the LWA wetlands. No significant removal of BOD has been observed between these two systems but the BOD is, as describes earlier, mainly removed by the pre-treatment biofilter. (Jenssen & Krogstad 2003)

Constructed wetlands and their complex biological, physical and chemical properties makes them efficiently remove bacteria, this has been demonstrated in numerous studies, e.g. Bavor et al., 1989; Gersberg et al., 1989; Batchelor et al., 1990; May et al., 1990; Otoova et al., 1997; Soto et al., 1998; according to Vymazal et al. 2003 . Typical removal rates for constructed wetlands are 2 and often 3-log reduction (Christian 1990; Soto et al. 1998, according to Vymazal et al. 2003).

The hydraulic retention time in the wetland filter, is an important factor when it comes to total treatment effect. See examples in Figure 4, on how Orthophosphate, BOD removal is increased with increased retention time. Figure 4 also shows how the number of fecal coliforms in the effluent is decreasing with increased retention time. Evaporation for the wetland increases the retention time, as water is removed from the system. This means not only size but type of wetland is determining retention time, as well as type of wetland and degree of planted area or open water. Retention time is also affected by the amount of roots in the filter in addition to the temporal variability of roots because of growth, decay and solids accumulation (US EPA 2000).

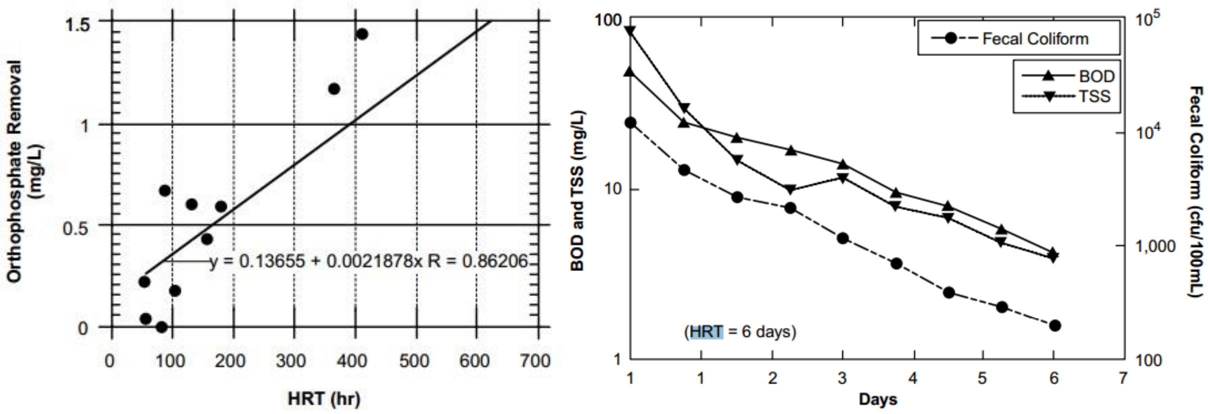

Figure 4, Left: Orthophosphate, BOD and Total Suspended Solids (TSS) removal, all increasing with increased Hydraulic Retention Time (HRT). Right: Number of fecal coliforms in the effluent, decreasing with increased HRT.

2.3.5 Plants on Constructed Wetlands

Plants in the wetland provides surface for the bacteria to grow on and also transports oxygen down to the rootzone. Furthermore the plants isolates the filter during winter, and evapotranspirate water in the summer. (NKF & NORVAR, 2001). However, the treatment effect of plants on constructed wetlands has been disputed. Evaluation of the role of plants, showed that there was an increased nitrogen removal effect in the root-zone, but regarding BOD and Phosphorus there was no significant effect (Zhu 1998; Mæhlum & Stålnacke 1999, according to Jenssen & Vråle 2003). As plants have not been found to be essential for the wastewaster treatment efficiency, some wetlands in Norway have been constructed with only with grass as a cover.

Nevertheless, there are numerous benefits of using planted constructed wetlands in urban areas, besides the intended function of treating wastewater. For the first wetlands with plants creates an aquatic habitat and attract various birds and animals. For the second green and blue surfaces cool down the environment as many cities are struggling with the heat effect of the vast amount of asphalt and concrete surfaces. For the third wetlands works as carbon sinks. Four the fourth wetlands provides opportunities for natural recreational experiences, and for the fifth and last constructed wetlands can provide the community with a location for education about nature and the hydrological cyle (The Australian Environment and Planning Directorate 2014). Wetlands are often used for retaining and treating stormwater, and there are examples where wetlands simultaneously provide a location for both wildlife and recreation (The Wildlife Trusts n. d.). Furthermore 50% of the world's wetlands have been removed since 1900 (UN 2014).

Constructed wetlands can also be used as green roofs. This is beneficial, since storage of water for dry periods can be a problem with the regular extensive green roofs (Song et al. 2013). The problem with constructed wetlands on roofs could be weight and leakages, but both of these can be handled by proper construction and maintenance. Additional benefits of constructed wetlands as green roofs is that they can handle larger rainfalls and take up more water by evapotranspiration, and thus significantly less water is led to urban drainage systems. With climate change the frequency of intense rainfalls will increase and thus rooftop wetlands can sustainably handle these rainfalls. And also the fact that the temperature of a roof with a constructed wetland is much lower that of a regular roof, e.g. with 5 degrees lower temperatures at the warmest day of the year. Increased biodiversity compared to a normal roof is another advantage. Because regular green roof often require a substantial amount of irrigation, it is estimated that wetland rooftops are only 10-14 % more expensive than other green roofs. Plant biomass is significantly higher for wetland rooftops than for other green roofs, and plants showed higher tolerance to both flooding and drought. Other benefits includes filtration of air, carbon sink potential and recreational and cultural value (Song et al. 2013).

The added positive effects of constructed wetlands plants, as increased biodiversity and recreational value are therefore important to take into account when estimating the effect of constructed wetlands for wastewater treatment in urban environments.

2.3.6 Seasonal Variations

There are numerous examples of constructed wetlands different climates, even in colder climates with ice and snow during the winter, as in Norway. Treatment in cold climates is possible but deeper wetlands are required to avoid frost. Larger wetlands might also be needed to increase the hydraulic retention time, normally a retention time of 4 weeks will give a sufficient treatment even at wintertime

(Jenssen & Krogstad 2003). In the summer, almost all of the water from the constructed wetland is evapotranspirated through the plants and thus the effluent is limited. This matches with that this season is the time when the receiving waters, i.e. rivers/creeks, are most vulnerable and thus provides a natural protection for these waters (Jenssen et al. 2006). The rootzone in constructed wetlands is providing suitable conditions for removing nitrogen as the zones around the roots offers both aerobe and anerobic conditions, but research has shown that the plants will not bring sufficient oxidation down to the rootzone in cold seasons (Brix & Siegrist, 1990, according to Jenssen et al. 2006). This can be compensated by using aerobic pre-treatment filters (Jenssen et al. 2006).

A study by Hiley (2003) of wetlands in cold climates showed that most of the systems showed same or better performance in wintertime, probably due to solids accumulation in colder climate wetlands. Other explanations are: that the wastewater itself may be significantly warmer than air temperature, that ice, snow and plant litter is insulating the wastewater from the air, that the amount of oxygen that can dissolve in water is higher at lower temperature. (Kadlec et al. 2003) also had results that showed little seasonal variation. The system was a subsurface flow wetland in Minnesota, and with regards to fecal coliforms the removal was between 99% and 100%. However, the average fluctuations from the effluent for BOD were 135 mg/L in wintertime, compared to 25 mg/L in the summertime. The inflow was almost constant at 185 mg/L. Total nitrogen reduction had small fluctuations with lowest reduction during summer and winter and highest during spring and fall, but because of evapotranspiration the total mass removal was highest in summer and lowest in spring. It should be noted that the system in Minnesota had not pre-treatment biofilters as used in Norway, and that this step can ensure a stable reduction of both nitrogen and BOD throughout the year. Other ways to enhance nitrogen removal, is to allow parts of the effluent to be continuously recirculated to the septic tank. Laber et al. (2003) found that an amount of 90% recirculation was the most efficient. Nitrogen removal can also be enhanced by bypassing some of the effluent of the septic tank with sand directly to the wetland, instead of using a pre-treatment unit (Giæver 2003). This was done in a well functional constructed wetland treating wastewater in Norway, above the polar circle, all year round. An airpocket under the ice and above the system was used to insulate the system, and an aerobic pre-treatment unit was also necessary (Giæver 2003).

Sewage bacteria's survival is adversely affected by lower temperatures, at the same time as higher temperatures not only favours bacteria but also their predators. Mechanical properties are generally the same throughout the year, but UV radiation and thus the efficiency of this removal will be higher in summertime (Vymazal et al. 2003). Since this thesis is regarding a sub-surface flow wetlands this factor can be ignored. Six sub-surface horizontal flow wetlands in the Czech Republic, treating municipal wastewater was investigated and the removal rates for total coliforms were 97,8-99,7 %, for fecal coliforms 90,1-99,9 % and fecal streptococci 93,5-99,5 %. No seasonal variation that was statistically significant was found (Vymazal et al. 2003).

Four factors that favours low fluctuation in treatment rates during the year in cold climates are: high sedimentation, oversized filters, seasonal sorption of ammonium and temperature adaption for the microbial community (Wittgren & Mæhlum according to Mæhlum & Jenssen, 2003). Calculations showed that theoretically it would be sufficient with 10 cm insulation on the top and one meter vertically on the sides to avoid freezing (Mæhlum & Jenssen, 2003). It is recommended with minimum 60 cm cover above the constructed wetland and let the filter itself be 90 centimetres deep to adjust to the colder climate. The most critical period for the system is time with where there is frost and ice but no snow, since the snow cover provides insulation (Mæhlum & Jenssen, 2003). The same source also found that despite some seasonal differences in treatment efficiencies, these differences were not statistically significant.

Generally, treatment in cold climates is absolutely possible but aerobic pre-treatment is recommended. Because constructed wetlands show weaknesses with heavy rain, partial freezing, spring snow melts and summer time evaporation, average values of treatment efficiencies should be used, not a limited number of grab samples.

2.4 Greywater Treatment by Large-scale Constructed Wetlands

The effluent values and treatment efficiencies for each system will be discussed in paragraph 4.3 when compared to the KL system. Only a table with an overview of this data will therefore be presented in this chapter.

2.4.1 Case Ås

In 1997 a greywater system for student dormitories, in Ås, Norway was built. The system serves 48 students, and consists of two biodomes for pre-treatment and a sub-surface horizontal wetland filter (Jenssen 2005). The wetland filter contains a LWA (not optimised for phosphorus reduction), and is covered with grass. Greywater was sufficiently treated with regards to phosphorus and nitrogen in the biofilter. However, to meet the requirements for BOD and indicator bacteria the wetland filter was necessary (Jenssen & Vråle 2003). The results of the treatment can be seen in Table 5. Even after 6 years since construction, no decline in nitrogen or phosphorus removal was measured (Jenssen & Vråle 2003).

Table 5, Effluent and treatment efficiencies for Ås constructed wetland system for the following parameters: BOD, Nitrogen, Phosphorus and Fecal coliforms

	Effluent	% Efficiency
BOD	6	93 %
Nitrogen	2,4	73 %
Phosphorus	0,1	90 %
Thermotolerant coliforms	0-1000	---

2.4.2 Case Bergen

Close to Bergen, Norway, 40 environmentally friendly houses were built in 1991. The greywater from the houses is separated from the blackwater and treated in a construced wetland that consist of LWA filter material (not filtralite-P). The pre-treatment is not in circular biodomes with nozzle as in the KL and Ås case, but instead with longer pipes that distribute the water on a filter surface. This was the step developed in Norway before the biodomes, and has a poorer utilisation of surface area and is thus expected to perform with a lower treatment efficiency than the circular biodomes. The effluent of the system is led to a nearby lake (Jenssen 2014b; Torvetua Huseierlag SA n.d.). The treatment results from Bergen can be seen in Table 6.

Table 6, Effluent and treatment efficiencies for Bergen constructed wetland system for the following parameters: BOD, Nitrogen and Phosphorus (Jenssen & Vråle 2003).

	Effluent (mg/l)	% Efficiency
BOD	15	96 %
Nitrogen	2,2	60 %
Phosphorus	0,19	79 %

2.4.3 Case Lübeck

Today around 3-400 greywater treatments plants exits in Germany, most of the time these plants treat greywater excluding kitchenwater (Nolde, 2005). In Flintenbreite, Lübeck, the greywater and blackwater from approximately 380 persons in an ecological settlement is treated separately. The greywater was treated in a constructed wetland and the planning of the settlement is based on an ecological approach to architecture, landscape planning, social cooperation, energy and sanitation (OtterWasser GmbH 2009). The filter material in the constructed wetland was coarse gravel (Jenssen 2014b). It was estimated that this system was 40 % more expensive to construct than a conventional system, but the operation costs are 25 % lower (OtterWasser GmbH 2009). The results of the greywater treatment can be seen in Table 7.

Table 7, Effluent and treatment efficiencies for Lübeck constructed wetland system for the following parameters: BOD, Nitrogen and Phosphorus (OtterWasser GmbH 2009)

	Effluent (mg/l)	% Efficiency
BOD	14	93 %
Nitrogen	2,7	78 %
Phosphorus	5,7	29 %

2.4.4 Case Kuching

In the city of Kuching in Malaysia a pilot project was set up in 2004 for 9 households. Before the project started, greywater and blackwater were already separated from each other. The problem was that both types of water were released more or less untreated into the nearby streams as the city had no proper sanitation system. Greywater was released directly and blackwater only received insufficient treatment in (often leaking) septic tanks – the consequence was pollution of local water bodies (Jenssen et al. 2005). The pilot project set up constructed wetlands for the greywater, after the same model as KL with 4 biodomes with Filtralite LWA media (2-4 mm) and the horizontally subsurface flow constructed wetland with crushed limestone aggregate (5-8 mm). In addition, the wetland's septic tank had been specifically developed to handle the excess grease produced because of the cooking habits in Malaysia. The blackwater was stored in holding tanks before collected by trucks to produce biogas and fertilizer. The home owners were very satisfied and even proud of their sanitation system. The new system demanded no change in habits, and was invisible as a recreational area was constructed on top of the treatment system. A substantial reduction in amount of rats was also observed, in addition to removing odour and flies. The project also made the families aware of the connection between pollution in the river and wastewater discharge from their own homes, and they could see the physical consequences of starting to treat of the wastewater before discharge (Jenssen et al. 2005). Reduction of both BOD and oil and grease was 99 %. Suspended solids was reduced with 97% and nitrogen with 92 %, for details see Table 8. Out of 13 samples, only one had E. coli concentrations higher than 1000/100 ml and only two had fecal coliforms concentrations above 1000/100ml. Some problems with clogging of biofilter was observed, this was probably due to suboptimal dosing frequency. The wetland was needed to reduce phosphorus and to achieve sufficient swimming water quality in the effluent with regards to bacteria (Jenssen et al. 2005).

Table 8, Effluent and treatment efficiencies for Kuching constructed wetland system for the following parameters: BOD, Nitrogen, Phosphorus, Fecal coliforms and E. coli. (Jenssen et al. 2005)

	Effluent	% Efficiency
BOD (mg/l)	2	98 %
Nitrogen (mg/l)	9,24	75 %
Phosphorus (mg/l)	0,33	86 %
Fecal coliforms (MPN/100ml)	646	
E. coli (MPN/100ml)	389	

2.5 Other Decentralized Solutions for Greywater Treatment

A number of solutions to treat greywater has been developed, with varying complexity and performance (Li et al. 2009). This paragraph provides a few examples.

In Norway greywater treatment for cabins has been performed with a biofilter only. It should be noted that these cabins often have very low loading of the filters but occasionally short periods of high loading. Some of the investigated biofilters consist of the material Filtralite-P, which as previously described optimises phosphorus binding. Treatment results can be seen in Table 9, compared to regulations the BOD and bacteria concentrations are quite high while the phosphorus and nitrogen levels are relatively low.

Table 9, Treatment efficiency and expected outlet concentration for greywater from Norwegian cabins treated by biofilter only. (Yri et al. 2007)

Parameter	**Expected Treatment efficiency**	**Measured Outlet concentration**
BOD	> 90 %	59 mg O/l
Nitrogen	> 25 %	11 mg N/l
Phosphrus	> 75 %	0,5 mg P/l
E. coli (#/100ml)	> 99 %	2561

Vertical flow filters has been investigated the recent years because they have a higher oxygen transfer rate than the horizontal ones. The problem with these filters is that the aeration is still limited and periodic alteration between different beds is necessary to avoid clogging (Sklarz et al. 2009). An experiment showed that 6 hours where sufficient to treat greywater to achieve the required effluent quality, but as the bacteria counts still were of the order 10^3 to 10^6 an UV unit had to be used to ensure sufficient hygienic quality for reuse. Because of build-up of scaling and biofilm, the UV unit had to be cleaned every 2-4 weeks (Sklarz et al. 2009).

A variety of technical solutions for compact treatment plants exist on the market, and although most of these are for wastewater some is also specialized for greywater only. One widespread is the solution GreyUse by the company Huber, which exist from smaller units to up to 3000 people capacity. These units, after a screening of the greywater, treats the water in a compact membrane bio-reactor and then passes it through an ultra-filtration membrane to retain solids and bacteria. The effluent fulfills the EU bathing water directive, and has a quality that allows for reuse for toilet flushing, laundry washing and irrigation (Huber Technology n.d.). A plant that can treat 450-800 l/day takes up only 4 m2. Another prefabricated compact solution is the Norwegian greywater treatment system Ecomotive, a system that only demands energy for a pump as the treatment is based on a sedimentation and filtering process (Ecomotive n.d.).

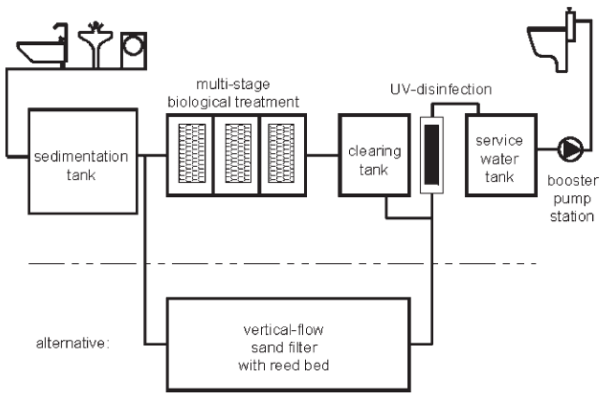

Figure 5, Recommended concept for greywater treatment from Nolde (2005). Note that a vertical flow sand filter reed bed (i.e. vertical constructed wetland) can replace a multi-stage biological treatment unit and cleaning tank.

Recommended concept for greywater treatment from Nolde (2005), can be seen in Figure 5. Note that a vertical flow sand filter reed bed (i.e. vertical constructed wetland) can replace a multi-stage biological treatment and a cleaning tank. UV disinfection is used to achieve hygienically clean water for reuse. The biological treatment could either be a multi-stage Rotating Biological Contactor, followed by a clearing tank to remove the biomass. Another option of biological treatment is an aerated flow-bed reactor as a Sequencing Batch Reactor. Here, foamcubes are used for fixing the biomass, and an automated sieve is holding interfering particles back. Greywater can also be treated by membrane systems, but these systems are still under development (Nolde 2005).

If the area is very densely populated there can be installed compact units with area requirements of less than 0.5 m2/person. An example from berlin is a compact plant in a 15 m2 basement that treat greywater (excludning kitchenwater) for 70 persons, and a similar system that confirms these results that treats greywater for 65 persons (Nolde 1995; 1996, 1999a; Bullermannet al. 2001, according to

Nolde 2005). Research has also shown that compounds that has been suspected for hindering optimal greywater treatment, i.e. common personal hygiene products, house-hold-cleaning chemicals, medicinal baths and faecal bacteria, does not pose any problems (Nolde 2005). A greywater reuse system in a hotel for 400 people in Germany treating greywater with a Rotating Biological Contactor, has been running successfully since 1996.The payback time for the system was calculated to be 6.5 years, but with experiences from this project the same treatment efficiency can be obtained with less investments (Nolde 2005). Li et al. (2009) found that mechanical treatment of greywater was not sufficient alone, neither was anaerobic treatment. The combination of mechanical filtration and an aerobic biological process was found to be the cheapest and most feasible solution for treating greywater, and for urban residential buildings for more than 500 persons a Moving Bed Reactor system was recommended.

The most common greywater recycling system in Germany is called Aquacycle. 95 % of the systems are installed for single or double family households, with a capacity of 600 L/d. The Aquacycle systems has a surface area of 0.81 m2 and are 1.88 m high. The operation costs are around 25€ per year for the energy, and the investment cost is 5000€ including installation. In total in a year this system can save up to 200m3 of water. Investments costs decrease with increased sizing of system. Effluent from these systems fulfils the EU Guidelines for bathing waters with regards to E. coli. Unpublished data also has shown that even with synthetic greywater with very high E. coli concentrations (above 10^7/mL) the effluent had a concentration of E. coli lower than the detection levels. In addition, influent with a concentration of 238 mg/L COD gave an effluent of 28 mg/L and 2.4 mg/L of COD and BOD7, respectively (Nolde 2005). The system can also be easily integrated with a module for recycling the heat of the greywater as well (Hansgrohe 2013)

Green and nature based solutions, as constructed wetlands, can be combined in many ways, also together with more or less conventional solutions. As space is limited in cities, it is also growing interest in using any urban surface for greywater treatment, including roofs and walls (Junge-Berberovic & Graber 2004). There are currently many different actors developing ideas on how greywater can be treated on walls, one example from Norway found for the first tests on this kind of system that the greywater could successfully be treated (Svete 2012). Generally optimising urban surfaces for multi-use can be an important part of greywater treatment in the future.

A greywater system was built in 1987 in Berlin, treating water for 250 inhabitants in an apartment building. (RoofWaterFarm 2014a). Water saving facilities was installed in the households, and a rainwater pond was created bordering a constructed wetland where the greywater were treated the first years. The constructed wetland was shut down, due to technical and economic reasons, when the first research period ended in 1993 (Stadtentwicklung Berlin n.d.). In 2006 the greywater system was re-engineered to optimize greywater reuse. On top of the constructed wetland and polishing pond there was built a mechanically-biologically unit that treats the water to bathing water quality. The water is later reused for flushing toilets and for irrigation. The original wetland is only used for receiving rainwater (RoofWaterFarm 2014a). The maintenance costs of the greywater recycling plant is relatively low, approximately on the level with a good German heating system, and the price of the reused water is considerably lower than prices of municipal water and wastewater. The water is used for toilet flushing all of the 250 inhabitants. The effluent values are <5 mg/L BOD7, turbidity below 1 NTU and the water fulfils the EU directive on bathing water quality (Nolde & Partner n.d.). In 2013, to increase the knowledge source separation and reuse of wastewater, the project was further expanded by installing the demonstration and test site ‘Roof Water-Farm’. This system now performs tests on the reclaimed greywaters quality with regards to both hygiene and micropollutants. In addition the site is used to produce fertilizer and to cultivate vegetables and fish, without soil. The fish excrement together with the greywater fertilizes the plants in an aquapond, while the blackwater is used to produce a liquid fertilizer for a hydropond. A pre-opening was celebrated January 20th 2014, and in June a public ceremony of tasting the first crops was held (RoofWaterFarm 2014a; RoofWaterFarm 2014b). The crops include strawberries and salad, and the fish species are carp and catfish. The event received a lot of attention in the media (Magazin 2014; Réthy 2014).

Generally these systems shows the variety of solutions and that there is a continuous development of new solutions. Greywater can be treated in various manners according to location, quality and discharge – and the effluent can also be reused.

2.6 Decentralized Greywater Treatment, with regards to Water, Energy and Nutrients

As mentioned in the introduction, treating greywater decentralised will allow for reuse of both water and nutrients. At the same time energy can be saved. Some more background information regarding these advantages and the need for these advantages to be developed will be explained in the following paragraphs.

2.6.1 Water

Today more than a billion people lack clean drinking water (Junge-Berberovic & Graber 2004), and it is estimated that the global water consumption will increase from 1995 to 2025 with 62% (Zadeh et al. 2013). For megacities water experts has reported that they predict emphasis on water reuse (55%) rather than using new sources (45%) (Economist Intelligence Unit 2007). As greywater is the fraction of the wastewater that is least polluted and with the largest volume, it is the most obvious fraction to recycle.

Recent years there has been a growing recognition for using reclaimed greywater. The most common forms of re-usage are irrigation, car washing, laundry and toilet flushing (NEERI & UNICEF 2007, according to Hyde 2013). To what extent the water needs to be treated depends on both the quality of the greywater and to what purpose it shall be used. Most places this recycling takes place excluding kitchen wastewater, as this waters concentration of grease would make it necessary with further treatment than other greywater (Hyde 2013). One important benefit of greywater recycling is that for new systems the cost of installation is found to be lower than for conventional centralized systems (Nolde 2005). Other benefits is that reusing greywater can reduce potable water use with 20-40 % (Donner et al. 2010). Morel & Diener (2006, according to Hyde 2013) reports that up to two thirds of the potable water use can be reduced. In many developing countries reusing greywater has an additional benefit by increasing water security for poorer households and that it can empower women, as these are of the ones in the households that has to spend their time on collecting potable water. The challenges to start reusing greywater are often to convince communities and politicians, as the barriers often are cultural beliefs, investment opportunities and issues around effluent ownership (Hyde 2013).

Nolde (2005) reports that an investigation where clothes washed in recycled greywater was compared to clothes washed in regular water there was no difference, resulting in the same number of bacteria counted on agar plates. Since many places in Germany already rainwater is used for washing of clothes there is strong reason to believe that recycled greywater also can be used for washing clothes. According to the WHO guidelines for safe use of wastewater, greywater and excreta, the limit for E. coli is 1000 per 100 ml. This value is for unrestricted irrigation, that is for even root crops and leaf crops (WHO & UNEP 2006).

Using greywater for toilet flushing only will produce an excess amount of greywater, as greywater is approximately 50-70% of the water outflow, while toilet flushing only consumes approximately 30% of the water inflow. Zadeh et al. (2013) presents an innovative way to improve the efficiency of greywater systems by connecting treated greywater (from hand basin, shower and bath only) outflow from households and nearby office buildings, to toilet flushing in the same buildings. The results of an economic analysis showed that the shared solution was the more beneficial than individual greywater systems for the household and offices (Zadeh et al. 2013), and this is an excellent example on how urban densities creates opportunities for combined systems that saves more energy and resources than the single solution. The importance to develop urban solutions is also highlighted in the latest Intergovernmental Panel on Climate Change (IPCC) report on mitigation. The report stresses that the next two decades are especially important as a large portion of the world's urban environment are developed during this period, and that the rapidly urbanizing settlements has highest potential for mitigation (IPCC 2014).

2.6.2 Nutrients and Energy

What we humans consider "waste" water is actually a resource, containing large amounts of phosphorus and nitrogen (Benetto et al. 2009). All fertilizer production, and thus all food production, require the two life-essential nutrients nitrogen and phosphorus. Both production of nitrogen and phosphorus requires large amounts of energy. Furthermore, phosphorus is derived from phosphate rock, and this has not only rapidly increased as a phosphorus fertilizer source since the 1960s (see Figure 6), it is estimated that the global reserves of phosphate rock are depleted in 50-100 years (Cordell et al. 2009). To ensure global food security, one of the grates challenges of the 21st century (Esrey 2002), replacements of phosphate rock is important. As nitrogen and phosphorus currently are treated as pollutants there is a great potential in designing sanitation systems that optimising recycling of these nutrients. Source separation of waste water into greywater and blackwater theoretically makes it possible to recycle approximately 74 % of the phosphorus and 90% of the nitrogen (Jenssen et al. 2003). Organic matter from human excreta also improves the structure and water-holding capacity of the soil (Esrey 2001).

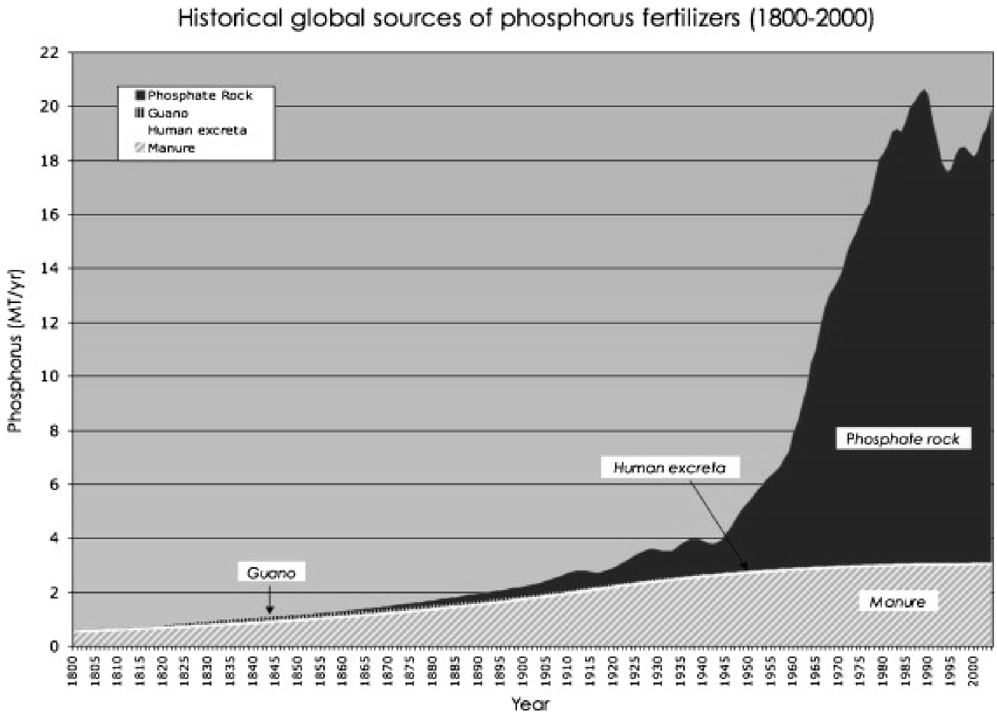

Figure 6, Historical global sources of phosphorus fertilizer, from 1800 to 2000. (Cordell et al. 2009)

The problems with the current centralised, water based, sanitation systems in the industrialised world today is that running WWTPs consumes large amounts of energy, in addition to the expenses of constructing and maintaining the complicated transportation systems for wastewater (Esrey 2001; Langergraber & Muellegger 2005). Decentralised solutions can drastically reduce the need for piping systems, which is the most expensive part of a traditional sewage system (Jenssen 2005). There will always be pathogens in human excreta, but by mixing this potentially harmful part with large amounts of water multiplies the magnitude of the problem (Langergraber & Muellegger 2005). By separating greywater out of the wastewater stream the volume that needs to be transported to the WWTPs is minimised to only 22 % and can be further reduced, by using vacuum or no-water toilets, to less than 10 % (Jenssen & Vråle 2003). This increases the opportunities for treating the blackwater on-site, and if this is not possible, the reduced volume makes the costs and environmental effects of transporting the blackwater significantly smaller. Blackwater also has a lower concentration of heavy metals than sewage sludge, so if blackwater is used as a fertilizer instead of sewage sludge or artificial fertilizers, heavy-metal content in food can be reduced (Tervahauta et al. 2014).

Recycling nutrients in human excreta is both safer and easier if it is neither mixed with other effluents and nor diluted to the degree it is today (Cordell et al. 2009). Further separation of urine from feces in the toilet bowl allows for individual storage and usage of urine as a fertiliser. Urine is not only the fraction that contains most of the nutrients, it is almost sterile and only needs a short time of storage before it can be diluted and applied directly as a fertilizer (Cordell et al. 2009) .

Instead of two linear approaches, one producing fertilizers and one treating the nutrients in human excreta as waste, the two can be connected in a closed loop and return the nutrients to the soil for healthy plant growth (Esrey 2001). In addition that the sale of the excreta for food production can create an income (Esrey 2001). As urban population is growing, and the amount of urban poor is growing, urban farming is becoming increasingly important for food security – as well as growing food closer to the consumers strengthens local communities. In the light of this, recycling nutrients from human excreta can create a local and stable production of fertilisers (Esrey 2001). Human waste can also, before being used as a fertiliser, be utilised for energy production in anaerobic digestion and thus reducing CO_2 emissions. Using biogas as a fuel means 95 % and 80 % reduced carbon and nitrous oxide emissions, respectively. In addition this fuel has no particulate emissions, and calculations in the UK revealed that there are sufficient amounts of excreta in the country to fuel half of the heavy goods vehicle fleet (Jewitt 2011).

Many more or less complicated systems has been suggested to holistically approach both the loops of nutrients and water in an urban setting. Mixing the feces with organic waste from kitchens is also an often suggested opportunity, as well as treating both greywater and stormwater together before recycling. A suggestion for a complete system can be seen in Figure 7.

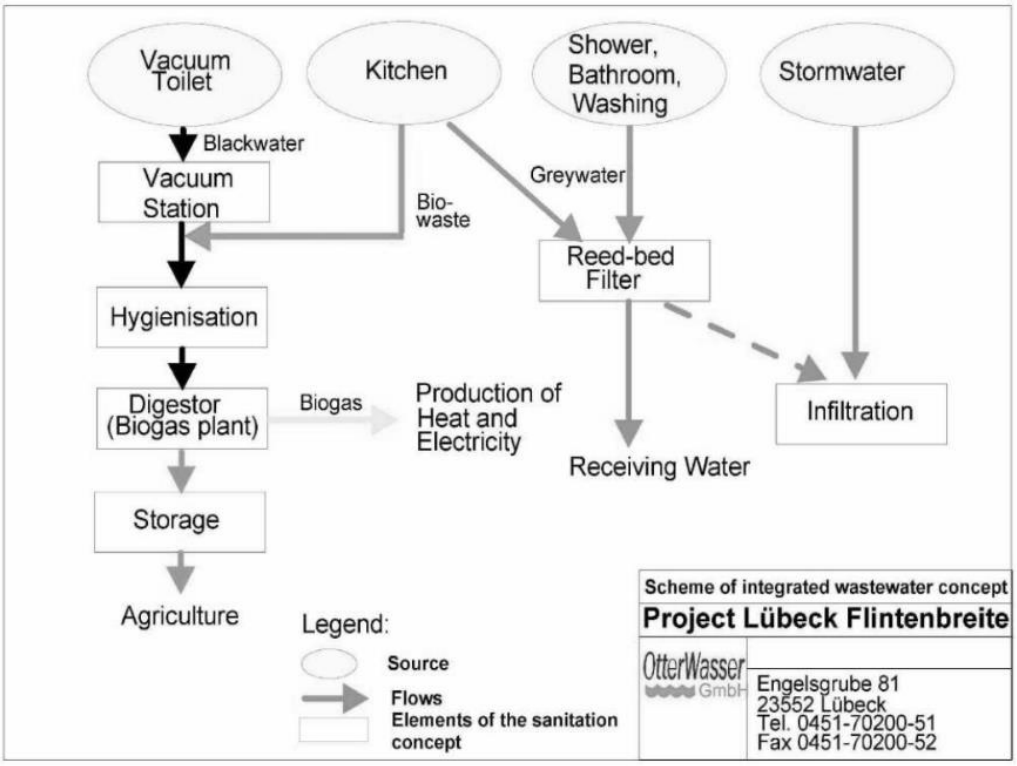

Figure 7, Scheme for integrated wastewater concept for the Flintenbreite project in Lübeck, Germany. (OtterWasser GmbH 2009)

3 Materials and Methods

3.1 Case: Klosterenga

The Klosterenga (KL) ecological building (Økologiboliger) was finished in year 2000 and consist of 6 floors with a total 35 apartments. It is estimated to house approximately 100 inhabitants. The buildings and their courtyard is optimised for saving energy and water, and the project was awarded the NBO best environmental project in the Nordic countries in 2000 (Enova SF 2003; USBL & Grindaker 2000). The blackwater are led to the municipal WWTP but the greywater is treated locally, in the courtyard. The treatment system consist of a septic tank followed by an aerobic vertical flow biofilter and a subsurface horizontal flow constructed wetland. After treatment the water is pumped to a small "Waterfall" to add recreational value to the courtyard, before the effluent finally is led to the nearby Hovin creek. The area needed for the total system is 1,5 m^2 per person, where 1/3 of the space is for the biofilter. The theoretic hydraulic loading is 10m^3/day. (Stenberg & Sørensen n.d.). For overview of the system see Figure 8, 9 and 10.

The technical description of the system that follows is retrieved as a combination of in-field observations, information from the drawings in appendix 1, information from Vråle (2008), Stenberg & Sørensen (n.d.) and USBL & Grindaker (2000) and personal communication with GOS, USBL, Petter Jenssen, Grindaker and landscape architect Askild H. Nielsen. Because this has been a long and tedious process caused by the systems combination of age and uniqueness, individual references for each detail is not possible to provide in the following paragraph.

The greywater starts its treatment in a 30 m^2 three chambers septic tank. From this tank the water is pumped and distributed in the 10 vertical down-flow single pass aerobic biofilters. Each filter is 0,6 meter deep and filled with 2-4 mm sized leca material of the type Filtralite. The total area of the biofilter is 72 m^2, and they are covered by 40 cm of bark. Airpumps are installed in the garage so that it is possible to additionally aerate the biofilters. The water is led by gravity from the filters to a distribution manhole at the beginning of the constructed wetland. From here the water enters the constructed wetland by two distribution pipes. One of the distribution pipes is deep down in the filter and one is nearer the surface. There are two measures to avoid frost in the filter during winter. One is that the upper distribution pipe can be shut off by a valve in the distribution manhole, allowing only water in the deeper levels of the wetland, the other is that the wetland is especially deep. The depth of the constructed wetland is 1,8 m, instead of the regular 1 m, and this depth also saves surface area. The surface area of the constructed wetland is approximately 110 m^2, and the volume is 216 m^3. The width is 11,75 m and the length is 9,3 m. The wetland filter is in a cast concrete basin, and has varying grain size. There are larger grain sizes at the beginning and the end of the system, but the main part of the filter consist of the LWA Filtralite -P size 0,5-4 mm. The first and last meter consist of Filtralite 4-10 mm, and the next to last meter of Filtralite 2-4 mm. The theoretical retention time in the wetland filter is 1 week, and the filtermaterial can be reused as a nutrient source when it is saturated with phosphorus (Kvarnström et al. 2004).

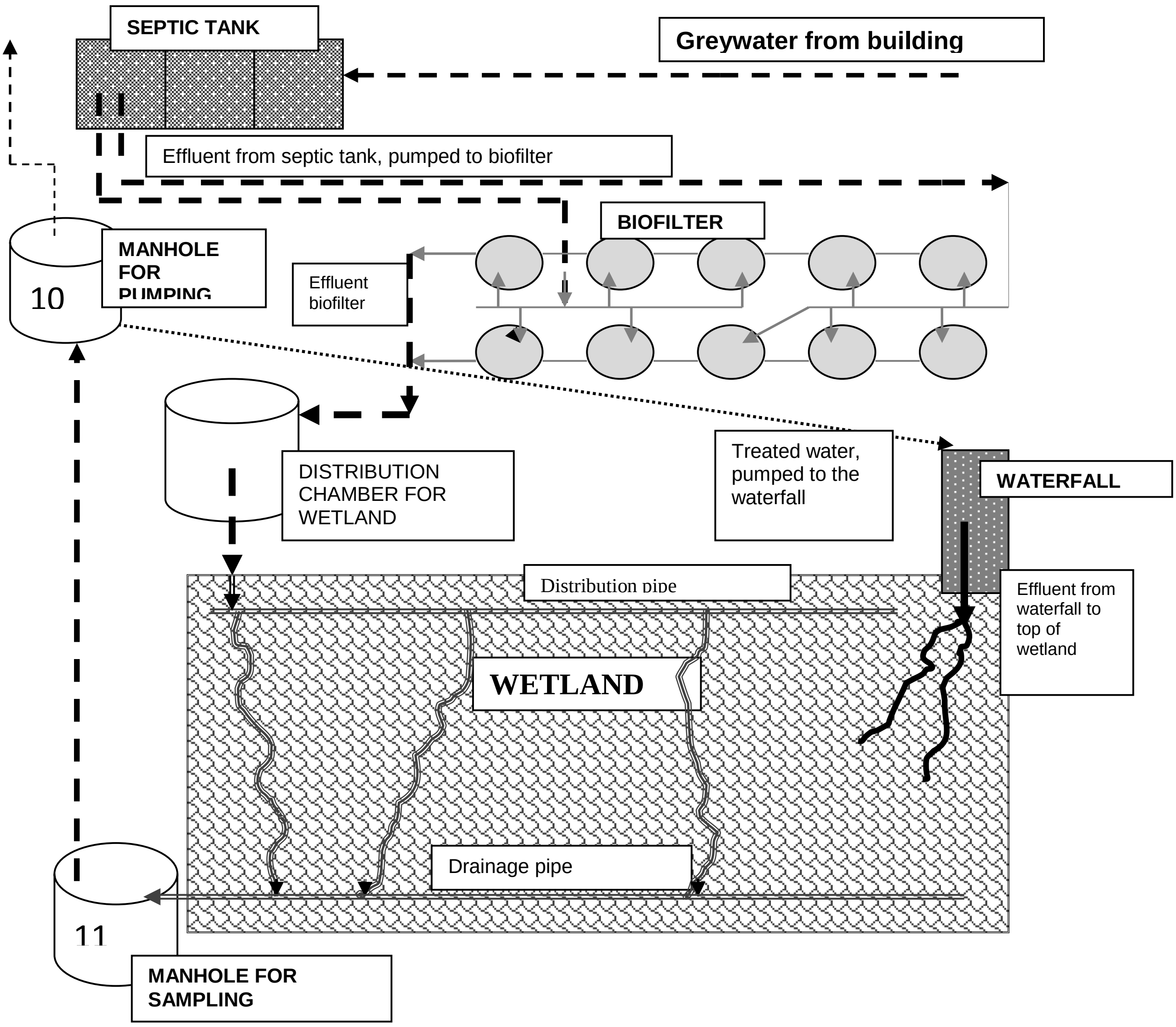

Figure 8, Overview of the treatment system at KL. The water starts in the septic tank where it is pumped to the biofilter. By gravity the water is led from the biolfilter to the constructed wetland. After the wetland the treated water goes to manhole #11, which is also the effluent sampling point. The water is then led by gravity to manhole # 10 where it is pumped to the "waterfall" as an aesthetic element in the courtyard. The water then runs out on top of the wetland and after a dam it is led to the nearby Hovin creek.

Next to the constructed wetland there is a hand pump that pumps collected rainwater from an underground tank, and this water can be utilised for irrigation in the courtyard. One pump has been assumed to be for treated greywater but no sources has confirmed this. At the end of the wetland there are drainage pipes collecting the water and leading it by gravity to manhole #11. This manhole has many functions: It is where the water level of the wetland can be adjusted, it is where a UV lamp originally was installed, and there is a tap for taking water samples of the effluent. From manhole #11 the water flows to manhole #10, this manhole has two pumps to pump the treated greywater up to the surface to the Waterfall, a sculptural cascade. From manhole #10 there is also an overflow outlet to the municipal sewage system. The purpose of the waterfall is not related to the treatment but rather to make the water visible and to contribute to the aesthetics of the courtyard. From the waterfall the water flows on the surface of the constructed wetland, and the exact technical details are not known but the water is then led to the Hovin creek.

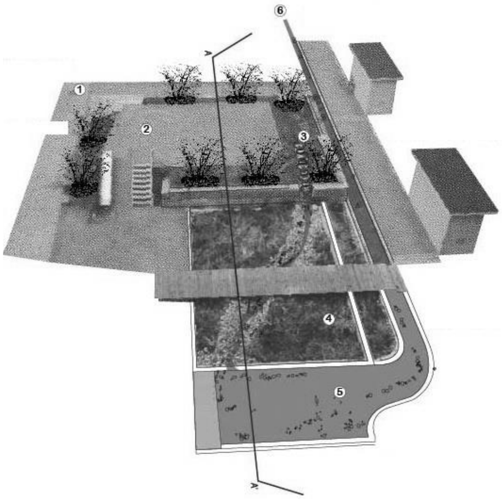

Figure 9, See also figure 10 for cross section from A-A. the numbers indicate location of the system. 1 is the septic tank, 2 are the biofilters, 3 is the waterfall and 4 is the constructed wetland (Stenberg & Sørensen n.d.).

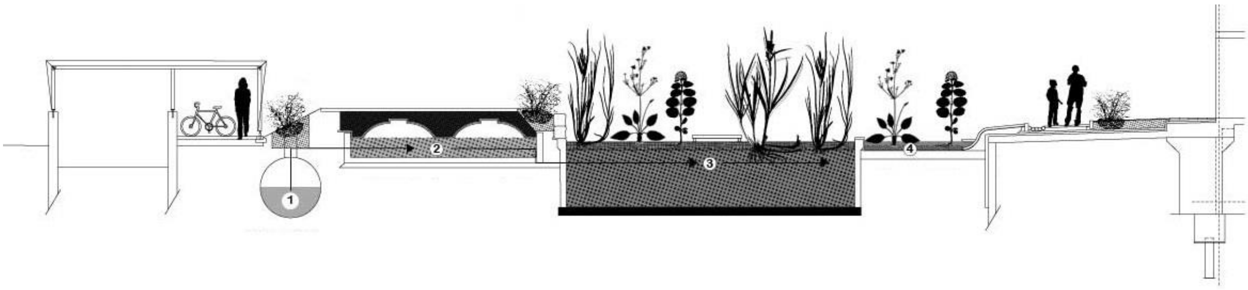

Figure 10 cross-section of system. 1 is the septic tank, 2 are the biofilters, 3 is the wetland, 4 is open water. See also figure 3 for overview, the cross section is marked with A-A here (Stenberg & Sørensen n.d.).

Most of the urban creeks in Oslo where in the time period 1850-1950 led into pipes and buried underground. The reason for this was a combination of that creeks competed with the space for urban development, and that the creeks where contaminated by sewage. As the value of the creeks, both environmentally, recreationally and culturally was realised during the 80s, programmes to re-open the creeks was started (Olje- og Energidepartementet 1994; Oslo Elveforum 2007). The Hovin creek is one of the previously closed creeks, but it was planned to be re-opened and used as an important integrated element in the KL park. This park is the immediate neighbour of the KL ecological building, and was partly finished in 2001. Bård Breivik was the artist that planned the park and decorated it with his stone sculptures, and many of the sculptures are designed with the intent of artistically shape the creek throughout the landscape. Because the creek could not be opened after all, the park was never completed (Skaare 2013). During construction of the greywater system and connection to the creek it was discovered that the Hovin creek was heavily polluted with sewage and thus a water trap had to be installed at KL to prevent smell (USBL & Grindaker 2000).

The UV lamp was only functional the first years of the system. It demanded much maintenance because of scaling on the lamp, it consumed electricity and the lamp itself needed to be changed too often – and the budget was limited As the results also showed that the water quality was sufficient without the lamp, it was removed from the system (Jenssen 2014a). It is required the effluent from KL fulfils the bathing water quality criteria described in paragraph 2.2.

The KL project is unique as a greywater treatment system never has been built in an urban setting in Norway before. As it was a pilot project it also led to some difficulties and a higher price, not only because there was little experience and little willingness from the entrepreneurs to take the risk to try out something new, but because of the limitations of space. As neither the groundwater level nor the level of the pipes in the building could be adjusted, the greywater comes from the building into a storage tank and is then pumped across the parking garage entrance, prior to entering the septic tank. This pump is very difficult to reach and monitor, and thus makes the system more vulnerable and complicates the maintenance (Nilsen 2014; USBL & Grindaker 2000).

The KL system has been under continuous supervision since it was constructed, but with different organisations responsible. The first years the Norwegian Cooperative Building and Housing Associations (USBL) together with the Norwegian University of Life Sciences (NMBU) had the supervision. Since 2008 the main responsibility was transferred to Oslo municipality. 4 samples a year shall be performed by Gamle Oslo Servicesentral (GOS), a custodian service partly organised by USBL. GOS is also responsible for maintenance of the building and the courtyard.

Figure 11, Picture taken in 2014 of the constructed wetland in front of the KL building. The elevated area to the left is the top of the biodomes.

3.2 Methods: Water Samples from Klosterenga

Samples were taken four times during spring 2014, with three weeks interval: 27th of January, 18th of February, 10th of March and 31st of March. During this period the weather changed from winter and snow to spring. At the 31st of March also a sample from the effluent of the septic tank was taken, by opening directly into this tank. All other samples were taken at the sampling point in manhole #11. Due to problems with the pump in the septic tank, two additional effluent samples were collected in the summer 2014 with a one week interval. The last sample was collected 10th of July. The temperatures from the sampling period can be seen in Figure 12.

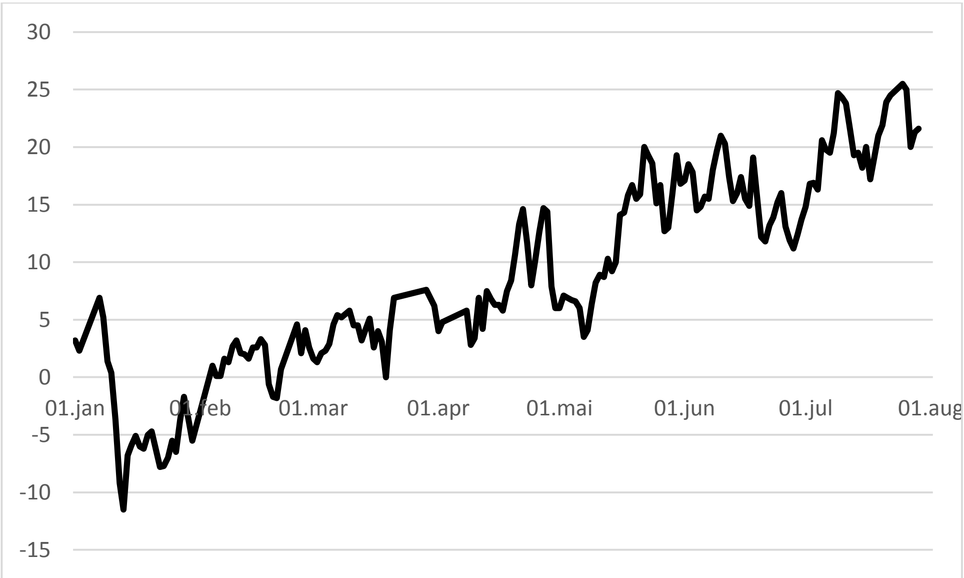

Figure 12, Temperature average daily value for Klosterenga area, in the time period the water samples were taken (Norwegian Meteorological Institute and Norwegian Broadcasting Corporation 2014)

The septic tank effluent will throughout this thesis be used to describe the influent of the total system. This is because that the septic tank is the point closest to the inlet of the system it is possible to retrieve a sample. In addition this sample can be seen to be representative for the influent concentrations, as the reduction of nutrients is usually 5-10 %, and the BOD reduction up to 30 %. Furthermore, generally in the literature, and thus also for most other systems that KL will be compared to, the influent concentration is represented by the septic tank effluent (see paragraph 2.1).

For every sample the bottle was, prior to sampling, rinsed with the sampling water. Samples were, with only a few exemptions, frozen before analysis in the lab was carried out. Three times also effluent samples for bacteria analysis were performed. Special disinfected bottles were used in these cases, and analysis performed by Bioforsk the same day.

3.2.1 Methods for Analysis of Water Samples

The water samples were analysed with regards to the following parameters: pH, conductivity, BOD, total phosphorus, orthophosphate, total nitrogen, nitrate, ammonia and bacteria. All analysis except from bacteria was carried out in the lab of Department of Environmental Sciences at Norwegian university of Life Sciences. Conductivity was measured with a Metrohm 712 Conductometer with a dynamic range from 0 µS/cm to 2000 mS/cm. pH was measured with a VWR sympHony SP70P meter. For both instruments the electrode was rinsed in deionized water, and wiped off with a tissue, between each measurement.

All other parameters where analysed with Hach Lange kits. Details for each parameter is provided in the following paragraphs. The results were read off with a Hach Lange DR 2800 barcode reading machine, and for heating of cuvettes a Hach Lange LT200 thermostat was used. The range of each of the kits where determined on background of expected value. Analysis revealed that there was no need to adjust any ranges, except from for total nitrogen. Two different kits where therefore used to analyse total nitrogen, but a test with both kits gave the same results – even though one of the kits displayed results below measuring range. The water samples had a low enough turbidity that no removal of suspended solids was necessary. All samples were thoroughly shaken in their sampling bottle before analysis to ensure they were homogenous.

3.2.2 BOD

To measure BOD, Oxitop method and equipment was used. Each sample was poured in to a 510mL dark-coloured glass bottle. The amount of sample varied with expected BOD outcome, according to Table 10. The samples from the septic tank were tested with both 0-200 and 0-400 range, while all the effluent samples were tested with the 0-40 range. Nitrification inhibitor was added to the each bottle, 20 drops per liter sample, to make sure that no nitrifying organisms will consume oxygen and disturb the results. A magnet stirrer was also added. Then, a deep rubber cap with air holes was placed at the top of the bottle, with three NaOH pellets added. Finally an Oxitop measuring head was screwed firmly on top of the bottle, and the measuring head including the expected range was registered with an OC100 controller. The bottle was then placed on a magnet-stirrer tray inside a dark thermostat cabinet with constant temperature of 20°C, as measurements with this method only happens between 15 and 21°C. After five days the OC100 controller was used again to read off the BOD value (WTW n.d.).

Table 10, Amount of water sample needed for different expected ranges when using the Oxitop BOD_5 method. (WTW n.d.)

Expected BOD range [mg/L]	**Amount of sample to be used [mL]**
0-40	432
0-80	365
0-200	250
0-400	164
0-800	97
0-2000	43.5

The oxitop method is a respiometric method, which means it is measuring change of pressure. When oxygen is consumed, the produced CO_2 reacts with the NaOH in the cap, and forms sodiumcarbonate (Na_2CO_3). This creates a negative pressure that the measure head register. Then, based on the ideal gas equation, the biochemical oxygen demand is calculated. The continuous stirring accelerates the exchange of oxygen from air to water as it is in the water phase the bacteria are consuming the oxygen. By freezing samples while storing them, cell walls of the microorganisms can burst and thus be damaged. Samples that have been stored by freezing therefore often results in up to 10 % lower values (WTW n.d.).

3.2.3 Orthophosphate and Total Phosphorus

The same kit, Hach Lange LCK 349, was used for measuring phosphorus and orthophosphate. The range for this kit is 0,05-1,5 mg/l P_{tot} and 0,15-4,5 mg/l PO4-P, and the pH and temperature range is be 2-10 and 15-25°C, respectively (Hach Lange 2013).

The chemical process is that first phosphate ions in an acidic solution reacts with molybdate and antimony ions. This forms an antimonyl phosphomolybdate complex, wich is then reduced by ascorbic acid to produce phosphomloybdendum blue. After 10 minutes waiting and shaking the cuvette was then wiped off and read of in the barcode scanner. For the analysis of total phosphorus, an electrolysis was additionally performed at the very beginning. It has not been reported any interference with results up to 250 mg/l Ca^{2+} and 100 mg/l $Mg^{2+,}$ 50 mg/l $Fe^{3+}/Fe^{2+}/Al^{3+}$, but it must be noted that the cumulative effects are not taken into account (Hach Lange 2013).

3.2.4 Total Nitrogen

Total nitrogen was measured with the Hach Lange kits LCK 338 and LCK 138. These kits are identical, except from their range. The LCK 338 has a range of 20-100 mg/l N_{tot}, as this range were discovered to be too high the LCK 138 with a range of 1-16 mg N/l was used instead. A few samples were tested with both methods and the results where more or less identical even though they, with the LCK 338, were below measuring range. The pH range was 3-12, and the temperature range was 15-25°C. What happens in the cuvettes is that a digestion with peroxodisulphate is oxidising inorganically and organically bound nitrogen, to nitrate. In a solution of sulphuric- and phosphoric acid these nitrate ions then react with 2,6-dimethylphenol to form nitrophenol. The cuvette was finally wiped off and read off in the barcode scanner (Hach Lange 2005a; Hach Lange 2005b).

3.2.5 Nitrate

Nitrate was measured with the Hach Lange kit LCK 339, which has a range of 0,23-13,50 mg/l NO3-N. The process is that nitrate ions in a solution sulphuric and- phosphoric acid reacts with 2,6-dimethylphenol and forms 4-nitro-2,6-dimethylphenol. The pH range is 3-10 and the temperature range 20-24°C. Interference from other ions is possible, but up to 50 mg/l Ca^{2+}/Fe^{3+} and 10 mg/l Fe^{2+} is tested to give no interference, although the cumulative effect is not known (Hach Lange 2005c).

3.2.6 Ammonia

For analysing ammonia the Hach Lange LCK 303 kit was used, which has the range 2-47 mg/l NH4-N. What happens in the cuvette is that ammonium ions react with salicylate- and hypochlorite ions in the presence of sodium nitroprusside. The pH is 12,6 during the reaction and the nitroprusside is a catalyst to produce indophenol blue. As a large excess amount of ammonia still could wrongly display results within the measuring range, dilution is recommended if the approximate range is not known to be surely under 47 mg/l. As total nitrogen was far below 47 mg/l in this thesis, no dilution was performed. The pH range for the kit is 4-9, and the temperature range is 20°C.The kit must be stored in a fridge but was taken out some time before analysing, to allow the kit to cool down to room temperature (Hach Lange 2000).

3.2.7 Indicator Bacteria

A water sample from March 10th, March 31st and August 4th was handed in to the lab at Bioforsk, Ås, and analysed for coliform bacteria and Escherichia coli. The metod used was Colilert 18/Quanti-Trays2000, and no dilution was performed. This is a most probable number method where a substrate is added, and if bacteria are present they will over time utilize this substrate to release chromogene or fluorochrome from the media. After 18 hours of incubation, the bacteria's presence is indirectly measured by measuring colour and fluorescence (Yri et al. 2007). This method is approved by the US Envionmental Protection Agency (Yri et al. 2007) and is recommended to be used instead as the standard method of the EU drinking directive, if the water is suspected to have higher counts than of drinking water quality (Schets et al. 2002).

4 Results and discussion

4.1 Time period 2001 to 2014

Effluent data from 2001 to 2014 was retrieved, but it should be noted that there are two major holes in the data set. For the first, no data between 2008 and 2014 were available. For the second, the system was closed between spring 2004 and May 2005. This was due to a misunderstanding during the construction phase that had caused the wrong filter material to be used in the pre-treatment domes. After an inspection revealed the mistake, as the filters had started to clog, the filter material was changed in 2004. Between autumn 2003 and summer 2006 no samples were taken. Still, the data set has values for more than 7 years, something that is quite unique in this setting, and the concentrations are from 25 different samples. Altogether this creates a valuable overview of the systems performance from start and up until 2014.

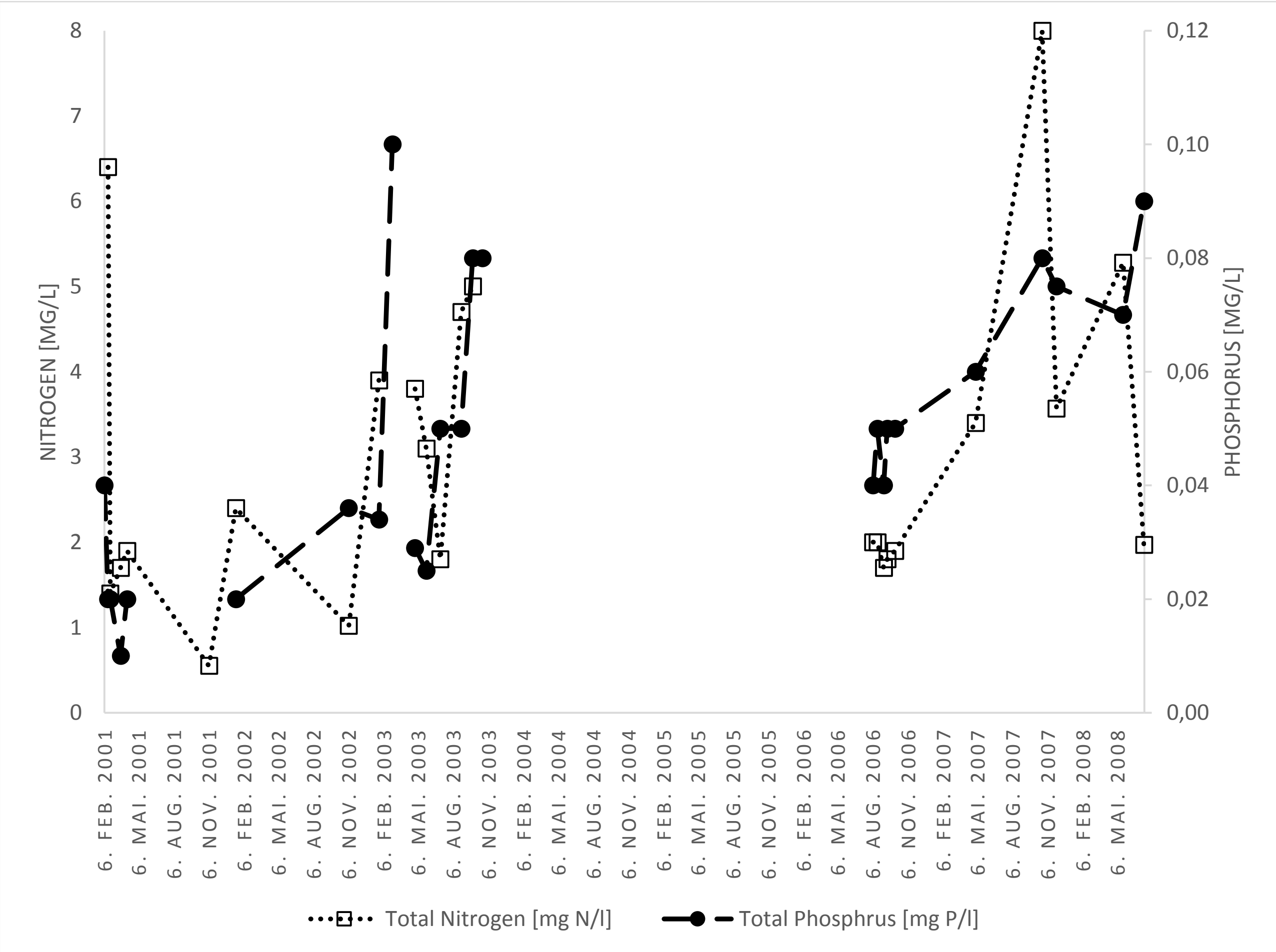

Figure 13, Data for effluent concentrations for the KL treatment system between 2001 and 2008.

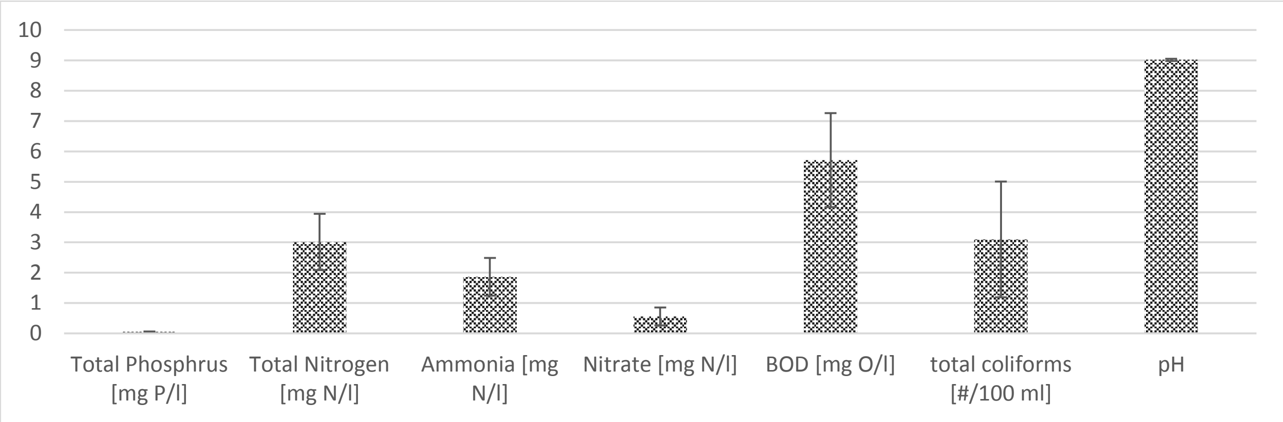

Figure 14, Average and standard deviation for the data up until 2014 (2001-2008) from KL.

The data from 2001 to 2014 are plotted as a function of time for nitrogen and phosphorus in Figure 13, and with mean and standard deviation for each of the parameters in Figure 14. As it can be seen from the relatively low standard deviation, all of the data are stable throughout the time period.

The mean value of total nitrogen was 3,01 mg N/l, which is low compared to the guideline of 15 mg N/l. Phosphorus and BOD has a mean of 0,05 mg P/l and 5,7 mg O/l respectively, which is also considerably lower than the discharge limit of 1 mg P/l and 25 mg O/l respectively. Data for pH were monitored only from 2006 and onwards, and had a mean value of 9. This is quite a high pH, but also expected from filters containing Filtalite-P. BOD and total coliforms are not plotted in the graph as a function of time because of few data points with relatively high values compared to phosphorus and nitrogen. The total amount of coliforms is very low compared to regulatory guidelines for good swimming water quality of 100 per 100 ml, with a mean value of 3 per 100 ml. In 2008 (27 June) E. coli from septic tank was more than 24000, this means a 3-log reduction of bacteria throughout the system, which must be considered as highly satisfactory.

The effluent data for all parameters has no statistically significant change before and after the 2004 improvement, except from phosphorus concentration in the effluent that is slowly increasing (p-value 0,05). The average concentration of ammonia in the effluent also dropped after the improvement from 2,1 to 1,5. This was not significant (p-value 0,26), but could still be a sign that the aeration in the biofilters was somewhat more efficient after the filter material was changed.

The hygienic quality of the Waterfall had around 2007 been questioned by the residents of the courtyard. However, test of the water quality of both the effluent and the waterfall itself concluded that there was no need to concern. The emptying of the septic tank in 2008 encountered some challenges as heavy metals had accumulated in the tank since it had not been emptied for 7 years. The sludge exceeded the municipality guidelines for heavy metals, and thus was requested to be disposed at a centre for toxic waste, instead of being disposed at the municipal receiving centre connected to the WWTP. What happens under the anaerobic conditions in the septic tank is a sulphate precipitation of the heavy metals, which makes them concentrated in the sludge (Veeken & Rulkens 2003). The precipitation means that the sludge can be exceeding guideline limits for specific uses, but at the same time it ensures a higher water quality for the wetland's effluent. Removing heavy metals by sulphate precipitation is a common method in wastewater treatment, and in some cases an anaerobic pre-treatment step is added for this purpose (Veeken & Rulkens 2003). It is also important to remember that the sludge from KL only contains pollutants from regular wastewater from the residents, only in a more concentrated form, and there should be no reason not to dispose this sludge at the municipal receiving centre. However, a more frequent emptying of the tank, approximately every 4th year is recommended (Jenssen 2014b; Lier Kommune 2014).

4.2 Status 2014

4.2.1 General Introduction

The results of the analysis of the water samples taken in 2014 can be seen in Figure 15 and Table 11, for general overview. Details will be provided for each parameter, in the following paragraphs. All data from 2001 to 2014 can be found in appendix 2.

Table 11, Overview of all results from 2014, including mean, standard deviation (SD), effluent divided by SD and influent into the system (In.). Numbers in parenthesis are not included in mean and average.

	27.jan	**18.feb**	**10.mar**	**31.mar**	**04.jul**	**10.jul**	**Effluent mean**	**Effluent SD**	**Effluent SD/mean**	**In.**
BOD [mg/l]	<5	<5	<5	2,8	5,3	6,7	**5,0**	**1,3**	**25 %**	225
Ortho-phosphate [mg/l]	0,34	0,061	0,077	0,22	0,29	0,42	**0,24**	**0,15**	**62 %**	0,30
Total Phosphrus [mg/l]	0,40	0,062	0,088	0,24	0,29	0,52	**0,27**	**0,18**	**66 %**	0,85
Total Nitrogen [mg/l]	2,29	2,39	2,23	1,15	2,75	2,58	**2,23**	**0,56**	**25 %**	10,3
Nitrate [mg/l]	0,78	0,92	1,2	0,089	0,15	0,034	**0,53**	**0,49**	**94 %**	0,14
Ammonia [mg/l]	(1,1)	(0,59)	(0,53)	(0,77)	2,04	2,41	**2,23**	**0,26**	**12 %**	6,54
Ph	(8,17)	(8,1)	(8,0)	(7,87)	7,45	7,8	**7,63**	**0,25**	**3 %**	6,36
Conductivity (µS/cm)	490,9	454,6	472,1	504,7	712,5	785	**570**	**141**	**25 %**	345,6
E. coli	--	--	(<1)	(<1)	--	18,9	**18,9**	**--**	**--**	--

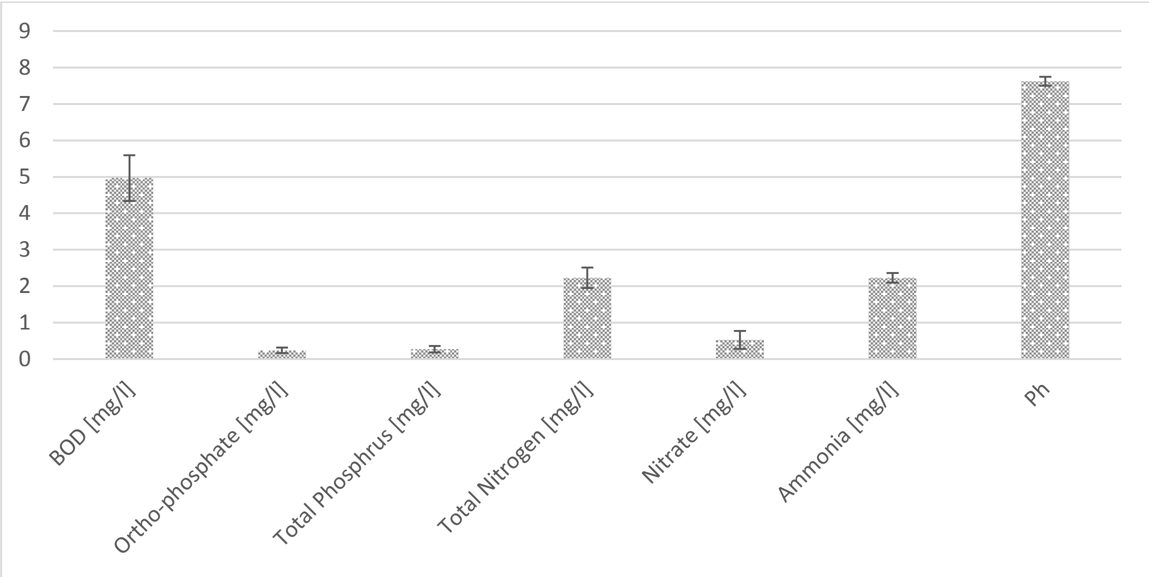

Figure 15, Overview of mean and standard deviation for all parameters for 2014

From October 2013 until end of May 2014 the pump from the septic tank to the biofilter was not functioning. This meant that the system was not receiving any new water and the water that was sampled from the effluent had a hydraulic retention time of months. The results before a new pump was installed were therefore compared with the results after the pump was started, to compare how the extended retention time affected the effluents quality. Four samples were taken before, and two samples were taken after the pump was started. A t-test revealed that there was no statistical significance difference for almost all of the parameters before and after the pump started. Only for ammonia and pH was there a statistical difference (p-value 0,01 and 0,05, respectively) and for further calculations the data only from July was used for these two parameters. For all other parameters the data from the entire 2014 period, January to July, was used.

Regarding Norwegian discharge limits, the nearby creek is classified as a sensitive recipient as it leads to the Oslo fjord. This is not only because of the type of recipient (fresh water, to a fjord with already high loads of nutrients) and area (between ‘Lindesnes’ and ‘Grense Jakobselv’, but also because the Oslo area is classified as so densely populated area (more than 100.000 inhabitants) that nitrogen removal also is necessary. In total this makes the demand according to Norwegian regulations for reduction throughout the system 70-90%, 70-80 % and 80 % for BOD, Nitrogen and Phosphorus, respectively. The discharge limits are 25 mg O/l, 10 mg N/l and 1mg P/l for BOD, Nitrogen and Phosphorus, respectively. As the system is treating only greywater, the lower of each of these values will be used. These treatment efficiencies are also identical to the ones as required by the municipal WWTP of Oslo today, with 70 % reduction of BOD and nitrogen and 90% reduction of phosphorus. For details on the regulations and the Norwegian law on pollution see paragraph 2.2.

4.2.2 BOD

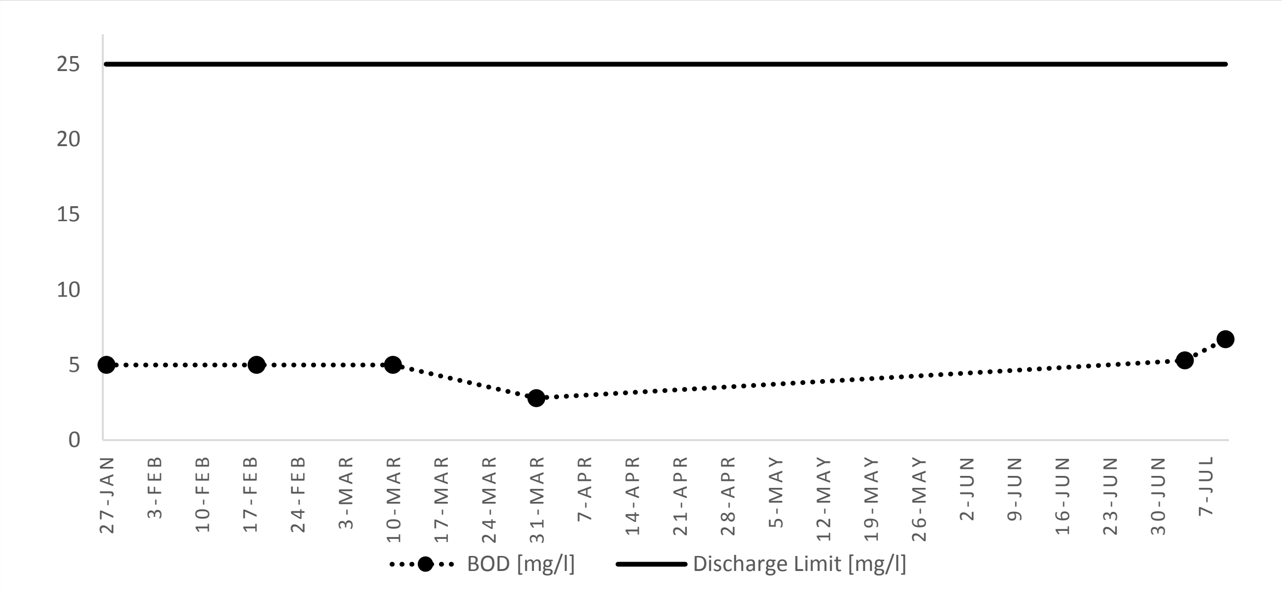

Figure 16, BOD effluent values in 2014 and the BOD discharge limit. The influent to the system (225 mg O/l) is not plotted on this figure as it was so high that it would make it impossible to distinguish the other graphs from each other.

The results for the BOD measurements, together with the discharge limit can be seen in Figure 16. The influent of BOD for the system was 225 mg/l which is well in accordance with the estimated average influent from the literature of 200-250 mg O /l. It can be seen that the values from 2014 are all around 5 and the average of these results is 4,9, although it must be kept in mind that the value is probably lower as <5 was the result in most cases. The standard deviation was 1,25, which is 25 % of the mean.

All the effluent concentrations are less than 30% of the discharge limit of 25 mg/l. The average between 2001 and 2008 was <5,7, this is slightly higher than 2014, but a t-test revealed that there is no significant difference in effluent values between the two time periods (p-value 0,59). This indicates that the BOD treatment capacity of the system is stable, and that the pre-treatment biodomes are operating as they should with regards to this parameter. It should be kept in mind that the biofilter was intentionally designed oversized, to create an extra robust filter. KL can be compared with the Ås case, a treatment system almost identical to the one at KL, and where the effluent and treatment efficiencies all met the regulations (see paragraph 2.4.1). If the necessary area per person from Ås is used (2 identical biodomes for 48 people), only 4-5 biodomes would have been sufficient at KL. This is half of what is installed today.

The reduction in BOD is 98 % which is a much higher efficiency than the 70 % demand according to Norwegian regulations. This efficiency is also higher than expected for Norwegian constructed wetlands treating regular wastewater (>90 %). The BOD results generally seem very stable, with a low concentration compared to discharge limits and highly satisfying treatment efficiency compared to the regulations.

4.2.3 Phosphorus

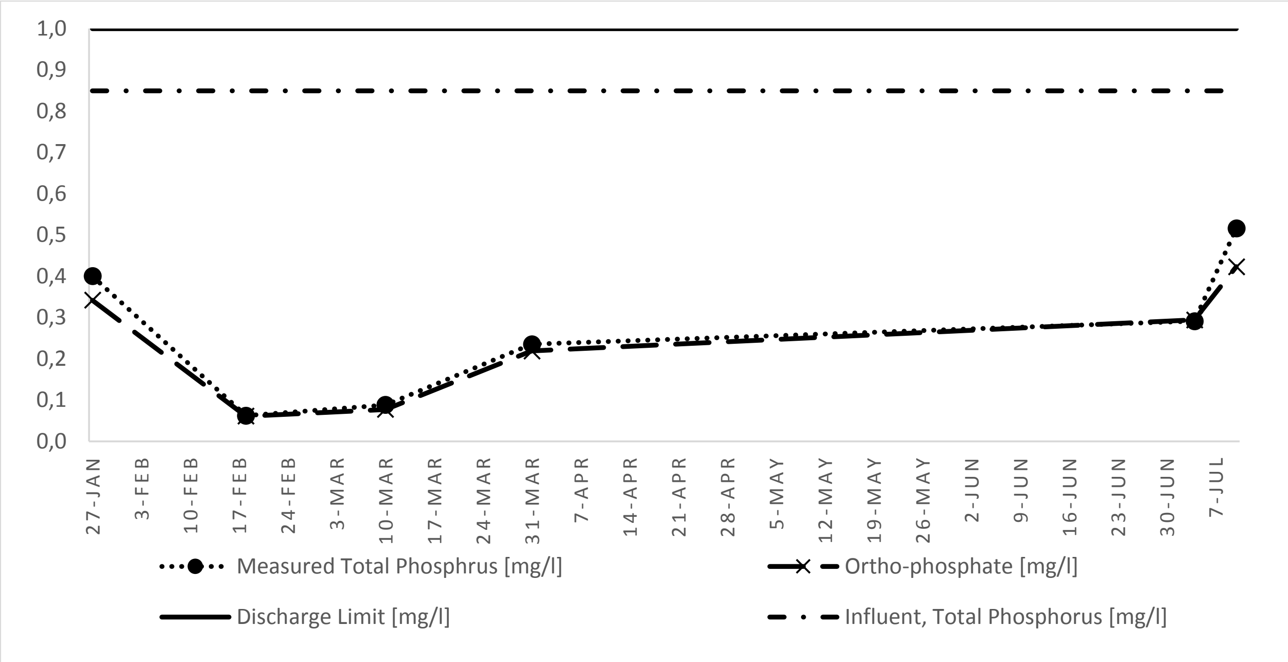

Figure 17, Total phosphorus and orthophosphate effluent results from 2014, total phosphorus influent in 2014 and discharge limit for total phosphorus.

In general the phosphorus concentrations in the effluent from KL is low. The concentration of orthophosphate is in average approximately 90% (82- 101%) of the total concentration of phosphorus. This is as expected and described in paragraph 2.1, and it means that most of the phosphorus is in soluble reactive form, which is also the form that can be bound in the filter material. The influent value of 0,85 mg P/l is somewhat lower than the expected 2-3 mg P/l. This could be because the effluent is derived from an avant-garde low energy use and eco-friendly building, thus with more environmentally conscious habitants. The average effluent is 0,27 mg P/l, and the standard deviation 0,18 which is more than 60 % of the mean. Still, the fluctuations of total phosphorus concentration in the effluent are minor compared to the discharge limit of 1 mg P/l.

The average before 2014 was 0,05 mg P/l, with a standard deviation of 0,02. The effluent results from 2014 where significantly higher than before 2014 (p-value 0,03). However, this was expected, as phosphorus sorption capacity is gradually decreasing as phosphorus is being adsorbed and thus reducing the number of available sorption sites. It was estimated by the time of construction, based on phosphorus capacity, that the filter material at KL will have a service life of approximaley 40 years (Jenssen & Vråle, 2003).

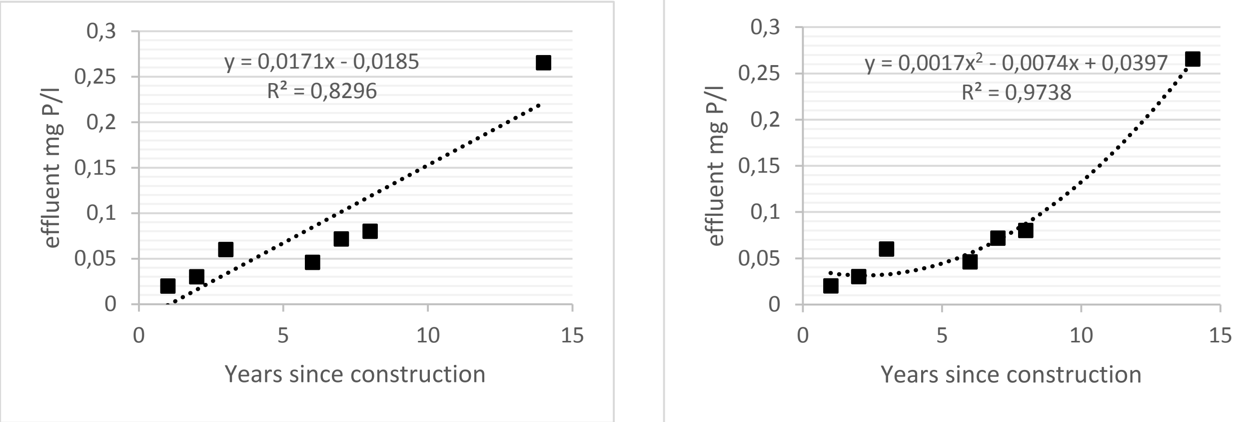

Figure 18, Regression function for total phosphorus effluent concentration (average value per year) as a function of years since construction. Linear regression to the left (R2=0,83) and 2nd order polynomial regression to the right (R2=0,97).

Average phosphorus effluent per year was plotted, and a linear regression was found to fit reasonably well (R^2=0,83), see the left graph of Figure 18. However, as the data suggest a more rapid decrease of available sorption sites, and as phosphorus sorption is a very complex process, other regressions were additionally tried on the data. A 2nd order polynomial function fitted best (R^2=0,97), see right graph of Figure 18. With this function the service life, that is the number of years from construction until the filter will release an effluent that exceeds the 1 mg P/l discharge limit, is 27 years. With the linear regression it can be calculated that the effluent will reach discharge limit after 59 years. As the Norwegian discharge limit is 1 mg P/l in average, and as the effluent concentration is very low the first years, the integral of the best fit (polynomial) regression, divided by number of years was calculated, see Figure 19. These calculations showed that the total service life of the filter would be 45 years. At this point the effluent concentrations is approximately 3 mg P /l. A service life of 45 years is 5 years longer than initially expected when the filter was constructed, and extending the time before a filter replacement is necessary will save both costs and energy.

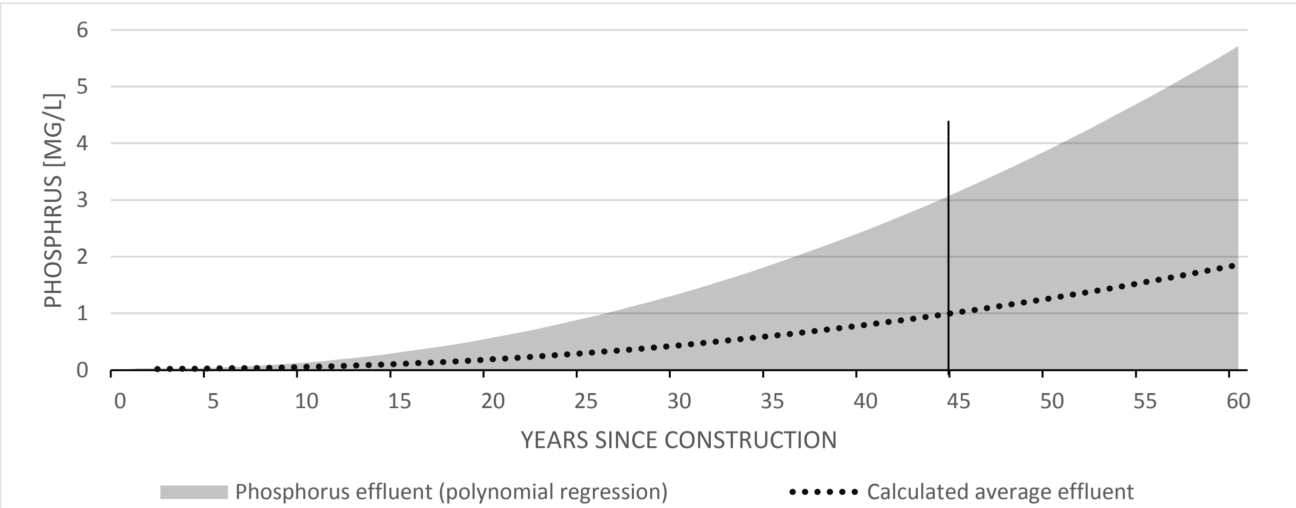

Figure 19, integral of the best fit (polynomial) regression (grey area), divided by number of years was calculated (dotted line). It was found that the average effluent would be 1 mg P/l after a lifetime of the filter of 45 years (black vertical line).

The total phosphorus concentration is reduced by 69 %, which is below the 80 % set in the Norwegian regulations for wastewater. However, it must be noted that that the influent into the system in 2014 was measured to already be below the discharge limit. The regulations also states that reduced requirements will often apply for greywater treatment, and fulfilling either % reduction or discharge limit is sufficient. Even with a 2-3 mg P/l influent (which can be expected from greywater, see paragraph 2.1), a 69 % reduction will still result in an effluent much lower than the discharge limit of 1 mg P/l. Overall the wetland filter at KL is highly efficient in treating the greywater, and it is even expected to have a service life which is 5 years longer than estimated at the time of construction.

4.2.4 Nitrogen

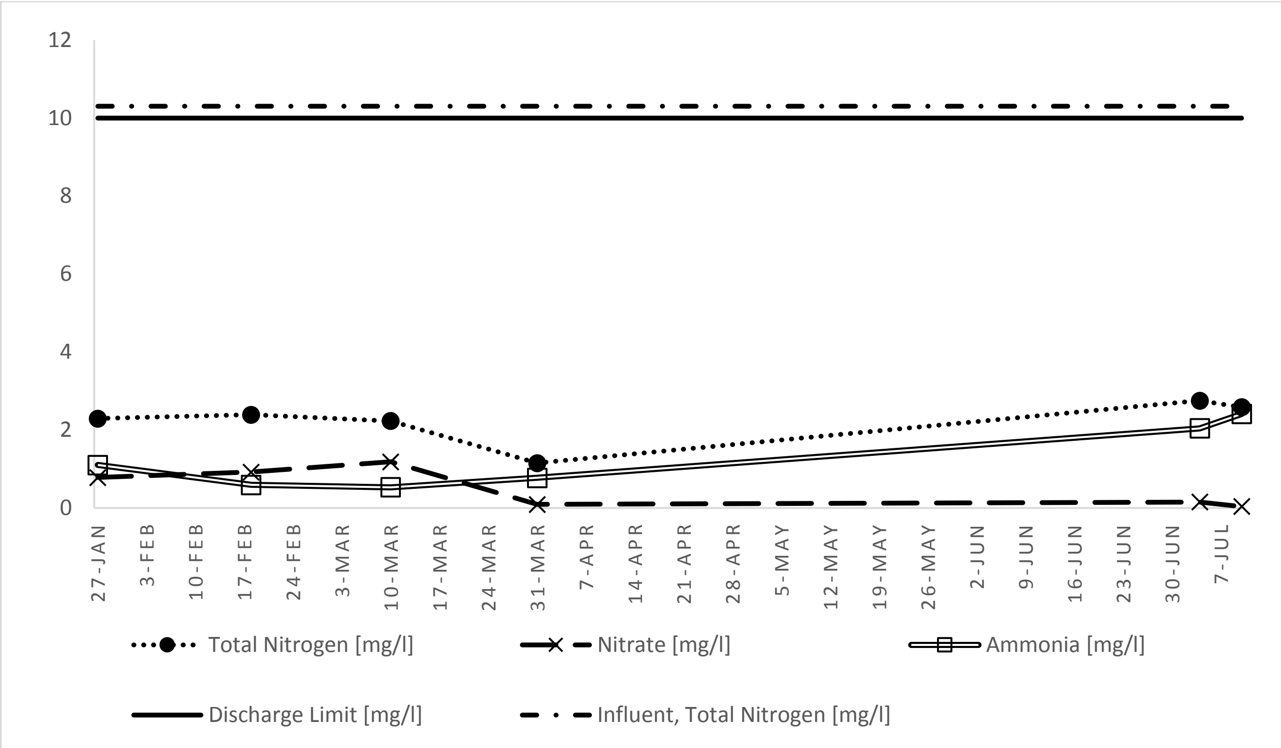

Figure 20, Total nitrogen, ammonia and nitrate effluent results from 2014, plotted together with the total nitrogen influent in 2014, and the discharge limit for total nitrogen.

The results for ammonia, nitrate and total nitrogen can be seen in Figure 20. The influent concentration for total nitrogen was 10,3 mg N /l, which fits well with the expected concentration of greywater from the literature of 9-10 mg N/l. The mean of the total nitrogen effluent was 2,2 mg N/l and the standard deviation was 0,56 which is only around 25 % of the mean. Although the p-value is marginal (0,09), there is no significant difference between total nitrogen data before and after 2014. If there would be a difference, the results only reflect a system that is becoming more stable and efficient as the average effluent up until 2014 was 3,01 mg N/l. The ammonia and nitrate concentrations are not significantly different from data before 2014, with p-values of 0,69 and 0,90 respectively.

As expected the ammonia values are decreasing from influent to effluent while the nitrate concentration is increasing, see Figure 21 The ammonia concentration falls with 66 % throughout the system while the nitrate concentration increases with 267 %. This nitrification indicates that the biofilter is performing as intended.

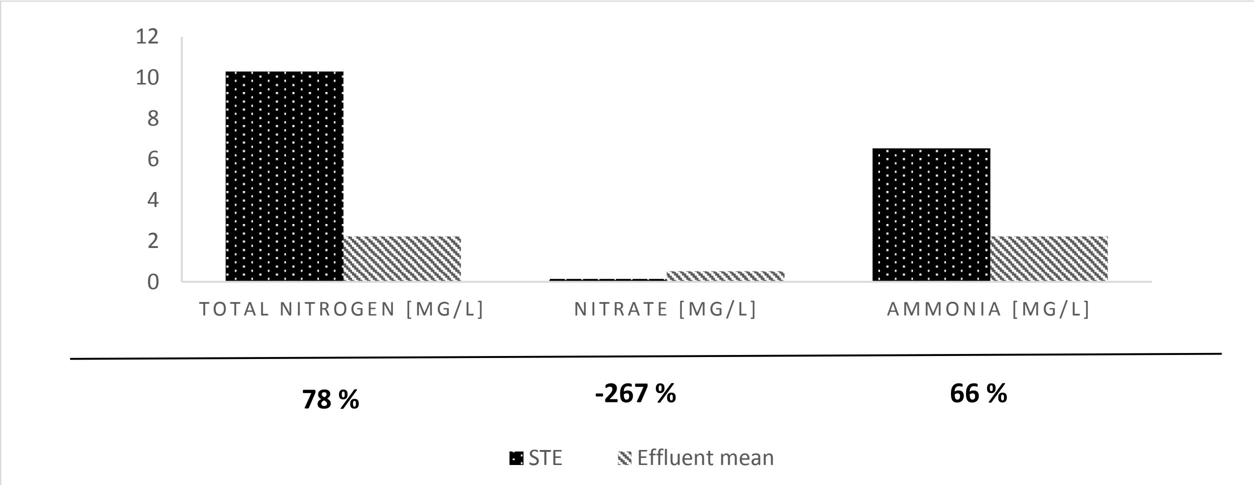

Figure 21, Influent and effluent values of nitrogen, nitrate and ammonia for the system. STE is the effluent form the septic tank which represents the influent value. Below each parameter is the percent reduction between influent and effluent.

It can be seen in Figure 20 that the concentration of nitrate is higher, and ammonia lower, with higher hydraulic retention time (January-march). This makes sense as a longer retention time would give the water more time in aerobic conditions and thus more nitrification is carried out. Although the elongated hydraulic retention time converts more ammonia into nitrate, the average value of total nitrogen is approximately the same when the retention time drops back to normal in July. There is no statistical difference (p-value 0,21) in the total nitrogen effluent between before and after July. The BOD data also indicates an efficient pre-treatment in the biofilters, as well as only 2 mg N/l in the effluent is much lower than the discharge guidlelines, so although ammonia levels could seem relatively high the total treatment efficiency is very satisfying.

As nitrogen removal is a biological reaction it was investigated for seasonal variability. Because of few data points, the extended retention time during the winter of 2014 and due to possible fluctuations with development over time, no conclusions or specific trends could be spotted. Bacterial processes are very complex and difficult to predict and as the greywater is relatively warm, the water in constructed wetlands system can keep a stable temperature although air temperature is changing. The results does therefore not prove anything with regards to seasonal variability but it could seem from the data from 2001-2014 that the effluent concentration is stable throughout the year

The reduction of total nitrogen in the system was 79 % which is higher than expected for constructed wetlands in Norway treating regular wastewater (50 %). It is also higher than the 70 % demand in the regulations for treatment efficiency. It is also worth mentioning that the influent value is only 0,3 mg N /l above discharge limits, and thus only a minor treatment is necessary with regards to nitrogen.

The effluent value of KL is in average only 22 % of the discharge limit of 10 mg N/l. The low value of nitrogen is also an indicator that fecal contamination, and number of E. coli. can be expected to be low. The effluent of 2,2 mg N/l also is below the drinking water guideline limit of 10 mg N/l (EU 1998; WHO 2011). In addition, the drinking water guideline is originally based on nitrate concentration causing blue baby syndrome. As the nitrate concentration in the effluent is only 0,5 mg N /l the water should be more than safe enough to drink with regards to nitrogen and nitrate, and using it for recreational purposes or bathing is legit.

4.2.5 Conductivity and pH

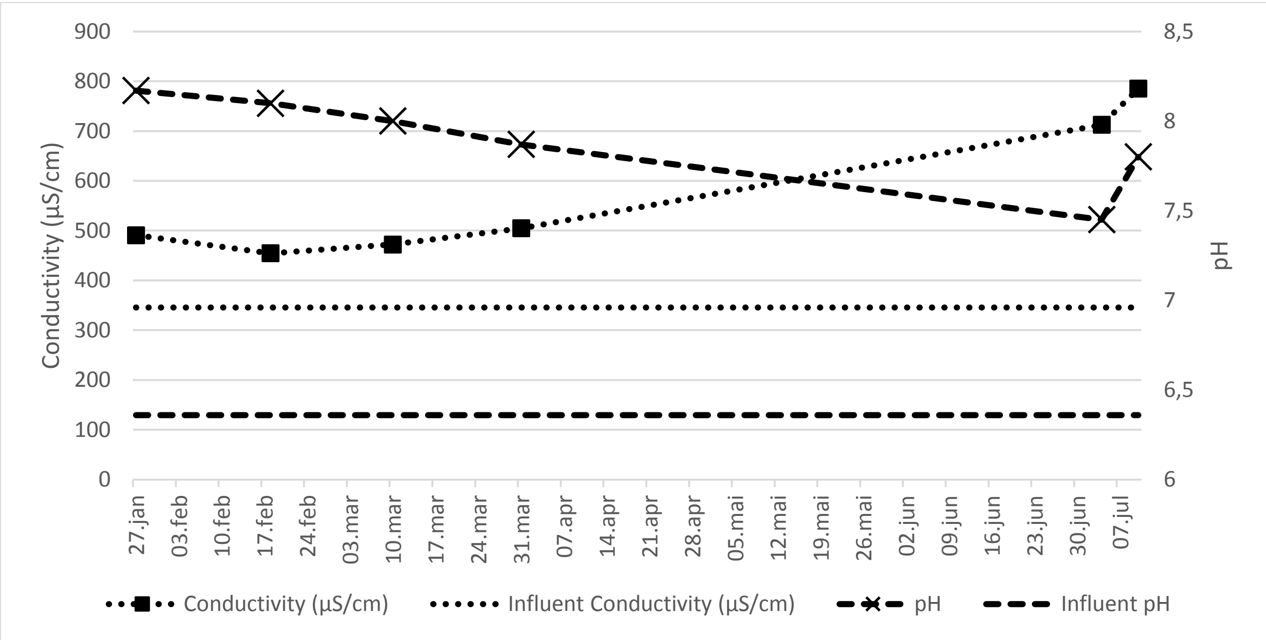

Figure 22, Influent and effluent values of conductivity and pH for KL in 2014.

The average pH was 7,9 with a standard deviation of only 0,26 (3 % of mean). The influent pH was measured to be 6,4. This fits well with the expected as pH for wastewater and a pH between 7-9 is optimal for nitrification and denitrification (Ødegaard et al. 2012). The mean pH value before 2014 was 9, and there was a significant difference in pH from before and after 2014 (p-value 9×10^{-5}). As described in paragraph 2.3.4, the increase of pH in the filter media is expected from filters containing Filtralite-P, and this effect is decreasing with the lifetime of the filter. The conductivity has a mean of 570µS/cm, and a standard deviation of approximately 25 % of this, which is 141. The influent of the system is 345 µS/cm. These results fits well with that leaking of calcium and magnesium from the filter mass is reported as the reason of increased conductivity of water flowing through filtralite-P filters (Skjønsberg 2010). Generally the results of pH and conductivity reflects that the filter is performing as intended.

4.2.6 Indicator Bacteria

The results of the bacteria analysis revealed that the most probable number (MPN) of E. coli per 100 ml, was 18,9. For both of the samples before July the MPN was less than one, but as the results from

July are quite low compared to the last result, and as they are from conditions with an extended retention time, the 18,9 per100ml is considered more representative than an average value. This result is still less than 4% of the threshold value set in the EU bathing water quality directive. So, even using only the highest value, the risk of the water containing a potentially harmful amount of pathogenic organisms must be considered very low.

Regarding the Norwegian bathing quality guidelines, the amount of indicator bacteria is considerably lower (1,9 %) than threshold limit. Furthermore the water quality achieves 'good' bathing standard in Norway as it only contains less than 20 % indicator bacteria compared to the threshold value. As the WHO guidelines for irrigation are a 100 times higher than the guidelines for swimming water quality, the analysis reveals that the water from KL is can be used for irrigation with no hygienic concerns of bacteria. This value is for unrestricted irrigation, which means that the water can be used even for edible crops as for example salad. The average MPN of E. coli before 2014 was 3, but with single samples with values as 8 and 10. A result of 19 is slightly higher but might as well be to random single events or uncertainties in the method, as there are few data points from relatively small grab samples. If the same amount of bacteria in the influent as in 2008 is assumed, the bacteria reduction is still 3 log, the same as before 2014. Overall, the results shows low concentrations of E. coli, and that the hygienic quality of the effluent is more than sufficient for both recreation and bathing, even after 14 years of treatment.

4.3 Compared to other Constructed Wetlands Treating Greywater

The cases of similar solutions described in the literature (see paragraph 2.4), are all systems treating greywater by constructed wetlands. Not too many cases were found during the literature study of large-scale systems treating greywater decentralised by constructed wetlands, this reflects that the KL system is quite unique. The comparison between the systems are somehow limited as the age of the system at the time of sampling was in most cases not possible to retrieve. It would have been interesting to have included this parameter in the comparison of the systems, but instead a more general comparison is made, where the effluent and treatment efficiency average of all of the systems except KL, is compared to the KL system in 2014. All data can be seen in appendix 3.

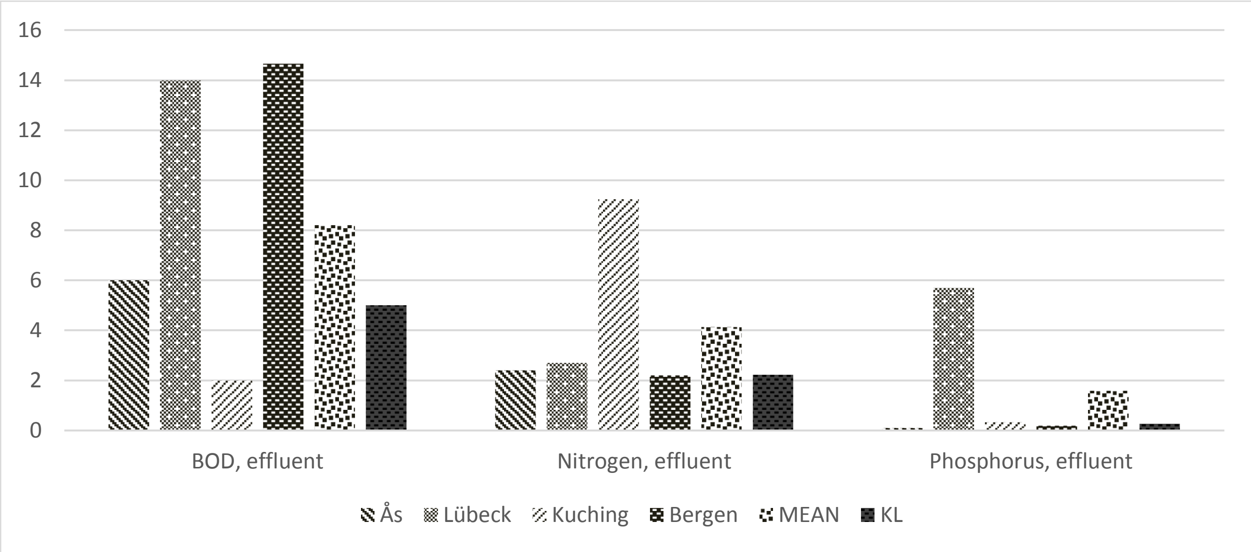

Figure 23, BOD, total nitrogen and total phosphorus effluent from each of the cases Ås, Lübeck, Kuching and Bergen and the mean value of these systems. The 2014 KL average value is also included.

Figure 23 shows the effluent concentrations for all of the similar systems, including their average, plotted together with the concentration in the effluent from KL in 2014. It can be seen that KL has a lower concentration than the average for all parameters. For BOD and Nitrogen the KL is 50-60 % lower than the mean of the other solutions, while for phosphorus the difference is just below 20 %. There is no significant difference in the effluent values between KL and the other treatments systems for any of the parameters, with a p-value of 0,3, 0,4 and 0,4 for BOD, nitrogen and for Phosphurus respectively. All of the systems, with regards to BOD and nitrogen, fulfil the Norwegian discharge limits. With regards to phosphorus the flintenbreite system exceeds the guidelines, but all the other systems have effluent concentrations of only 10-31 % of the discharge limit, and KL has as previously mentioned 27 %.

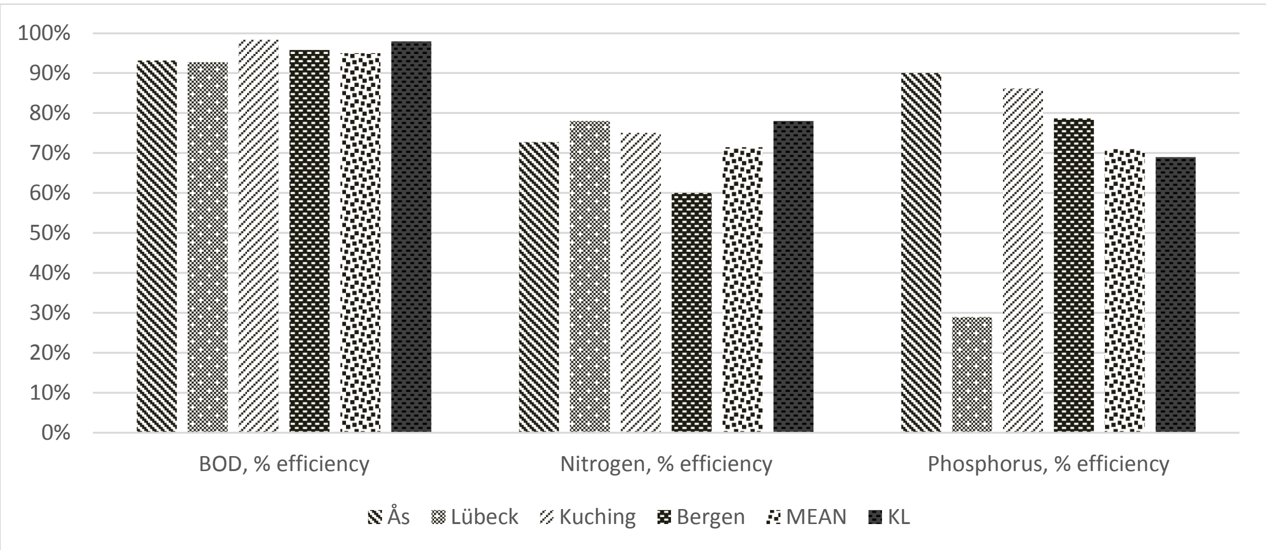

Figure 24, treatment efficiencies (%) for each of the cases Ås, Lübeck, Kuching and Bergen, as well as the the mean value of these systems. The 2014 KL average value is also included.

The treatment efficiencies for the similar systems, including their mean, is plotted together with the average treatment efficiency of KL in 2014 in Figure 24. For both BOD and Nitrogen removal KL has a higher removal percent than the average of the other solutions. The phosphorus efficiency is slightly lower for KL than the average of the other solutions, but this is most likely because KL is the system with the longest lifetime. The effluent from KL is after more than 13 years since construction while the other data are averages over a few years and for systems with an age of 1-6 years. However, the treatment efficiency of phosphorus is only 2 % lower than average and the value cannot be considered too exact. The treatment efficiencies had also no significant difference from the KL 2014 data, with P-values of 0,12, 0,14 and 0,88 for BOD, nitrogen and phosphorus, respectively.

It is challenging to compare the values overall as greywater in some of the cases might be excluding water from kitchens and because of the wide variations of the habits of the users. For each of the systems exact dimensions of treatment system and amount of users is mostly unknown as well. Ås and Bergen both has a LWA (not Filtralie-P) as filter material, and a pre-treatment step. Kuching has biodomes as pre-treatment but in the wetland a local material was used made out of crushed limestome. This system is generally performing well, and although the effluent value of nitrogen is a little high the system fulfils the guidelines. The nitrogen removal efficiency at Bergen is 60 % and thus not sufficient to meet the regulations for % reduction. The reduced efficiency is most likely due to the pre-treatment step is simpler here, and not as optimised with regards of spreading the wastewater on a larger surface area, as is the case with the later developed biodomes that Ås and KL has. However, the Bergen system has a nitrogen effluent concentration that is only 15 % of the regulations. Regarding % phosphorus reduction only the Ås system fulfils the regulations, but as mentioned earlier all phosphorus values except from Kuching are below effluent limits of 1 mg P/l.

The Flintenbreite case only has a septic tank, no biodomes before the wetland, and the filter material is unknown. Depending on the aeration the BOD and N removal could be expected to be lower in this system compared to the others, but at least a lower efficiency in removing phosphorus is expected. The results show that Flintenbreite performs well with regards to nitrogen and BOD but poorly with regards to phosphorus. Using a filter media enhancing phosphorus binding could be a solution to optimise this. Generally the results across the different large-scale greywater wetland systems is similar. Overall it seems that KL is representative for other similar solutions, and is generally performing better, despite its longer lifespan.

4.4 KL System Compared with Oslo Municipality's Existing Solution

4.4.1 Mass effluent and environmental status of the recipient

If the greywater had not been treated in the courtyard at KL it would have been sent to the WWTP Bekkelaget. The effluent of this plant is released in the inner parts of the Oslo fjord. The Oslo fjord is vulnerable to pollution, especially the inner part as the only way out for the water is through a passage only 1 km wide and 20 m deep (Thaulow & Faafeng 2013). The fjord had its highest amount of pollution in the 70's, and the situation, especially over the last decades, has significantly improved since then. However, after the beginning of the 00's this improvement stagnated and the last few years an increase in pollutant loading has been observed, followed by algae growth. The water quality today can be defined as good but not sufficient. Periodically there are poor oxygen conditions in deep waters, in addition to algal blooms caused by nutrients and organic matter concentrations that exceed the tolerance limits of the fjord. In addition, periodically there are many places with insufficient hygienic quality for bathing (Thaulow & Faafeng 2013). At the same time the population of Oslo is growing rapidly, as it is in fact the fastest growing capital in Europe (Savage 2014), and the current WWTP and distribution systems are already exceeding their capacity limit. Increased rainfall adds further pressure on the distribution system, with leads to more frequent sewage overflows. And rainfall, especially the intense events that leads to overflows, are expected to increase even further with climate change. As many of the areas in the inner parts of the Oslo fjord are defined as recreational areas, and because of the new EU water framework directive, the expected standards for the fjord are steadily increasing (Thaulow & Faafeng 2013). All of these factors mean that there is a goal to reduce the loading of nutrients and organic matter to the fjord.

A comparison was made between the effluent of KL and the effluent of the Bekkelaget WWTP to give an indication about the difference in treatment efficiency and mass loading to the Oslo fjord. Because KL treats water from only 100 persons, it was calculated the mass per person per year released from each plant. The results can be seen in Figure 25 and calculations in appendix 4.

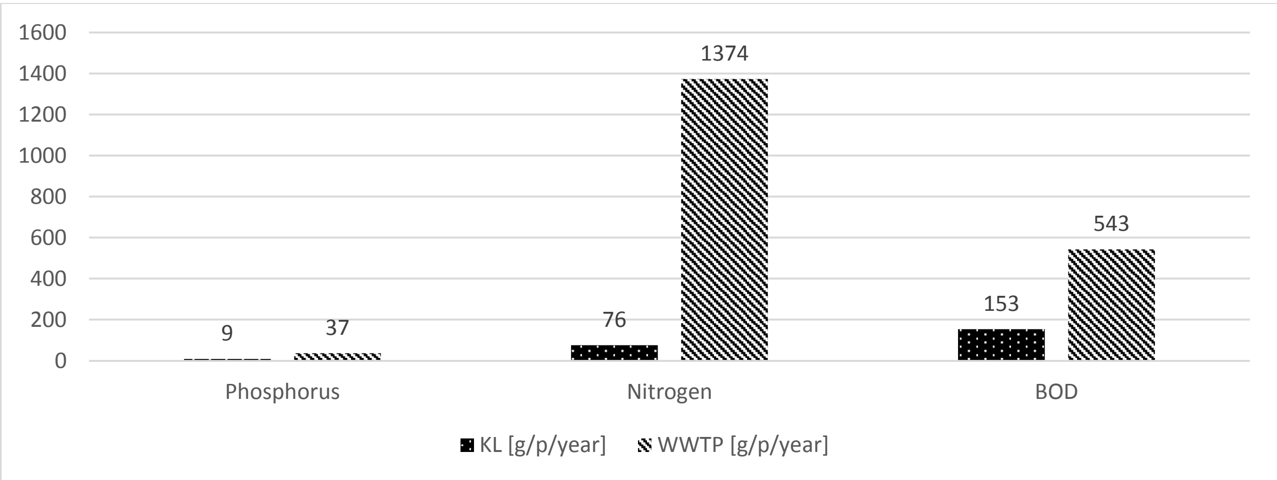

Figure 25, Mass of pollutants released for each of the parameters phosphorus, nitrogen and BOD – from KL and the municipal centralized WWTP - per person per year.

A significantly lower effluent by mass from KL can be observed, compared to the WWTP. This difference is 75 % and 72 % for phosphorus and BOD, respectively. For nitrogen the difference is as great as 94 %. This calculation is based on that the blackwater is not treated as waste in the centralised water-based plant, but instead treated separately with nutrient recycling and energy recovery as the main goal. This would imply environmental benefits in addition to the reduced nutrient loading. It is clear that a 70-95 % reduction of mass loading per year would have great impact on the water quality in the Oslo fjord.

4.4.2 Economic Considerations

It is very difficult to make a good economic comparison of a source separation system as at Klosterenga with the existing sewer system in Oslo, and this is not within the scope of thesis. However, I have tried to elucidate some economic aspects. The comparison of KL is made assuming the previously calculated 45 years of service time, based on phosphorus sorption, which means from 2001 to 2046.

Oslo municipality are facing increasing costs to secure the adequate infrastructure for the future. The Oslo WWTP's capacity is currently exceeding its limits, and an expansion of capacity will be attained by constructing a new plant. The cost of the new plant is estimated to be approximately 2,7 billion Norwegian kroner (VAnytt 2013). Furthermore, much of the wastewater from Oslo municipality is led to a WWTP outside city limits, and this plants capacity is also under pressure and will be expanded within few years as well. In addition to the WWTP comes the costs of maintaining and upgrading the pipe infrastructure to sufficient quality. The combined cost of pipes and the new treatment plant up until 2030 is estimated to 1,8 billion kroner per year for Oslo municipality (Ødegård et al. 2013). This number contains many uncertainties, but would result in a cost as high as 2600 per person per year.

The economic comparison of the centralised sewage system of the city of Oslo (OCS) with the KL greywater decentralised system (KLD) are made with regards to the greywater fraction only. The cost of greywater treatment by OCS was calculated as following: The wastewater bill for the KL building in 2010, for blackwater and greywater together, would have been 53 750 kroner. As the wastewater bill covers all investments, operation and management of the OCS, this number is representing the yearly cost of treating the wastewater from KL, if no greywater was separated. As wastewater bills are based on volume, the greywater cost for OCS can be estimated to be 75 % of this bill. Using this number, and taking into account that the Oslo Municipality Water and Sewerage Works (VAV) has reported that the wastewater bill will increase with 5% every year the coming years, inflation included (Oslo Kommune Vann- og Avløpsetaten 2014), the yearly costs were calculated. The sum of the costs from 2001 to 2046 gives a total cost of the OCS treatment of the greywater from KL of 4,4 million kroners. For details see appendix 5.

The cost per year of the KLD was 50 235 kr in 2014. This number is including investments of the system, a yearly inspection, as well as the regular changing of pumps and emptying of the septic tank. Electricity consumption is considered negligible, as the required electricity for the pumps is reported to be very little and only is a minor part of the building's total electricity consumption (Stenberg & Sørensen n.d.). With inflation taken into account, the total costs for the KLD from 2001 to 2046 is estimated to be 2,9 million kroners. For details see appendix 5. The results show that the total costs of treatment of greywater with the KLD is only 66 % of the OCS.

The calculated numbers are a rough estimate and many factors could not be taken directly into consideration. It is important to remember that if only blackwater was sent to the WWTP, this would give a more concentrated flow, which is easier to treat for the WWTP (Bolmstedt 2004). Lower flow rates through the system means decreased effluent concentrations, and added nutrient and organic matter enhances the treatment processes at the WWTP (Bolmstedt 2004). Reducing the loading on the transportation system would also save costs, as less new volume would be needed. The total wastewater fee at KL is also excluding the connection fee to the municipal system, and also considerably lower than the 2600 per person per year for Oslo towards 2030, previously estimated by another source (Ødegård et al. 2013). The costs and earnings of the scenario where the blackwater is collected separately, for biogas and fertiliser production were also not possible to take into account. However, Gray and Booker (2003) showed that for a hypothetical system for 10 000 people, treating greywater and blackwater separate and decentralised was cheaper than using combined sewers to a centralised plant. Two assessments made for the city of Kuching Malaysia with 500 000 inhabitants, also showed that a decentralised system based on source separation and wetlands for greywater treatment was cheaper than a centralized system (Hanserud 2004; Mamit et al. 2005). However, Jenssen and A. Vatn (1991) anticipated that decentralized a source separating system would be more expensive to start with but cheaper in the long run, especially if environmental benefits were taken into account. The environmental benefits on increased recycling could not be included in this analysis, and a cost-benefit analysis or similar is recommended to further investigate the effect of the KLD compared to the OCS.

Other uncertainties in the numbers in the calculation is that the assumed 5% yearly increase in the wastewater bill is in 'Scenario 2' by VAV, a scenario which would only maintain the existing standard. Scenario 1 has a 5,3 % increase in the bill, where the system would be upgraded to meet plans and policies by having an increased capacity, more blue and green structures and less leakages and overflows (Oslo Kommune Vann- og Avløpsetaten 2014). Because of uncertainties scenario 2 was chosen in this thesis, but choosing scenario 1 instead KLD would only cost 60% of the OCS. The environmental effect of KL could probably be the same, or most likely even greater, for a lower price.

Although the results that KL has 60-70% of the costs of the existing solution involve many uncertainties, it can be estimated that having the greywater treated at KL would probably not be more expensive than treating the greywater by the centralised sewer system that exists today. Further comparison of the two solutions, to reveal how scale and other factors can be optimized, is recommended.

4.4.3 Potential Impact for Policies and Plans

There are many plans and policies that regulates water and sanitation for Oslo municipality. The following paragraph gives an overview of relevant visions and priorities for systems as KL in the city of Oslo. Table 12 sums up the main relevant plans and policies for now and the future.

Table 12, Relevant goals in current policies and plans regarding KL and the handling of wastewater in Oslo's future. (Oslo Kommune 2011; Oslo Kommune Byrådet 2014; Oslo Kommune Byrådsavdeling for Miljø og Samferdsel 2014; Oslo Kommune Vann- og Avløpsetaten 2014)

	Byøkologisk program (2011-2016)	Kommuneplan (-2030)	Handlingsplan miljø og klima (2013-2016)	Hovedplan avløp (2014-2030)
Increase recycling of waste resources	*	*		
Keep and strengthen green and blue structures	*	*	*	
Test and develop new environmental solutions	*			
Opening rivers and creeks	*		*	*
International leading environmental city		*		
More decentralised and integrated handling of stormwater			*	*
Improve hygienic/chemical/ecological status in fjord		*	*	*
Reduce volume of water in sewage pipes			*	*

Urbanecological program 2011-2026 (Byøkologisk program 2011-2026)

This plan focuses on sustainability and blue and green structures, recycling of waste resources and has an extensive focus on opening previously piped rivers and creeks. There is also a goal to make Oslo a pioneering city when it comes to test and develop environmental solutions. Approved by the Oslo city council 23 march 2011 (Oslo Kommune 2011).

Municipality plan, Oslo towards 2030, smart, safe and green (kommuneplan Oslo mot 2030 – Smart, trygg og grønn)

Aims to make Oslo an internationally leading environmental friendly city, and climate emissions shall be reduced by 50 % before 2030 compared to 1991 levels. Oslo shall increasingly be more climate-friendly, green, blue and the inhabitants shall be secured access to air and water of good quality. It shall be invested in efficient utilisation of resources and a cyclical approach to waste management. Approved by the Oslo city council 26th of September 2012 (Oslo Kommune Byrådet 2014).

Actionplan Environment and Climate 2013-2016

This plan addresses the need on securing the city against the increased precipitation expected by climate change. It is therefore recommended to increase the percentage of green surface, opening creeks and use to stormwater as a resource. The action plan furthermore highlights that the current water quality of the Oslo fjord is insufficient, and that the sewage leakages and overflows is one of the main reasons for this. Because of the demands from the European Water Framework Directive on good ecological and chemical status, resource demanding measures must be implemented before

2021. Reducing volume loading to sewage pipes is essential for this and handling stormwater decentralized is an important measure to attain this goal (Oslo Kommune Byrådsavdeling for Miljø og Samferdsel 2014).

Main Plan for Wastewater (2014-2030)

This report is written by Oslo Municipality Water and Sewerage Works (VAV) and is their main plan towards 2030. In addition to the water framework directive's demand for good chemical and ecological status, VAV aims to ensure good hygienic conditions in urban streams and in the Oslo fjord. Other main goals are to ensure both that the sewage is safely transported and that its energy potential is utilised for the city's greater good. Sub goals are sewer separation and increased local handling of stormwater, to reduce the pressure on the existing sewage system. Re-opening of natural creeks is a priority. The current state of the Oslo watercourses is very poor with regards to chemical quality. Currently a high pressure is maintained in the pipes to reduce overflows according to legislation and plans, but this also leads to a higher amount of leakages (Oslo Kommune Vann- og Avløpsetaten 2014).

VAV and their future plans contain many good initiatives, as utilizing the heat in the wastewater and to continue to make biogas of the sludge from the Oslo WWTP (Oslo Kommune Vann- og Avløpsetaten 2014). The sludge is also reused as fertilizer today. However, WWTPs are as described earlier very energy consuming and in addition 58 % of the water entering the wasterwater treatment plant today is either stormwater or unwanted leakages into the pipes. These fractions are unnecessarily diluting the nutrients before treatment, and thus is hindering recycling. In addition, at the same time as the city is growing fast and has limited treatment capacity VAV are allowing more wastewater from the neighbouring municipalities to be added to the Oslo network (Oslo Kommune Vann- og Avløpsetaten 2014).

Opening of the Hovin creek

The Hovin creek was led into pipes in the 1960s, but with the current plans as described earlier, it is desirable to open as many parts of this creek as possible. The upper parts of the creek are already re-opened. In a new development area of Oslo, Tidemannsbyen, bringing the Hovin creek out of the pipes and up to the surface is an essential element, with more than a kilometre of the creek re-opening (Oslo Kommune 2014). The Hovin creek is one out of 8 currently prioritised watercourses in Oslo, when it comes to opening of creeks and rivers.

It has been reported that the creek does not have sufficiently hygienic and chemical status to be brought to the surface. VAV reported in 2012 that the concentration of both nutrients and metals are high enough to consider the stream polluted, in addition to that the water is dominated by pollution-tolerant algaea. The flow of the Hovin creek is estimated to be 180 l/s and there are 16 sewage overflows and 45 stormwater pipes, leading directly into the creek. (Oslo Kommune Vann- og Avløpseateten 2012). Furthermore the Norwegian water resources and energy directorate reports that a very high number of intestinal bacteria, in addition to a very high level of nutrients has been detected in the in the Hovin creek (Vann-Nett n.d.). VAV are currently working with minimising the two sources that pollutes the creek upstream: sewage leakages and connected stormwater from roads and parking lots, to make the opening of the creek downstream possible (Oslo Kommune Vann- og Avløpseateten 2014). Opening creeks contributes to both chemically and ecological improved quality of the stream. The regulation plan for the Hovin creek and KL sculpture park is currently in progress (Jensen 2013). Drawings can be seen in Figure 26 (the courtyard where the greywater treatment plant is located is the one right across from the park, behind the football field to the right).

Figure 26, Plans for how the Hovin Creek (dark grey) will look as a part of the sculpture park, when opened (Jensen 2013).

In the whole the future goals of Oslo municipality can be achieved by using systems treating greywater by constructed wetlands in an urban setting. The relevance to each of the points in Table 12 is highlighted below:

Increase recycling of waste resources, as the blackwater from KL provides a more concentrated effluent of nutrients, and this source separation optimises recycling.

Strengthen the blue and green structures, as the system is green and blue in itself, and also promotes biodiversity. The green advantages of constructed wetlands was described in paragraph 2.3.5 To make a city bluer and greener it is a great benefit that infrastructures have a function beyond their "colour", as the density of cities makes space limited.

Reduce volume of water in the sewage pipes, by source separating the greywater and treating it decentralised, less volume is led to the sewage system which reduces overflows. In addition it increases the treatment efficiency at the WWTP as the nutrients would be more concentrated.

Improve hygienic/chemical/ecological status in the fjord, as less volume loading of WWTP leads to less overflows from the wastewater system but also since the treatment process itself becomes more efficient when the influent is more concentrated. In addition, as the previous results in this thesis has shown, the mass of pollutants per person released will be much lower by using systems as KL.

More decentralised solutions for stormwater, opens up for decentralisation in general especially for the sake of reducing loading on the sewage system and WWTP. In addition, decentralised solutions generally increases awareness about water consumption (Sauri 2013). Decentralised treatment of stormwater has shown that the future solutions to urban wastewater challenges are not necessarily more advanced or technically complex, but rather that collaboration across different sectors can create integrated solutions with mutual benefits (Bahri 2012). Starting to consider this integration and decentralisation for greywater would be an obvious next step.

Opening rivers and creeks. The Hovin creek, to which the effluent of KL is connected, is in the process of being re-opened and integrated in the neighbouring park. This means the KL system can become a statement on the positive contribution recycled wastewater can have in society. The KL system can both can raise awareness among the users on wastewater production and demonstrate how wastewater can be a resource – utilised for example for irrigation of the park and local urban farming projects.

To be an internationally leading city and to develop and test out new solutions are both goals that highlights how KL is important even it is just as a pilot project. The effect of KL in itself is not immense. However the KL project has been very successful, with many valuable lessons learned that makes way for scaling up this type of sanitary solution.

It is important that although this thesis argues that decentralised systems are viable solutions that should be implemented, this does not mean that all previous centralised solutions should be discarded. There are numerous ways to combine and use the strength of the two together, and existing infrastructure should always be taken into account. To treat only blackwater and heavily polluted stormwater in the centralised system could be one option, another option is to have a few decentralised greywater treatment plants while the remaining water is sent to the centralised system. As KL is an evidence of, these type of systems can easily be integrated with existing infrastructure and gradually be scaled up to more units.

4.5 Suggestions for Further Research and for KLs future

This section will come with suggestions for further research, in addition to suggestions for improvements that could be interesting for the constructed wetland greywater treatment system at KL.

1. *Investigate concentrations and treatment efficiencies for micropollutants, and other pollutants.* Special attention should be paid if some of these pollutants are not broken down or removed in this type of treatment system. And in addition it could be investigated whether the pollutants are persistent, toxic, and bioaccumalutive, to decide their faith after going to the nearby creek. The results would indicate if there are disadvantages with the specific treatment method, or if there is a need to change the legislation of allowed compounds in products that are intended to end up in greywater, as the faith of many pollutant in the regular centralised treatments systems often not is known either. American research has shown that nature based systems with soil or similar filter media can remove a large amount of organic micropollutants. Further investigations of other hygienic parameters in the system, as virus and other microorganisms, could also be interesting to investigate, also from the biofilter only.

2. The *nozzles in the biodomes should be serviced*. Although the treatment results are good, a yearly inspection is recommended. As the service life of the previous pumps from the septic

tank was only three years, it could be that the nozzles are clogged and the pumps had to provide a higher pressure than necessary. Installing a pressure measure unit right after the septic tank for constant monitoring could also be an advantage to detect if the nozzles are in the process of clogging. Allowing for easier access to the lids of the biodomes than today, where they have to be dug out, would also make regular service of the nozzles easier.
On July 4th it was dug down until the lid of one of the biofilters and it was opened for inspection. As the pump from the septic tank was not running at that point and attempts to imitate a higher water level in the septic tank to make it start was not successful, not much information was retrieved from this inspection. The nozzle was also too firmly fasten to be released for individual inspection.

If there is need to enhance the aerobic conditions and increase the nitrification in the biofilter there is the possibility to use the already installed air-pumps. An increased control of when the pump runs could further optimise the loading of the biofilters. Today the pumps are controlled only by the water level of the tank, but with an additional timer installed the loadings could be smaller and more frequent. This is a quite cheap and simple measure that would enhance the filters treatment efficiency. However, as the guidelines for total nitrogen in the effluent already are fulfilled, this would be more for research purposes.

3. *Reuse the treated greywater.* The water could be used for irrigation in the courtyard. The handpumps in the yard originally installed is probably only for collected stormwater and the pumps have been shut off for years. Additional handpumps could be located outside the courtyard for public use. In both cases a clear labelling, that this is not potable water, is important. As the nearby park requires large amounts of water for irrigation each year, using the water here seems to be an excellent way to save potable water. At the moment there are also many urban gardening projects nearby the courtyard, and even in the KL sculpture park there are boxes with flowers and edible crops. As the greywater fulfils irrigation guidelines the water could be utilized as a resource for the neighbourhood community garden both with regards to water and nutrients. Of course a continued regular monitoring of the quality of the effluent from KL is a prerequisite to ensure that the sufficient hygienic quality is maintained. Reusing the water for toilet flushing is also an option, but as this would demand quite a lot of piping system it is not realistic to happen in the near future unless the whole building is in need of renovation. However, reusing the water is quite simple and especially during summer when the water consumption in Oslo is at its highest because of garden irrigation, the greywater could contribute to reduce the drinking water demand.

4. To start *scaling up the KL pilot system* to more constructed wetlands treating greywater in Oslo and at the same time start collecting the blackwater for treatment. Some minor local composting could also be an option to save energy for transportation and to use the recycled nutrients for fertilising the increasing amount of urban farming that is taking place in Oslo. If more systems like KL should be built an extensive report on lessons learned from both planning and maintenance from the involved stakeholders should be performed. There were

many challenges in the beginning and many lessons can be learned from the system. The challenges were mainly due to that neither the landscape designers nor the entrepreneurs had done something similar before, and in addition the compactness of the plant and the design of the building created some challenges of letting the water travel solely by gravity from the building to the septic tank. Despite the challenges in the beginning, the KL system is still performing well after 13 years since construction, and because of the environmental and economic advantages estimated in this thesis it is clear that Oslo as a whole would gain by scaling up this system to more units.

5. Occasionally, while sampling water at KL, some smell was registered along the northern edge of the septic tank. *Covering the aeration vent* from the tank with bark could solve this problem.

6. To make a more *in-depth study of solutions treating greywater, especially in urban settings* could also be interesting as the time for this thesis was restricted. To compare both treatment efficiencies and price with years since construction could give even more insight. A cost benefit analysis, or similar, also comparing with the centralised system, could also give valuable comprehensions. The system at KL's main challenge is that is space demanding, and where space is limited compact treatment solutions as bioreactors and other package treatment plants could be used. For the future of sanitation a «one-size-fits-all» does not have to be the solution, but rather different solutions, both centralised and decentralised, adjusted for each specific situation.

7. *Investigate if the constructed wetland could have been designed smaller, or even consist of only a biofilter.* Previous studies have reported that both a 70 % BOD reduction and a 2-3 log reduction of indicator bacteria can be obtained in the pre-treatment biofilter, and that for not vulnerable recipient a biofilter can often be sufficient treatment for greywater. Denitrification can happen in anaerobe microzones, and nitrification takes place in the aerobe zones. The constructed wetland is mainly for phosphorus and bacteria reduction and is the most space consuming part of the system. The components that needs most treatment is the BOD and bacteria in greywater, and as this thesis has shown the influent of the system already fulfils discharge limits with regards to phosphorus and almost also with nitrogen. The constructed wetland can be an aesthetic integrated green element as at KL and it is good as a polishing step for security reasons, but it should be further investigated if it actually is necessary. Create a way to take samples from the biofilter effluent would be necessary to see how well this unit performs alone. Starting to use the UV treatment again instead could be a space-saving measure compared to the wetland, if further hygienic treatment is needed after the biofilter. However, as this is more expensive and energy consuming, and also demands more maintenance, this should probably only be done if more systems had a UV treatment step. When more similar systems are installed some routine of maintenance, and more knowledge on the systems, could be established. The biofilter at KL is as described oversized, with probably twice the necessary size, which indicates that the area requirements could also be reduced with regards to the biofilters.

8. To start *using the system during wintertim*e again. The system was running successfully during winter the first years but as the people responsible for maintenance changed and some knowledge was lost, the current maintainers shuts the system off during minus degrees. The system is designed for winter usage, with additional depth of the wetland filter, and an option to only put the lowest distribution pipe of the wetland in use to avoid freezing. There are many wetlands treating wastewater that has documented that treatment all year in cold climates is possible, and often the treatment is just as efficient as during the other seasons.

9. As 13 years have passed since construction, few of the current residents in the KL courtyard know of the greywater treatment system and what it does. As these types of systems are useful for creating awareness on environmental issues, especially water consumption, an *information sheet to explain briefly the system's function and effect should be visible in the courtyard*. After agreement with the people maintaining the courtyard today, the author of this thesis will produce and hang up these information sheets autumn 2014.

5 Conclusion

All effluent concentrations has fulfilled discharge limits for phosphorus, nitrogen, BOD and indicator bacteria from time of construction in 2001 until today. There were no significant change in the effluent from 2001-2013 compared to 2014, except for pH and phosphorus. These two factors were also the only ones expected to change as the sorption capacity and pH of the material will slowly decrease over time, if the system is functioning as intended. After 13 years the phosphorus concentration in the effluent still is only 0,27 mg P/l, which is less than 30 % of discharge limit of 1 mg P/l. The effluent concentrations of BOD and Nitrogen was 5 mg O /l and 2,2 mg N/l, respectively. BOD and nitrogen results indicate that the pre-treatment filters are performing as intended. BOD is below the discharge limit of 25 mg O/l in the Norwegian requirements for urban areas. With regards to nitrogen the treated greywater achieves drinking water quality. The results of indicator bacteria show that the water holds the requirements for good bathing water with a good margin, and that the water quality is high enough to be used for irrigation of edible crops.

The main concern when treating greywater is to reduce BOD and bacteria concentrations, which is also the two parameters the KL system treats most efficiently. The influent (greywater after septic tank treatment) already fulfils discharge limits with regards to phosphorus, and exceeds the drinking water requirement for nitrogen with only 3%. This means sufficient treatment efficiency for these two parameters is achieved with minimal treatment. It was calculated that the total service life of the wetland filter with regard to phosphorus will be 45 years, and for the biofilters the operational lifetime will be even longer.

Compared to average effluent concentrations values of other case studies of large-scale constructed wetlands treating greywater, KL performed better with regards to BOD, nitrogen and phosphorus. There was no significant difference, but the data from Klosterenga represent 14 years of operation while the others are in the order of 1-6 years.

A constructed wetland like KL makes it possible to save water by utilising the high-quality effluent for example for: toilet flushing, laundry, car washing or irrigation. The KL system opens interesting possibilities for reduced energy use for transportation of wastewater and production of biogas that should be investigated. The KL system furthermore contributes to make the city more blue and green, as the constructed wetland system has positive effects on recreation and contributes to a higher urban biodiversity. Because of the source separation, the KL system improves nutrient recycling, and it also reduces volume loading on a centralised wastewater system that is struggling with insufficient capacity. All these benefits mean that implementing decentralised greywater treatment systems such as KL on a larger scale, will actively contribute to achieve the goals of the plans and policies regarding wastewater handling for Oslo municipality.

A rough economic estimate suggests that the greywater treatment at KL only costs 66% of centralised treatment for the same water, and more extensive use of a source separating system has the potential to reduce the nutrient load to the fjord substantially compared to the current solution. However, a more comprehensive study comparison is necessary to fully elucidate costs and benefits of the centralised compared to the decentralised source separating system.

This thesis has shown that it is possible to treat greywater in a relatively simple system even though the system is situated in a dense urban setting with marginal space – and that high effluent quality is produced after more than a decade of operation. The system at KL demonstrates that the future of wastewater treatment can be a set of integrated solutions with cross-sectorial benefits, and that sanitation solutions is an important part of the puzzle for achieving more sustainable cities.

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APPENDIXES

Appendix 1: Technical Drawing of the Klosterenga system

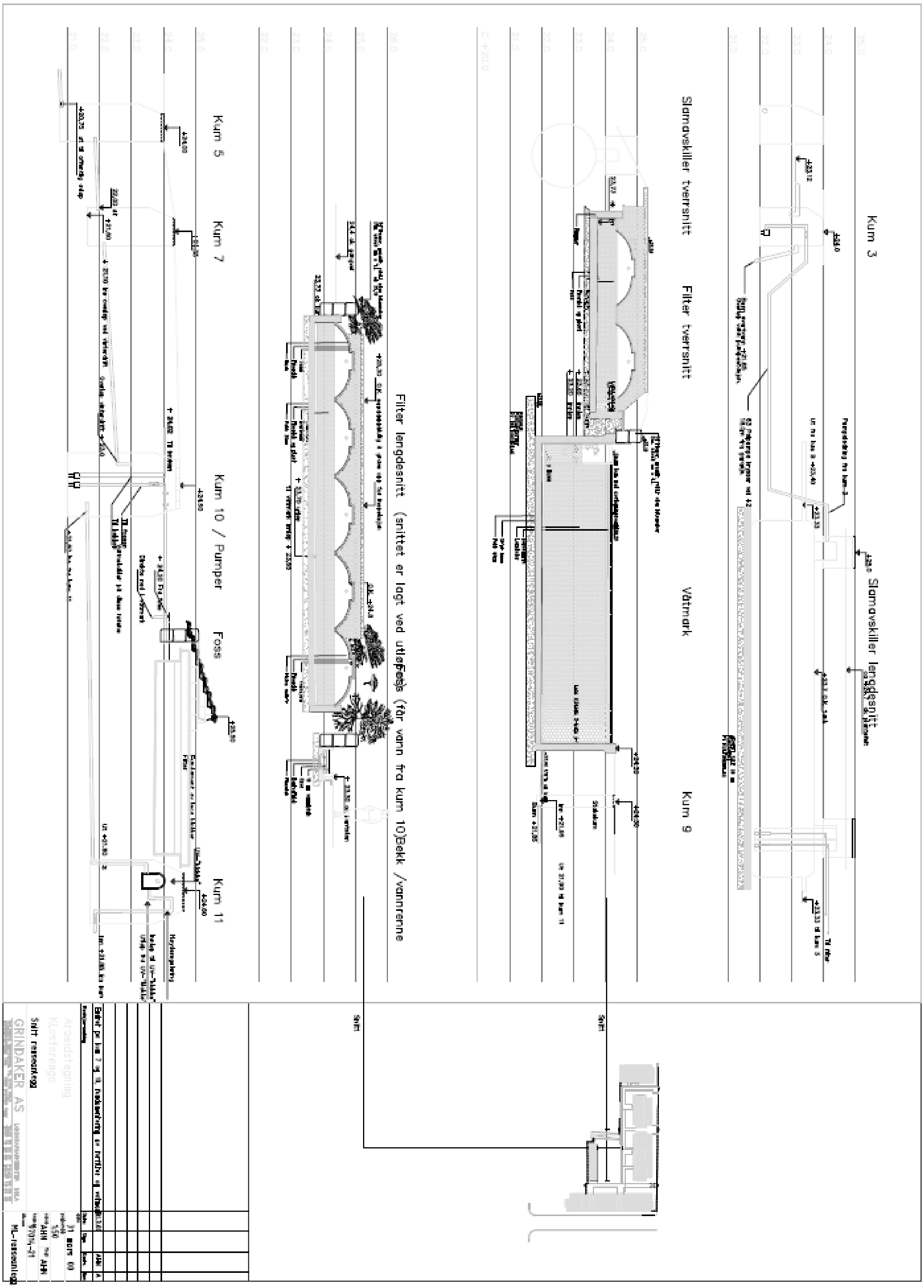
Appendix 2: All Effluent Data From Klosterenga 2001-2014

Appendix 3: Klosterenga compared with other cases of large-scale decentralised constructed wetlands treating greywater

Appendix 4: Klosterenga calculations by mass

Appendix 5: Klosterenga economic calculations

APPENDIX 1: Technical Drawing of the Klosterenga system



APPENDIX 2: All Effluent Data From Klosterenga 2001-2014

date	Total Phosphrus [mg P/l]	Total Nitrogen [mg N/l]	Ammonia [mg N/l]	Nitrate [mg N/l]	BOD [mg O/l]	E. coli [#/100 ml]	pH
6. feb. 2001	0,04			0,09			
15. feb. 2001	0,02	6,40	2,10	0,03			
21. feb. 2001	0,02	1,40	0,49	0,44			
20. mar. 2001	0,01	1,70	1,40	0,03			
6. apr. 2001	0,02	1,90	1,60	0,03			
6. nov. 2001		0,55	0,13	0,22			
15. jan. 2002	0,02	2,40	0,89	1,20			
6. nov. 2002	0,04	1,02					
24. jan. 2003	0,03	3,90	3,30	0,00	7		
28. feb. 2003	0,10		3,80	0,00	12		
26. mar. 2003			4,05	0,06			
28. apr. 2003	0,03	3,80					
28. mai. 2003	0,03	3,10	1,44				
3. jul. 2003	0,05	1,80	1,04	0,76	3		
27. aug. 2003	0,05	4,70	3,94	1,31	3		
26. sep. 2003	0,08	5,00	3,47	1,81			
21. okt. 2003	0,08						
7. aug. 2006	0,04	2,0	1,3	0,51	<5	0	9,09
18. aug. 2006	0,05	2,0	1,2	0,48		0	9,12
4. sep. 2006	0,04	1,7	1,1	0,39	<5	1	9,03
13. sep. 2006	0,05	1,8	1,0	0,23	<5	0	8,9
3. okt. 2006	0,05	1,9	0,7	0,42		8	9
2. mai. 2007	0,06	3,4	2,3	<0,02		2	8,98
23. okt. 2007	0,08	8,0	1,4	0,76		0	
29. nov. 2007	0,075	3,57	1,8	1,02		7	
21. mai. 2008	0,07	5,28	3,88	2,05		3	
15. jul. 2008	0,09	1,97	0,642	0,98		<10	
27. jan. 2014	0,4	2,29	1,1	0,78	<5		8,17
18. feb. 2014	0,062	2,39	0,589	0,918	<5		8,1
10. mar. 2014	0,088	2,23	0,53	1,18	<5	1	8
31. mar. 2014	0,235	1,15	0,771	0,089	2,8	0	7,87
4. jul. 2014	0,291	2,75	2,04	0,149	5,3		7,45
10. jul. 2014	0,516	2,58	2,41	0,034	6,7	19	7,8
average until 2008	**0,05**	**3,01**	**1,87**	**0,56**	**<5,714**	**3,1**	**9,02**
average 2014	**0,27**	**2,23**	**1,24**	**0,53**	**4,97**	**6,67**	**8,04**
july 2014	**0,40**	**2,67**	**2,23**	**0,09**	**6,00**	**19,00**	**7,63**
total average	**0,07**	**2,98**	**1,77**	**0,63**	**5,3**	**2,67**	**8,63**
Average until 2008	**0,05**	**3,01**	**1,87**	**0,56**	**5,71**	**3,10**	**9,02**

SD until 2008	**0,02**	**1,85**	**1,24**	**0,59**	**3,09**	**3,81**	**0,08**
	1,00	**15,00**	**15,00**	**15,00**	**25,00**		
	0,01	**0,92**	**0,62**	**0,30**	**1,55**	**1,91**	**0,04**
	0,51	**0,61**	**0,66**	**1,06**	**0,54**	**1,23**	**0,01**
f-test	0 %	2 %	33 %	73 %	7 %		5 %
	3	3	2	2	2		2
t-test: 2001-2008 vs 2014	**0,03**	**0,09**	**0,69**	**0,90**	**0,59**		**0,000009**

APPENDIX 3: Klosterenga compared with other cases of large-scale decentralised constructed wetlands treating greywater

	BOD5		N		P	
	BOD, effluent	BOD, % efficiency	Nitrogen, effluent	Nitrogen, % efficiency	Phosphorus, effluent	Phosphorus, % efficiency
Ås	*6*	*93 %*	*2,4*	*73 %*	*0,1*	*90 %*
Lübeck	*14*	*93 %*	*2,7*	*78 %*	*5,7*	*29 %*
Kuching	*2*	*98 %*	*9,24*	*75 %*	*0,33*	*86 %*
Bergen	*15*	*96 %*	*2,2*	*60 %*	*0,19*	*79 %*
MEAN	**9,2**	**95 %**	**4,1**	**71 %**	**1,6**	**71 %**

KL (avrage 2014)	**5**	**98 %**	**2,23**	**78 %**	**0,27**	**69 %**
4. July	*5,3*	*98 %*	*2,75*	*73 %*	*0,29*	*66 %*
10. July	*6,7*	*97 %*	*2,58*	*75 %*	*0,52*	*39 %*

f-test	23 %	25 %	1 %	22 %	9 %	89 %
	2	2	3	2	2	2
t-test	0,53	0,31	0,45	0,68	0,60	0,46

APPENDIX 4: Klosterenga calculations by mass

1. KLOSTERENGA, 2014				
			(multiply by a 105 l/person/day and 365 days, minus 10 % for absence and holidays)	
		mg/l	mg/person/year	**g/person/year**
BOD		4,45	153491,625	**153**
Ortho-phosphate		0,236	8140,23	**8**
Total phosphrus		0,265	9140,5125	**9**
Total nitrogen		2,206	76090,455	**76**
Nitrate		0,525	18108,5625	**18**
Ammonia		2,195	75711,0375	**76**

2. WWTP Bekkelaget, 2012		
	Effluent data	***2012 (divide by 300 000 person equivalent it is treating for, multiply by 10^6 for gram)***
	2012	**g/person/year**
total phosphorus	11,19	**37,3**
BOD5	163	**543,3333333**
Total Nitrogen	412,2	**1374**

3. COMPARISION

	KL [g/p/year]	WWTP [g/p/year]	% Difference KL and WWTP
Phosphorus	9	37	**75 %**
Nitrogen	76	1374	**94 %**
BOD	153	543	**72 %**

APPENDIX 5: Klosterenga economic calculations

1. KLOSTERENGA (KLD)					
Investment					
	price per unit	pr person	service life	price per year	notes
initial cost	1 000 000	10000	45	45 009	
pumps	38 000	380	15	2 929	[1]
annula costs investmnets				***47 938***	
Operation and Maintenance					
	Price	pr person	Interval (every #th year)	price per year	notes
septic tank emptying	5 187	52	4	1 297	[2]
inspection	1 000	10	1	1 000	[3]
annual costs for opertaion and maintenace (O&M)				***2 297***	
TOTAL ANNUAL COSTS (sum investments and O&M)				**50 235**	

assumed intrest rate from bank: 0,04

inflasion

0,02

estimated from average inflasion from SSB (1998-2013) http://ssb.no/priser-og-prisindekser/statistikker/kpi/maaned/2014-08-11?fane=tabell

[1]
(phonecall 07.08, GOS, currently maintaining Klosterenga, 2 pumps of 15 000, two of 4 000)

[2]
(phonecall, SEPTIK TANK CO AS, 07.08, emptying of 10 m3 septic tankt in oslo area, including deposit of sludge)

[3]
(1 man for 2 hours, 500 kr/ hour, estimated with petter jenssen 07.08)

year	Total annual costs per year corrigated for inflasion	year	Total annual costs per year corrigated for inflasion
2001	38 833	*2024*	61 236
2002	39 610	*2025*	62 461
2003	40 402	*2026*	63 710
2004	41 210	*2027*	64 984
2005	42 034	*2028*	66 284
2006	42 875	*2029*	67 610
2007	43 733	*2030*	68 962
2008	44 607	*2031*	70 341
2009	45 499	*2032*	71 748
2010	46 409	*2033*	73 183
2011	47 338	*2034*	74 646
2012	48 284	*2035*	76 139
2013	49 250	*2036*	77 662
2014	**50 235**	*2037*	79 215
2015	51 240	*2038*	80 800

2016	52 264	*2039*	82 416
2017	53 310	*2040*	84 064
2018	54 376	*2041*	85 745
2019	55 463	*2042*	87 460
2020	56 573	*2043*	89 209
2021	57 704	*2044*	90 994
2022	58 858	*2045*	92 814
2023	60 035	*2046*	94 670
		sum all years	**2 886 497**

2. CENTRALISED SYSTEM (OCS)

a.)

wastewater bill for KL for 2010, data from VAV, document:

"07/03114-21 - GNR 233 BNR 509 - ØSTFOLDGATA 1 B - Klosterenga Økologiboliger - Beregning av årsgebyr for vann og avløp - Vedtak om redusering av avløpsgebyr"

53750 total wastewater bill 2010

75 % greywater fraction

40312,5 greywater wastewater bill

0,05 increasment of this bill per year gives the following table

(assuming 4% increase per year from 2001 to 2010, according to data in 'Hovedplan avløp'.)

b.)

year	**total annual costs corrigated for inflasion**	**per person**	*year*	**total annual costs corrigated for inflasion**	**per person**
2001	27918	279	*2024*	79816	798
2002	29081	291	*2025*	83807	838
2003	30293	303	*2026*	87997	880
2004	31555	316	*2027*	92397	924

2005	32870	329	*2028*	97017	970
2006	34239	342	*2029*	101868	1019
2007	35666	357	*2030*	106961	1070
2008	37152	372	*2031*	112309	1123
2009	38700	387	*2032*	117925	1179
2010	**40312,5**	403	*2033*	123821	1238
2011	42328	423	*2034*	130012	1300
2012	44445	444	*2035*	136512	1365
2013	46667	467	*2036*	143338	1433
2014	49000	490	*2037*	150505	1505
2015	51450	515	*2038*	158030	1580
2016	54023	540	*2039*	165932	1659
2017	56724	567	*2040*	174228	1742
2018	59560	596	*2041*	182940	1829
2019	62538	625	*2042*	192087	1921
2020	65665	657	*2043*	201691	2017
2021	68948	689	*2044*	211776	2118
2022	72395	724	*2045*	222364	2224
2023	76015	760	*2046*	233483	2335
			sum all years	**4 394 358**	

3: **Difference centralised solution and KL** **66 %**