



**A long-term performance evaluation of a hybrid
natural wastewater treatment system at Vidaråsen
Camphill, Andebu Norway**

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Summary

Treatment systems like constructed wetlands and ponds have been successfully applied in Natural the treatment of domestic wastewater both in warm and cold climate. If well operated and maintained these systems perform well and produce a consistent effluent quality that meets the local permit requirements. This study examines long-term performance data of Vidaråsen wastewater treatment system in Vidaråsen Camphill in Andebu municipality in Norway. Founded in 1966, Vidaråsen Camphill is a first Camphill village in Norway. Vidaråsen is a small community comprising around 200 people. The community includes a dairy, a food-processing workshop, a bakery, a laundry, animal husbandry, horticulture and a herb garden. The Camphill village has its own wastewater treatment system since transport of wastewater to the nearest municipal system would be very expensive. Before 1998, Vidaråsen Camphill had wastewater treatment consisting of chemical precipitation of phosphorus (P) followed by biological treatment in a pond system. However, because of the high operating cost of the chemical treatment and low reuse value of the chemically precipitated sludge, an entirely new fully nature based treatment system was built in September 1998. The new system utilizes the combination of ponds and horizontal and vertical flow constructed wetlands. The system had test plant status until January 2002 and had to meet the stringent effluent P requirement of 0.4 mg/l and a total organic carbon (TOC) requirement of 10 mg/l. The system consists of following sequence of treatment units: primary settling tank (septic tank) → two pre-filters (vertical and horizontal flow constructed wetland) → advanced facultative pond (AFP) → three stabilization ponds→and two horizontal flow constructed wetlands.

The pre-filters, which are configured in series, are filled with shell sand, which has high P adsorption capacity in comparison to normal sand. The main feature of the AFP is that it has a distinct aerobic and anaerobic zone. The AFP is equipped with flow forms (cascade aeration), which helps to maintain the high level of dissolved oxygen concentration in the upper layer of the pond for enhancement of aerobic degradation. The deep center pit of the AFP is particularly designed to promote anaerobic degradation and thus low sludge production. The AFP is followed by the three stabilization ponds in series. The pond effluent finally passes through two horizontal flow (HF) beds. The horizontal flow constructed wetlands (CW) are filled with shell sand.

This study evaluates the performance of the Vidaråsen system for suspended solid (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP) and Thermotolerant Coliforms (TtC) from 2004 to 2014. The samples were collected several times a year both in warm and cold months. The grab samples from the influent (outlet of the septic tank), final effluent (outlet of HF constructed wetland) are analyzed for BOD, COD and TP. SS, and TtC is analyzed only for the final effluent. Influent and effluent from each treatment stages were analyzed only for TP. The average yearly performance data shows that the Vidaråsen system was capable to meet the effluent permit requirement for all the parameters. The average yearly effluent concentration for SS, BOD, COD, TN, and TTC was 98%, 99%, 95%, 89% and 99.9% respectively. This high degree of removal efficiency is difficult to achieve by stand-alone CW or pond system. Analysis of seasonal performance for nitrogen shows that the effluent concentration increased in colder months. The frequency distribution of outlet phosphorus showed that the system produced outlet phosphorus concentration below 0.4mg/l 75% of the time during sampling. The final outlet total coliform met both the European and Norwegian requirement for a bathing water quality. The per capita area requirement is 11 m² which is higher than the compact filter bed used in Norway. The evaluation of treatment performance from this study as well as from the earlier study shows that even without the ponds number 2 and 3 the system is able to meet the permit requirement. Therefore the optimization of land area should be given due consideration if such systems is to be replicated elsewhere.

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Acronyms and Abbreviations

AFP	Advanced Facultative Pond
Al	Aluminum
BOD	Biological Oxygen Demand
CaCO ₃	Calcium Carbonate
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DO	Dissolved Oxygen
Fe	Iron
FWS	Free Water Surface
HF	Horizontal Flow
HSSW	Horizontal Sub-Surface Flow
LWA	Light Weight Aggregate
MgCO ₃	Magnesium Carbonate
P	Phosphorus
SF	Surface Flow
SS	Suspended solids
SSF	Sub-Surface Flow
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TtC	Thermotolerant Coliform
UV	Ultra Violet
VF	Vertical Flow
WHO	World Health Organization

1 Introduction

About 17 % of the population in Norway are connected to small-scale decentralized systems or onsite (Berge and Mellem 2011). In Norway, the onsite and decentralized treatment facilities are particularly used for cottages and in sparsely populated rural communities. Connection of such isolated and rural entities to centralized sewage treatment facilities will be expensive. The small-scale wastewater treatment systems are also gaining attention because these systems offer the possibilities for recycling and reuse of the valuable resources embedded in the domestic wastewater (Todt et al. 2015). Blackwater (urine and feces) contains the majority of Nitrogen (N), Phosphorus (P) and Potassium (K) in wastewater and these elements are the main macronutrients for plant production and major components of artificial fertilizer (Halberg et al. 2006). If the nutrient from the Norwegian wastewater can be recovered, the application of mineral fertilizer can be reduced by 10-20% (Jenssen et al. 1991).

The conventional centralized system removes the nutrient from wastewater and meets the desired effluent standard. However, recycling of nutrient back to agriculture in conventional centralized system is low (Ødegaard et al. 2002). In a conventional system direct application of the treated sludge to agricultural land is the only pathway to recycle the nutrients to agricultural land. Norwegian public health and environmental authorities encourages the use of sludge on land whenever possible, however Norwegian regulation also requires that sludge must undergo certain treatment steps before use (Ødegaard et al. 2002). The sludge must, therefore be stabilized, disinfected and dewatered before application to farmland. The common treatment option for sludge include anaerobic digestion, aerobic digestion and composting (Ødegaard et al. 2002). The recycling of phosphorus (P) in biosolids is low because of the pressure to reduce the application of such solids on agricultural land and therefore most of the phosphorus is dispersed in the environment and thus lost for future generations (Barnard (2009). Most of the wastewater sludge in Norway are used as bio-soils in green areas and very little amount is returned to productive land (Ødegaard et al. 2002). The chemically stabilized sludge, that is the most common in Norway, is not an attractive fertilizer for agricultural use because of low P availability in sludge precipitated with aluminum or iron based coagulants (Krogstad et al. 2005). The study showed that sewage sludge from biological purification without chemical additives and lime treatment produced a sludge with a P fertilizing effect comparable to inorganic fertilizers (Krogstad et al. 2005).

Removal of nutrients to prevent the eutrophication of receiving water bodies is a key priority of wastewater treatment in Norway. Small-scale wastewater treatment systems in rural Norway discharging to freshwater also have a strict requirement of P-removal of 90% P-reduction. The effluent P discharge standard set by most of the municipalities in Norway is 1 mg P/ lit (Jenssen et al. (2005). Therefore, there is a possibility of recovery of P from small-scale decentralized systems in Norway. Some municipalities also have set the discharge standard for nitrogen to protect the groundwater (Jenssen et al. 2005).

The decentralized options used in Norway includes the natural treatment systems like soil infiltration (Jenssen and Siegrist 1990), wetlands (Heistad et al. 2006), and ponds (Browne and Jenssen 2005). Mechanized biological/chemical “package” treatment plants are used where soil conditions does not allow infiltration or other natural system options (Johannessen et al. 2012). In areas having soil with good hydraulic properties soil infiltration systems had been the most common treatment of wastewater in individual households in Norway (Jenssen and Siegrist 1990).

Since the small-scale wastewater treatment systems require high degree of performance to meet the effluent permit requirement set by municipalities, robust treatment schemes like high performance compact filter beds or the combination of high performance pond and constructed wetland system are used (Browne and Jenssen 2005; Jenssen et al. 2010).

At Vidaråsen Camphill, Andebu municipality, wastewater system consisting a hybrid system - combination of high performance ponds and constructed wetlands - was built in 1998 (Browne and Jenssen 2005; Hensel 1999). In this study performance evaluation of Vidaråsen Camphill system has been conducted based on the long-term monitoring data.

2 Objectives of the study

The goal of the study is to evaluate the long-term performance of the Vidaråsen Camphill pond/reed bed system. The specific objectives of the study are

- To analyze the organic matter (BOD, COD), nutrient (TN, TP) and microbiological removal efficiency (TtC)
- To examine the seasonal variation in the treatment performance

3 Background

3.1 Natural Vs conventional Wastewater Treatment

Conventional wastewater treatment systems can achieve a high degree of purification. However, the energy requirement in conventional system such as activated sludge treatment is high and the operation and maintenance is difficult (Tchobanoglous 1991). The natural treatment system utilizes none or very few mechanical equipment. Typically, these processes are supported by natural components such as microbial organisms. Usually the plant plays significant role in the treatment process. The natural treatment system mimics the purification process occurring in the nature. Using plants to purify wastewater has always fascinated researchers and holds an aesthetic value to the public as well. Consequently many natural systems such as oxidation ponds/lagoons, land application systems etc., that use the ability of the plant species in up taking or degrading the pollutants were developed.

In recent years, constructed wetland and pond system has emerged as an attractive low-cost wastewater treatment alternatives. Pond and constructed wetland system has been used in both warm and cold climates (Jenssen et al. 2005, Browne and Jenssen 2005, Kadlec and Wallace 2009). Among the natural treatment systems, constructed wetland appears to be an appropriate alternative that can be employed in both developed and developing countries. Constructed wetland treatment systems have been in operation in many of the European and American countries for more than two decades now, and significant advances has been made in the engineering knowledge of creating constructed wetlands (Vymazal J. 2011, Cooper, P. 2009, Reed S. C. 2001).

3.2 Decentralized treatment in Norway

In Norway, the decentralized treatment facilities are opted for rural communities where connection to sewer networks to nearby centralized conventional treatment facilities are expensive. Some decentralized wastewater treatment technologies used in Norway are presented in Table 1. The decentralized wastewater management systems in Norway can be broadly classified according to the way the wastewater stream is handled: (1) Dry sanitation system (2) Treatment system to treat mixed wastewater based on water toilets (3) Dry toilets (system with source separation). Dry sanitation are the most efficient systems regarding retaining of nutrients especially in combination with urine. Dry sanitation consists of on-site composting of excreta. No flush water is used in such systems. Dry sanitation has been

successfully implemented on many remote houses and infrastructures in Norway (Jönssen and Vinnerås 2007). The mixed wastewater treatment system consist of a septic tank combined with one or the combination of following treatment systems: Onsite- package treatment, infiltration systems, filter beds (with and without plants), sand filters. Systems with source separation mean that the toilet waste (blackwater) and greywater (water from shower, washing of dishes, clothes etc.) is treated separately. In many cases, the organic household waste as well as other non-toxic biodegradable organic waste can be treated in the same process (Ødegaard et al.2002). Treatment of greywater from 33 apartments by a biofilter/constructed wetland system in Klosterenga Oslo is one example of source separating in Norway (Jenssen et al. 2005).

Table 1: Decentralized wastewater treatment technologies in Norway

Wastewater type	Main treatment unit
Dry sanitation	<ul style="list-style-type: none"> • Composting
<u>Combined wastewater based on water closet</u> (Blackwater +Greywater)	<ul style="list-style-type: none"> • Filterbed (with or without plants) • Infiltration systems (sand filters, mounds, soil) • Package treatment
<u>Dry toilets (system with source separation)</u>	
Black water with vacuum toilets/low flush toilets	<ul style="list-style-type: none"> • Liquid composting reactor
Urine diversion system	<ul style="list-style-type: none"> • Storage and application of urine
Greywater separation	<ul style="list-style-type: none"> • Filterbed (with or without plants) • Infiltration systems (sand filters, mounds, soil) • Package treatment

Natural wastewater treatment system like constructed wetlands and ponds have been used as a decentralized treatment facilities in Norway and elsewhere (Steinmann et al. 2003; Jenssen et al. 2005; Browne and Jenssen 2005) . These natural systems have been able to meet the stringent discharged standard (Heistad et al. 2006, Jenssen et al. 2005). In order to meet the stringent P removal requirement the common decentralized system in Norway is compact filter beds or onsite prefabricated package treatment with chemical P removal (Heistad et al. 2006, Johannessen et al. 2012). High performance compact filter bed system for cold climates have been pioneered in Norway (Heistad et al 2006). Compact filter beds have been used to treat combined wastewater and greywater (Jenssen et al. 2003; Jenssen et al. 2005). Compact filter beds consist of a septic tank followed by an aerobic pre-treatment biofilter and a HF constructed wetland with or without plants.

The Compact filter beds have specialized P-sorbing media like shell sand and Filtralite P. Package treatment systems started to be introduced in Norway in the 1980's (Johannessen 2012). About 4% of on-site sanitation system in Norway is prefabricated package treatment plants (Johannessen 2012).

The advantage of natural system over chemical package treatment are no requirement of chemicals and energy. The sludge generated from the chemical treatment units may not be suitable for agricultural application. The disadvantage of the natural systems are large area requirement and the long-term performance reliability of such systems.

3.3 CW as decentralized treatment

Constructed wetlands are widely used natural treatment system. CW is used to treat wastewater from a single household to a large community. Because of its simplicity and robust performance in both cold and warm climates, it has been extensively used worldwide (Shrestha 1999, Reed S. C. 2001, Haberl 1999). Constructed wetlands has been applied to treat wastewater from individual households, community, institutions, and industries (Reed 2001). Constructed wetlands has also been used for treatment of storm water runoff, landfill and leachate treatment and sludge dewatering (Nielsen, S. 2003; Mæhlum and Stålnacke 1999).

Treatment of wastewater in wetlands is a relatively recent technology. In 1953, Dr. Kathe Seidl of Max Planck Institute in Plon, Germany first reported about the possibility to lessen the over-fertilization, pollution and silting up of inland waters through appropriate plants (Brix, 1994b). Subsurface flow constructed wetlands first emerged as a wastewater treatment technology in Western Europe based on research by Seidel (1966). Early developmental work in the United States commenced in the early 1980s with the research of Wolverson, et al. (1983) and Gersberg et al. (1985). Since its initial 'discovery' research, efforts to harness and develop the natural treatment ability of wetland systems have led to significant advances in the knowledge of engineering the wetlands.

Constructed wetlands are broadly classified as surface flow (SF) and subsurface flow (SSF) wetland (Brix 1994). The surface flow systems are flooded and the water level is above the media surface. The subsurface flow systems are designed to maintain the water below the media surface. SF wetlands are not preferred for warmer climates because of odor and vector problems (Kadlec and Wallace 2009). SF wetlands are not common in cold climates with freezing temperature in winter. The subsurface flows are further divided into horizontal flow (HF) and

vertical flow (VF) depending on the direction of wastewater moving through the media (Brix 1994).

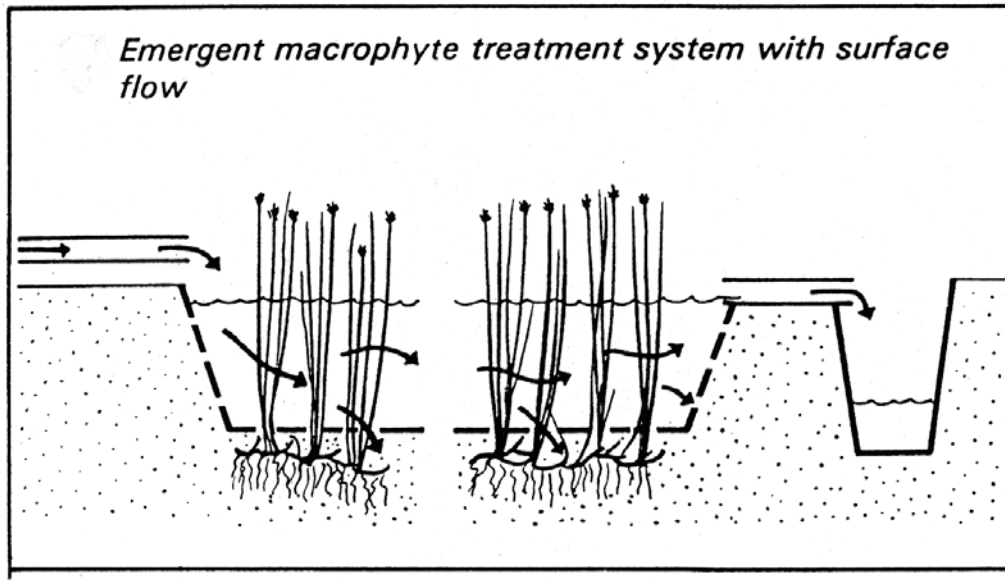


Figure 1: Surface flow constructed wetland (Shrestha 1999)

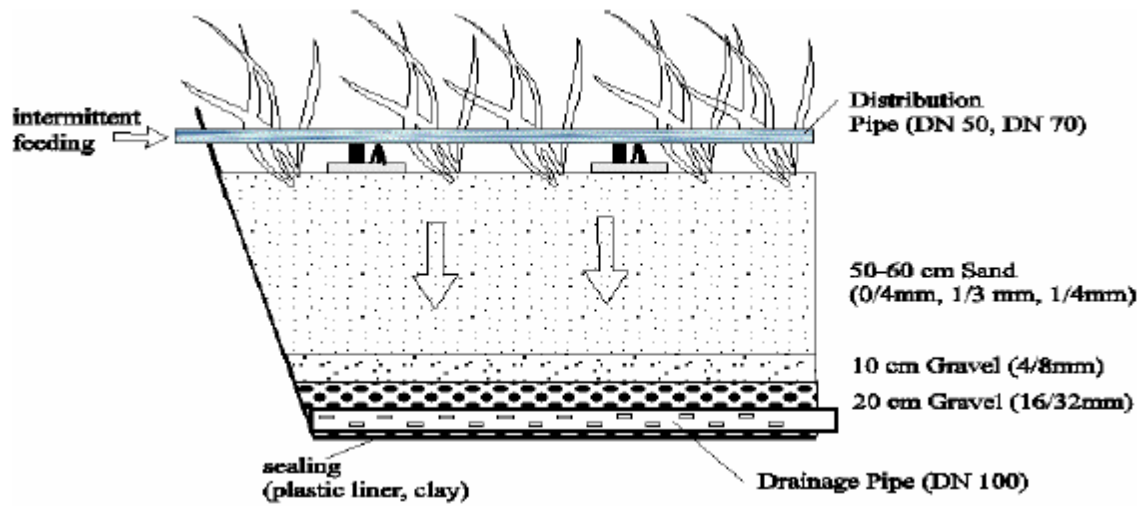


Figure 2: Vertical flow subsurface constructed wetland (Shrestha 1999).

In horizontal flow constructed wetlands water is fed at one end and the treated water exit from the other end. HF constructed are continuous or batch fed (Kadlec and Wallace 2009). HF constructed wetland have high BOD, COD and TSS removal efficiency but removal of nutrient

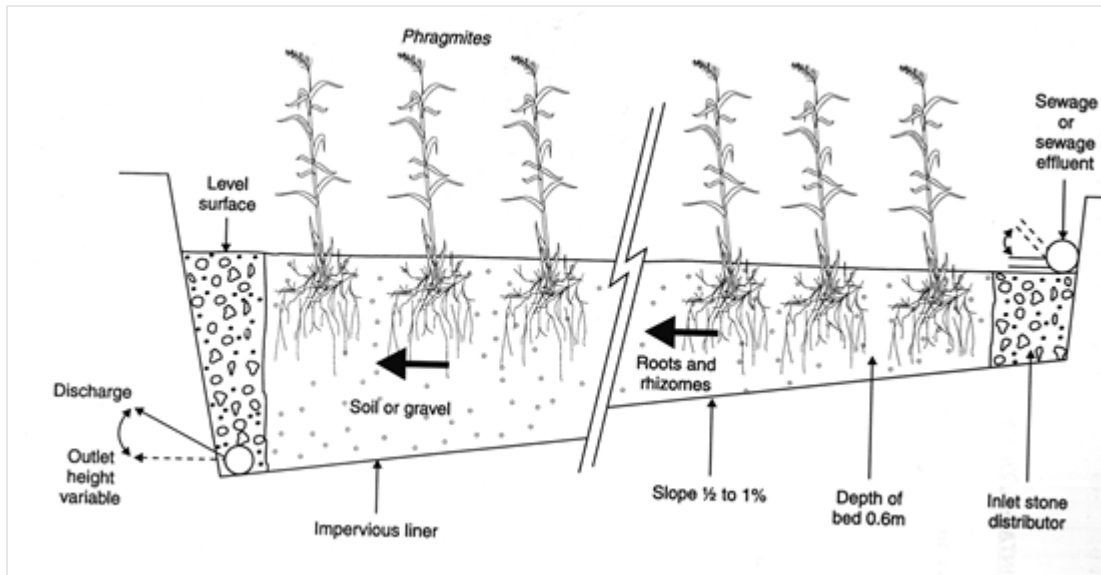


Figure 3: Horizontal flow subsurface constructed wetland (Shrestha 1999).

is relatively low (Vymazal 2005). Oxygen transport capacity of plants in HSSW is not sufficient to sustain both oxidation and nitrification (Vymazal 2005).

In vertical flow constructed wetlands, wastewater is spread over the bed and the wastewater infiltrates into the bed vertically. Vertical flow wetlands are intermittently applied to increase the air and reduce the bed clogging (Brix 2005). Intermittent dosing in VFB will draw air into the unsaturated pore of the bed (Hunter et al 2001). VF CW have greater O₂ transportation capacity therefore much better nitrification (Vymazal 2009, cooper 2009). VFB bed provide good removal of organics and suspended solids but typically provide little denitrification. Therefore, removal of total nitrogen in these systems is limited (Vymazal 2005)

If P removal is a main aim of the purification, process HF CW are preferred (Luederitz et al. 2001). HF CW have the possibility to accumulate large quantity of P in humic substances. (Lüderitz et al. 2001). It is possible to have high P removal in HF wetland by use of porous media with high content of iron oxides that has high phosphorus adsorption capacity (Jenssen et al. 1993)

3.3.1 Pollutant removal mechanism in CW

Removal of pollutant in a constructed wetland is believed to be accomplished in the following ways (Kadlec and Wallace 2009; Vymazal 2005; Vymazal 2009):

- Direct uptake of pollutants by the plants
- Plants providing large surface area on which microbial degradation occurs
- Decreasing velocity of solids to allow sedimentation of solids
- Filtering of large particle through root and reed masses
- Adsorption of nutrients (such as nitrates and phosphates) by soil and substrate media
- Wetland detention time allowing for natural die-off of pathogens
- UV radiation and excretion of antibiotics by plant to remove pathogens

The primary treated raw water passes horizontally or vertically through a gravel and sand bed which has the roots of wetland plant spread thickly in the gravel matrix. Both gravel and the plants provided large surface area for biofilm growth (Kadlec and Wallace 2009). The large size particulate matters is removed by settling and entrapment in the void spaces in the gravel or rock media. Most of the removal occurs within the first few meters of travel distance from the inlet zone (Kadlec and Wallace 2009). The wetland plants release the oxygen through roots generated during photosynthesis process (Brix 1994a). During respiration, oxygen leaking out through the root hairs of the plants into the surrounding water environment may create an oxygen rich area around the root zone (Rhizosphere) of plants. Such oxygen leaks helps to maintain partially aerobic conditions in the constructed wetland bed. The oxygen so generated is used by the variety of microorganism to oxidize aerobically the organic matter and the nutrients in the effluent.

The nitrogen transformation in CW includes ammonia volatilization, nitrification, denitrification, nitrogen fixation, plant and microbial uptake, mineralization, sorption, burial (Vymazal 2007). Biological nitrification followed by denitrification is believed to be the major pathway for ammonia removal in constructed wetlands. There are also anaerobic pockets where nitrified compounds gets denitrified (Vymazal 2007) .

The major P removal process in CW is sorption, precipitation, plant uptake ((Vymazal 2007). P uptake in constructed wetland is low unless media with high aluminum, iron and calcium content are used (Vymazal 2007, Shrestha 1999, Pandey et al. 2013). Compact filter beds in Norway use specialized P-sorbing media like shell sand (Filtermar) or Filtralite P which have

high P removal efficiency. Filterlite P is commercially available expanded clay product with high pH (more than 10) and high Ca and Mg content required for good P removal. The grain size is 0-4mm and, effective porosity of 40% and particle porosity of 60% (Ádám et al. 2006). The P adsorption capacity of Norwegian filterlite P is 12 g/kg (Jenssen et al. 2005). Estimated life time of 40 m³ of Filterlite P treating average inlet P concentration of 10 mg/l is about 15 years (Jenssen et al. 2010). After the P-saturation is reached the P rich media is an excellent slow release P-fertilizer product due to calcium bound P (Jenssen et al. 2010). Shell sand is a natural carbonatic material mainly produced by shells, snails and coral alga (*Lithothamnion* sp.) (Roseth 2000). Filtermar (Shell sand) are naturally harvested along the Norwegian coast line. Shell sand contains CaCO₃ and MgCO₃. Shell sand have highest P adsorption capacity (Jenssen et al. 2005). It contains 10 times more Ca content than Filterlite P and therefore has more durable P sorption capacity (Adam et al 2007, Ganesh et al. 2013). The adsorption capacity of shell sand is 17gP/kg (Roseth 2000). Iron rich natural sands are also used as media. Natural sand with iron content can adsorp 1gP/Kg

Package treatment systems started to be introduced in Norway in the 1980's (Johannessen and Krogstad 2012). These systems are mainly used in rural Norway and use Fe- or Al-salts to precipitate P. Thus, they face the same challenge of nutrient availability as sludge from the large treatment systems.

During photosynthesis process plants releases oxygen into the beds via the rizhomes (Brix 1994a). This oxygen leak from the plants provide aerobic pockets in the bed to allow aerobic decomposition. Plants roots uptake the nitrogen and phosphorus available in the water phase and utilizes for its growth. The removal of nitrogen and phosphorus by plant uptake is about 10 to 15% (Kadlec and Wallace 2009), which is not very significant in comparison to the total removal of 80% to 90% by the biological processes.

Pathogen removal in wetland is primarily due to settling, straining, endogenous respiration and due to predation by protozoa (Stott and Tanner 2005). In CW beds with light weight aggregate (LWA) have high fecal coliform removal efficiency both at high and low pH (Jenssen et al. 2005). CW with long retention time have high degree of fecal coliform removal (Jenssen and Vråle, 2003). With longer retention time pathogen die-off due to endogenous respiration.

3.3.2 First order reaction kinetics in subsurface flow constructed wetland

The removal of organic matter and the nutrient in the constructed wetland is assumed to follow a plug flow first order kinetic model (Kadlec and Wallace 2009). The expression for the first order kinetic model is given by

$$(C_i)/(C_e) = e^{-k_a/q} \dots\dots\dots(1)$$

Where, C_i = inlet concentration, g/m^3 ; C_e = effluent concentration, g/m^3 ; q = hydraulic loading rate (HLR), m/day , k_a = areal rate constant. The theoretical hydraulic retention time, t_n , can be calculated by using equation (2).

$$t_n = V\eta/Q \dots\dots\dots(2)$$

Where, V = wetland volume, m^3 , η = porosity of the bed (in fraction), Q = wastewater flow, m^3/day . The hydraulic loading rate q (m/day) can be calculated by Equation (3).

$$q = Q/A \dots\dots\dots(3)$$

Where, A = surface area of wetland, m^2 .

The area requirement based on the first order kinetic model is

$$A_h = \frac{Q(\ln C_i - \ln C_e)}{k_a} \dots\dots\dots(4)$$

The rate constant is temperature dependent and the effect of the temperature on the rate constant is calculated using the following equation:

$$k_T = k_{20} \theta^{(T-20)} \dots\dots\dots(5)$$

Where, k_T is areal rate constant at temperature T ($^{\circ}C$) and θ is the temperature correction factor (dimension less).

The rate constant can also be expressed in a volumetric basis (k_v) which is expressed as day^{-1} .

The relation between k_v and k_a are given by equation 5:

$$k_a = k_v * h * \eta \dots\dots\dots(6)$$

Where, η = porosity, in percent and h = depth of wetland bed in meter.

It is believed that the plug flow rate constant for subsurface flow constructed wetlands is higher than those for facultative lagoons or for SF wetlands because the surface area available on the media in the SSF wetlands is much higher than in the other two cases (Reed et al. 1988). This surface area supports the development, and retention, of attached-growth microorganisms which are believed to provide most of the treatment responses in the system. Table 2 compares the rate constants for these three treatment concepts, at an “apparent” organic loading of 110 kg/ha/d. The rate constant for the SF wetland is about an order of magnitude higher than facultative lagoons, and about double the value for FWS wetlands (Reed et. al. 1988).

Table 2: Comparison of First Order Plug Flow Rate

S. No.	Treatment Process	Rate Constant (Kv in d ⁻¹)
1	Subsurface Flow Wetland	1.104
2	Facultative Lagoon	0.117
3	Free Water Surface Wetland	0.501

3.3.3 CW in cold climate

In cold climate the bio-chemical reaction in the natural systems like constructed wetland slows down during winter when there is drop in the temperature below freezing (Kadlec and Wallace 2009, Reed 2001). Constructed wetland can work effectively even during winter if adequate depth and freezing zone is provided (Mæhlum and Stålnacke 1999). During frosty period, the ice forms downwards in the water and causes the water levels to drop rapidly. This will affect the temperature in the system and would disturb the energy balance of the system (Jenssen et al. 1996). In order to take account the winter freezing conditions the sizing of these systems are modified for instance by providing the additional depth. According to the guideline, the depth of the constructed wetland recommended is minimum 1 meter to provide insulation in the system (Jenssen et al.2006). This allows the snow to freeze on top layer and have enough hydraulic capacity in the wetland below. However, an early snow cover is important because it reduces the heat loss from wetlands. The growth of plant during winter slows down and therefore there is not much contribution of plant in supplying oxygen in the bed or removing

the organic matter and nutrient by plant uptake (Mæhlum and Stålnacke 1999). However the large surface area provided by the root zones maintain the high cleaning ability (Jenssen et al. 2005).

The plant cover has a limited insulating effect but gives an aesthetic design to the wetland systems (Jenssen et al., 1996). Results from research and pilot plant indicates that constructed wetland systems can be designed for satisfactory operation in cold climates as either main processing wastewater system or as a supplement to other treatment systems (Jenssen et al. 2005). Where there are requirements for high phosphorus removal, the cost effectiveness of constructed wetland system is uncertain (Mæhlum 1998). In cases where nitrogen removal is important, constructed wetland systems should be considered as an alternative to other treatment methods (Heistad et al. 2006, Jenssen et al. 2005). Constructed wetland systems constitutes viable options to upgrade the existing facilities for treating wastewater, especially when there is demand for better removal of nitrogen or pathogens. In addition, constructed wetland has big potential for removing suspended solids, because they act as buffers when prior devices fail. In Norway compact filter beds are used consisting of aerobic bio filter followed by HF constructed wetland. The research result indicates good cleaning results for wetland systems constructed in cold climates, provided with pretreatment and filter media with good phosphorus binding capacity (Jenssen et al. 2005).

3.3.4 Pond system

Ponds are low cost natural system that are used to treat both domestic and industrial wastewater (Mara 2009). The advantage of pond systems are: inexpensive; easy to construct; easy to operate and maintain (Gloyna 1971). The disadvantage is that they require large area therefore preferred where land price is low and land is readily available. Pond may produce odor and nuisance if not properly operated and maintained (Crites and Technobanoglous 1998). Ponds are therefore usually located away from inhabited areas. In warm climate pond systems needs special treatment to prevent mosquito breeding (WHO 1987). Pond systems has been built in both cold and warm climate (Mara 2009). Ponds are broadly classified as anaerobic pond, facultative pond and maturation pond (Crites and Technobanoglous (1998). The general configuration of pond system is shown in figure 4.

Anaerobic ponds

The anaerobic ponds are the first step treatment in the pond system. These ponds are deep; the depth ranging from 3 m to 5 m and the hydraulic retention time between 1-3 days (Steen 2003). The anaerobic condition prevails throughout the depth of the pond. Most of the particulate solid material is settled in the anaerobic pond therefore sludge production in the anaerobic pond is higher in comparison to other types of ponds. The organic loading rate of anaerobic ponds depends on the ambient temperature. The recommended organic loading rate at lower temperature is 0.1 kg BOD/m²/day (Steen 2003).

Facultative pond

The facultative ponds are the most commonly used pond system for wastewater treatment (Olukanni and Ducoste 2011). The facultative ponds are normally placed after anaerobic ponds (WHO 1987). Facultative ponds are also used as the first step of secondary treatment (Finney and Middlebrooks 1980). In that case, a septic tank is used for primary treatment. In the facultative pond, the biodegradation in the oxygen-rich top layer is aerobic while the underlying zone is anoxic or anaerobic (Crites and Technobanoglous 1998). Facultative ponds are shallower than anaerobic ponds. The depth of a facultative pond is usually 1.5 m to 2.5 m (Crites and Technobanoglous 1998). The hydraulic retention time is between 5 -15 days (Steen 2003). The loading rate in the facultative pond also depends on the ambient temperature. In the ponds above 42° latitude, an organic loading rate of 29 kg/BOD₅/ha/day and an average retention time of 117 days has been used with satisfactory performance (Finney and Middlebrooks 1980). Maturation ponds are placed after the facultative pond.

Maturation or polishing pond

Maturation ponds have shallow depth (0.5 m to 1 m) and algal photosynthesis occurs throughout the whole depth of the pond. Maturation ponds have longer detention times from 20 to 30 days (Steen 2003). The primary objective of using a maturation pond is for pathogen removal. Maturation ponds are designed based on required pathogen removal rates (WHO 1987).

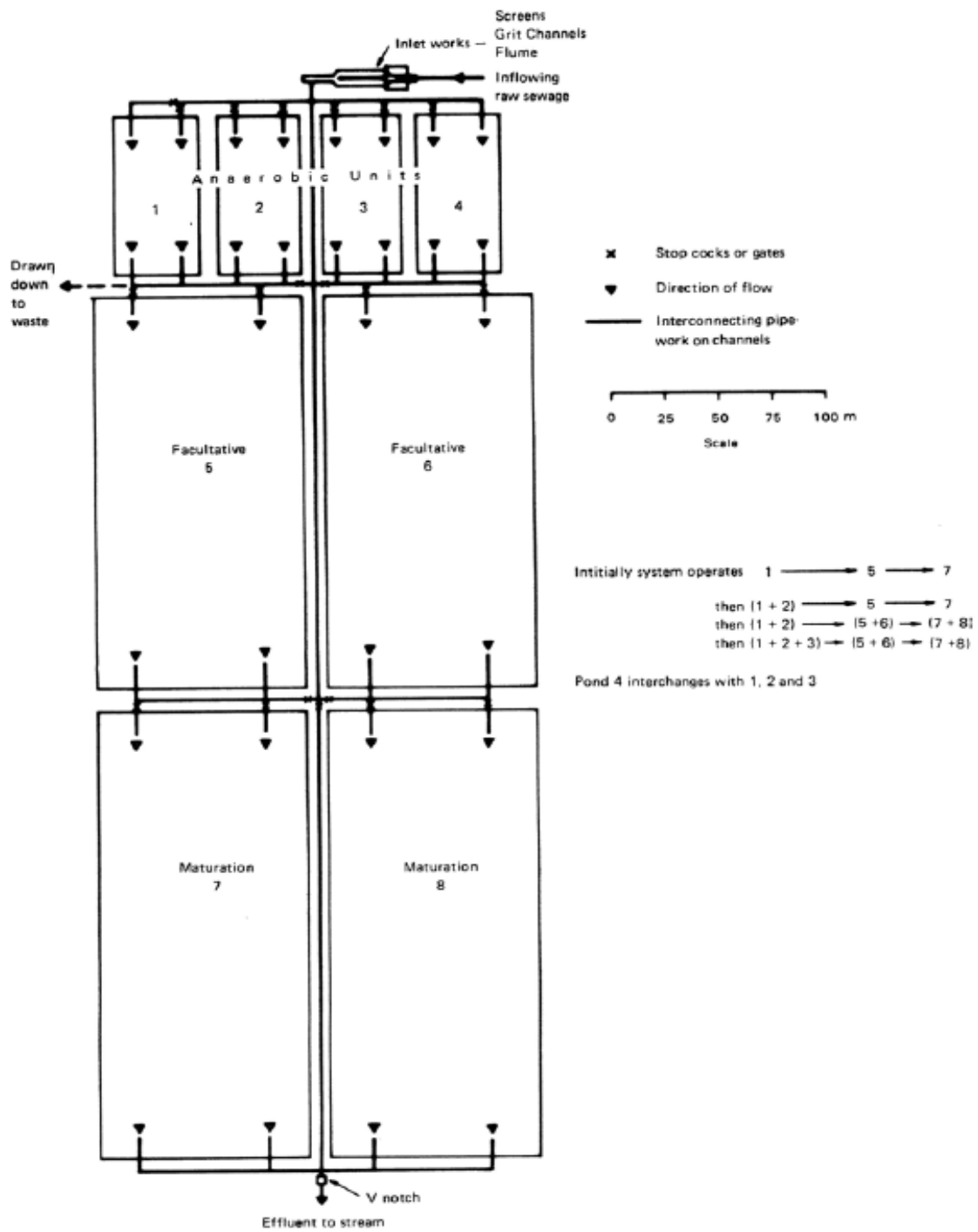


Figure 4: Configuration of pond system (Arthur et al. 1983)

3.3.5 Pollutant removal process in Pond systems

Pollutant removal in the pond is by sedimentation, biological degradation, volatilization (WHO 1987). The purification processes are temperature dependent and varies slightly over the year (WHO 1987). The particulate matter settles by sedimentation process forming sludge at the bottom. The algae bacteria symbiosis plays major role in the biodegradation of organic matter and nutrients in the pond system (Tchobanoglous 1991) . The nutrients in the wastewater enhances the growth of phytoplankton (algae) and duckweeds in ponds. Algae by photosynthesis process releases oxygen which is utilized by the aerobic bacteria for the degradation of organic matter and nutrients. Large size predators like fishes eat the bacteria and other small microorganisms. In the bottom layer where anoxic conditions prevail, anaerobic biodegradation of organic matter and nutrient occurs (WHO 1987). In anaerobic pond the pollutant removal is mainly by sedimentation and anaerobic biodegradation. In facultative pond removal mechanism is sedimentation, aerobic and anaerobic bio-degradation (Steen 2003). The effluent BOD value achieved in the facultative pond range from 20 -60 mg/l, while TSS vary from 30 – 150 mg/l (Steen 2003). The nitrogen removal in facultative pond is primarily by ammonia volatilization and 80% of TN removal is achieved in properly operated facultative pond (Rockne and Brezonik 2006).

In maturation pond the organic matter and nutrient removal is by aerobic degradation (WHO 1987). The long detention time and the shallow depth allow the wastewater to get exposed to the sun for longer period and thus pathogens are killed by ultraviolet radiation from sun and by natural die off (decay) . The fecal coliform and virus die-off rates in maturation pond may reach over 3 to 4 log unit (Steen 2003). BOD removal in the maturation pond may reach up to 25% (Mara and Pearson 1986).

3.3.6 Advance integrated pond system

The facultative pond used in the Vidaråsen system is US patented pond system invented by William J. Oswald (Oswald 1990). The modified pond system is called Advances Facultative Pond (AFP). The modified system has a deep pit in the center of the pond where the stable microbiological methane fermentation zone is established. The deep pit are especially designed to avoid intrusion of the oxygen which otherwise inhibits the methane formation (Oswald 1990). The raw water is introduced at the bottom of these pits and because of the low upflow velocity, the settleable particles settle at the pit bottom. Because of the anaerobic digestion of

the sludge, less volume of sludge is generated for disposal. There are some systems, which are in operation for up to 20 years without sludge removal (Oswald 1990).

A well-constructed AFP pond can remove 60-80% of incoming organic matter (BOD) and in practice all the original suspended matter (Oswald 1990). Analysis results from two pond systems with AFP shows 70-90% elimination of organic matter, 60% nitrogen and 7% phosphorus (Oswald, 1990). The high pH in the surface increases the rate of die-away of pathogenic bacteria.

3.3.7 Hybrid system

Hybrid system; a combination of different types of treatment units are used to achieve substantial reduction of both the organic matter and the nutrients (Browne and Jenssen 2005, Vymazal 2005, Hunter et al. 2001).

In case of constructed wetlands the HF constructed wetlands have high degree of suspended solid and organic matter removal, while the nitrification is very limited (Vymazal 2005). Unless media with high P adsorption capacity are used, P removal in the horizontal flow wetlands are very low (Vymazal 2009, cooper 2009). The vertical flow wetlands have high degree of BOD, SS and ammonia nitrogen removal but nitrate and phosphorus removal is limited (Vymazal 2005). The HF and VF bed are combined in different ways to achieve high degree of removal of both organic matter and total nitrogen (Vymazal 2005; Laber et al 1997, Jenssen et al. 2005). In the pond system by virtue of algae growth the dissolved nutrients in the wastewater is reduced. But the algae can also be washed out with the effluent causing increase in effluent suspended concentration and triggering the oxygen demand in the receiving stream (Steinmann et al 2003). In some pond system filter dams in the outlet is introduced to capture the washed out algae in the pond effluent and improve the performance of the system (Shipin et al 2005; Melián et al.2010). Pond system can improve the dissolved oxygen concentration in the wastewater and retain the suspended solids but they do not have sufficient biomass to perform the microbial degradation like in constructed wetlands or soil infiltration systems (Steinmann et al 2003). Constructed wetlands and infiltration systems have large microbial biomass attached to the media and plant roots (in case of CW) that can degrade the pollutant in the incoming wastewater (Kadlec and Wallace 2009; Jenssen and Siegrist 1990). The combination of pond and CW have been capable of improving the overall performance of the system (Steinmann et al 2003).

3.4 Primary treatment in septic tanks:

Septic tanks are the most common primary treatment units used in onsite or decentralized wastewater treatment systems (Leverenz et al. 2010). The key function of septic tank is to separate and retain settleable solids (sludge) and floatables (scum) from the incoming wastewater. The general configuration of septic tank is shown in figure.5. Septic tank generally have three characteristics layer: scum at the top, a clear zone in the middle and the sludge layer at the bottom (figure 5.) Properly operated septic tank has both facultative and anaerobic environment (D Amato et al. 2008). At or near the surface facultative as well as aerobic condition prevail while the bottom part is mostly anaerobic. The settled solids are anaerobically degraded over a long period. Septic tank generates methane gases, which needs to be vented out.

The design of septic tank involves sizing space for scum accumulation, space for settling and the space for holding accumulated sludge (Leverenz et al. 2010). The theoretical hydraulic retention time of the septic tank typically varies from 24 hr. to 72 hr. (D Amato et al. 2008). Septic tank capacity varies from 2.8 to 5 m³ when used for single house (Crites and Technobanoglous 1998). Norwegian Pollution Control Authority (SFT) has published its own guidelines for septic tanks for 50-500 people (SFT, TA-515, 1980). Dimensioning of the septic tank depends on the amount of wastewater to be treated, accumulated sludge volumes and the removal of sludge.

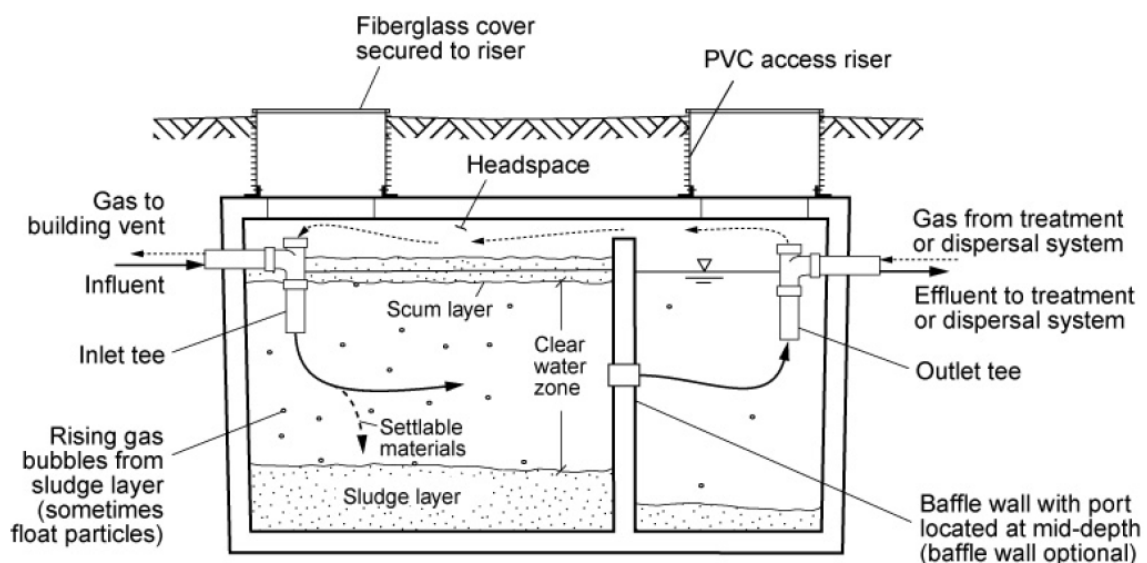


Figure 5: Sectional view of dual compartment septic tank (Source Leverenz, et al. 2010)

Septic tanks are divided into two classes, A and B, depending on the satisfactory emptying of the sludge. Class A is permanent septic tanks build before the infiltration or sand filter system which has a minimum of 18 hours of residence time. Class B is permanent sludge separators with direct outlet to a good recipient with minimum of 9 hours of theoretical residence time for the wastewater. The guidelines, depending upon emptying frequency and classification, total wet volume (water volume + sludge volume) for a septic tank is between 150-430 lit/person, while dimensioning rule for the septic tank gives wet volume in the area for 1000-1500 lit./person connected (SFT, TA-515, 1980). The expected removal efficiency of septic tank is 5-10% of TP and TN, 25-35% of organic matter (BOD), 95% of settleable/floatable materials, 30-60% of SS and low reduction of pathogens (viruses, bacteria and parasites)(Jenssen et al. 2006).

3.5 Discharge standard for small scale systems

There are certain emission permits from the municipality, which has to be met before discharging the treated wastewater in the water bodies. The performance of the small scale plants are regulated by the national pollution control regulation requirement of 90% removal of total phosphorus and 5 day BOD (Johannessen 2012). Besides in most cases the municipality have their own requirement particularly when effluent is discharged in the environmentally sensitive area. The effluent P requirement for the Vidaråsen system is 0.4 mg/l. In most cases the local regulation issued by municipality demand the effluent P limit of 1mg/l and 25 mg/l for BOD (Heistad et al. 2006). In addition, it has set conditions that Vidaråsen shall explain how sludge from the treatment plant and septic tank will be treated and disposed. (Browne and Jenssen 2003)

4 Methodology

4.1 Study area

Vidaråsen Camphill is located in south east of Norway in the Andebu municipality in Vestfold county. The climate is typical for inland southern Norway with cold winters (-5 to -25° C) and short warm summers (15 to 25° C). Average annual precipitation is 1035 mm (Hensel 1999). The Vidaråsen Camphill was constructed in 1966 to accommodate the physically and mentally handicapped children and adults. At present the Camphill accommodates 200 people. The camp consist of dairy, a food processing workshop, a bakery, a laundry, animal husbandry and a herb garden which is going to be finished by Spring 2016.

4.2 Overview of wastewater treatment system at Vidaråsen

Vidaråsen Camphill has its own wastewater treatment system. Before 1998, Vidaråsen Camphill had wastewater treatment by chemical P precipitation followed by biological treatment in pond system. However, because of the high operating cost of the chemical P treatment and also low reuse value of chemically precipitated sludge, in September 1998, an entirely nature based treatment system; a combination of pond and constructed wetland, was established. The system had test plant status until January 2002 and had to meet the stringent effluent P requirement of 0.4 mg/l and a total organic carbon (TOC) requirement of 10 mg/l.

The system consists of following sequence of treatment units: primary settling tank (septic tank) → two pre-filters → (vertical and horizontal flow constructed wetland), advanced facultative pond (AFP) → and three stabilization ponds → and two horizontal flow constructed wetlands. The treated wastewater is then finally discharged into the Skorge River, which flows on the west side of the village. The layout of the Vidaråsen system is presented in figure 6. The estimated loading of the system is 200 p.e, with an average flow-rate of 30m³/day. The design information of the individual units in the Vidaråsen is summarized in table 3.

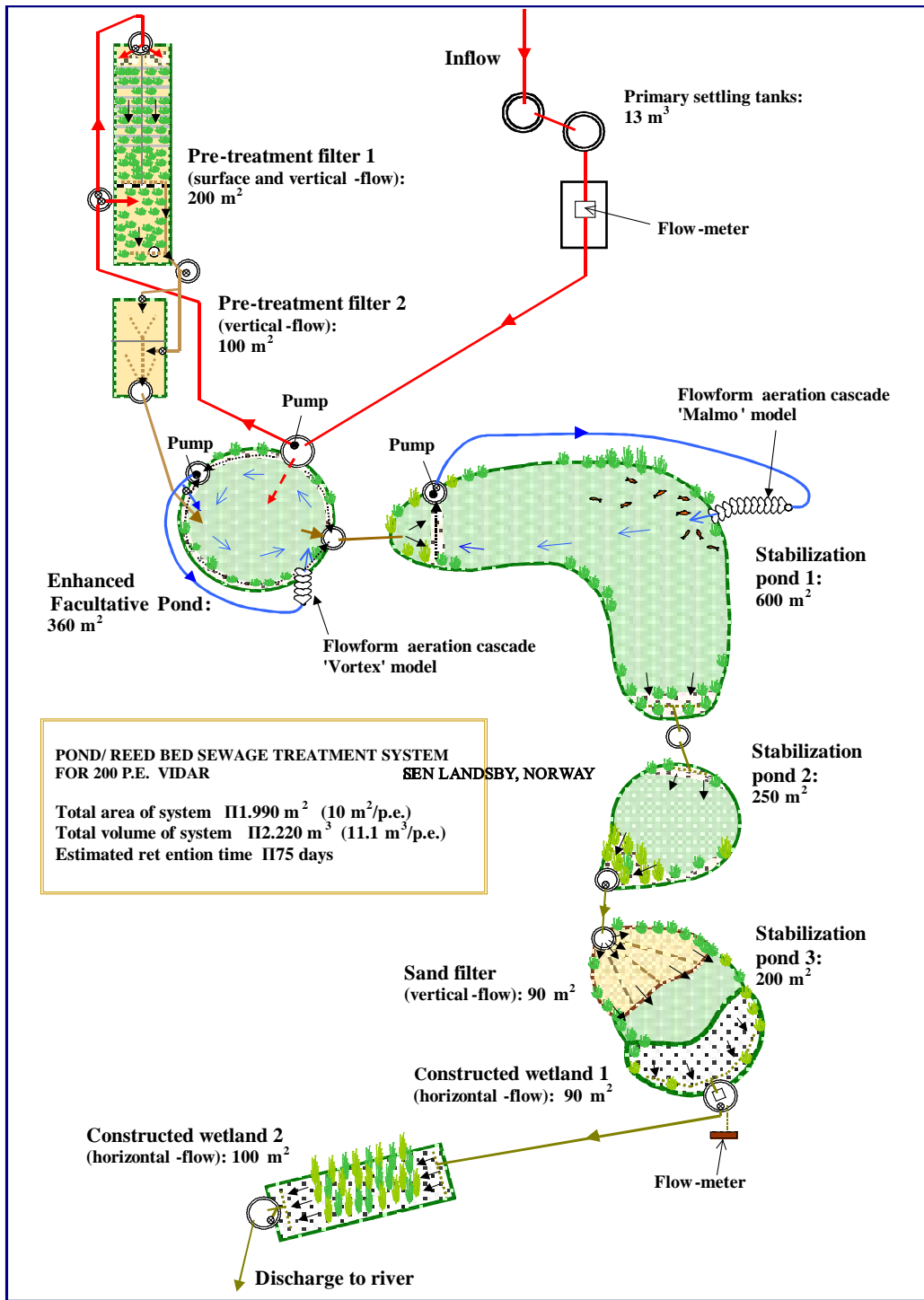


Figure 6: Layout diagram of wastewater treatment system at Vidaråsen Camphill (Browne and Jenssen 2005)

Table 3: Design information of the different stages of the treatment unit at Vidaråsen (Size and hydraulic retention time) (Browne & Petter 2005)

Units	Surface area(m ²)	Depth (m)	Volume (m ³)	HRT (days)	Notes
Septic Tank	-	-	13	0.4	Average flow rate of the system 30 m ³ /d
Pre-filter 1	200	0.6	120	1.4	Hydraulic loading (pre-filter 1) - 15cm/d
Pre-filter 2	100	0.9	90	1.04	Hydraulic loading (pre-filter 2)- 30 cm/d
AFP	360	1.5	540	18	
Pond 1	600	1.2	720	24	
Pond 2	250	1.5	375	12.5	
Sand filter	90				
Pond 3	200	1.5	300	16	Porosity - 0.35 (assumed)
Wetland 1	90	1	90	1.05	
Wetland 2	100	1	100	1.17	
Total	1990			75	

4.2.1 Primary settling tank

There are two septic tanks to collect the wastewater from the camp. The total volume of the septic tank is 13 m³. The septic tank is designed for a hydraulic retention time of 18 hours. The wastewater from the septic tank flows through a 150 meter pipe to the chamber close to the facultative pond from where it is pumped to the pretreatment filters.

4.2.2 Pretreatment filter

The effluent from the septic tank is pumped into the pre-treatment filters (Figure 7). Pretreatment filters are essentially subsurface flow constructed wetlands. There are two pre-treatment filters in series. The area of the first filter is 200 m². Second pre-filter 100 m². The first filter is planted and consists of three cells with 30 cm sand over 30 cm of graded gravel

(Figure 7). Wastewater is applied to each cell for one week alternatively at an hydraulic load of 15cm/day. The wastewater is applied vertically over the filter beds.

The wastewater from the first pre-filter unit flows to the second pre-treatment filter by gravity. The second filter consists of two cells. The filter media consists of 50 cm sand over 50 cm graded gravel. The wastewater from the first pre-treatment filter is fed for a week at an loading rate of 30cm/day alternatively in each cell. Both the filters have aeration pipes at the floor of the bed. The pretreatment filters are partly planted (Figure 8). The second filter is covered with 30 cm of straw to insulate from the frost during winter.

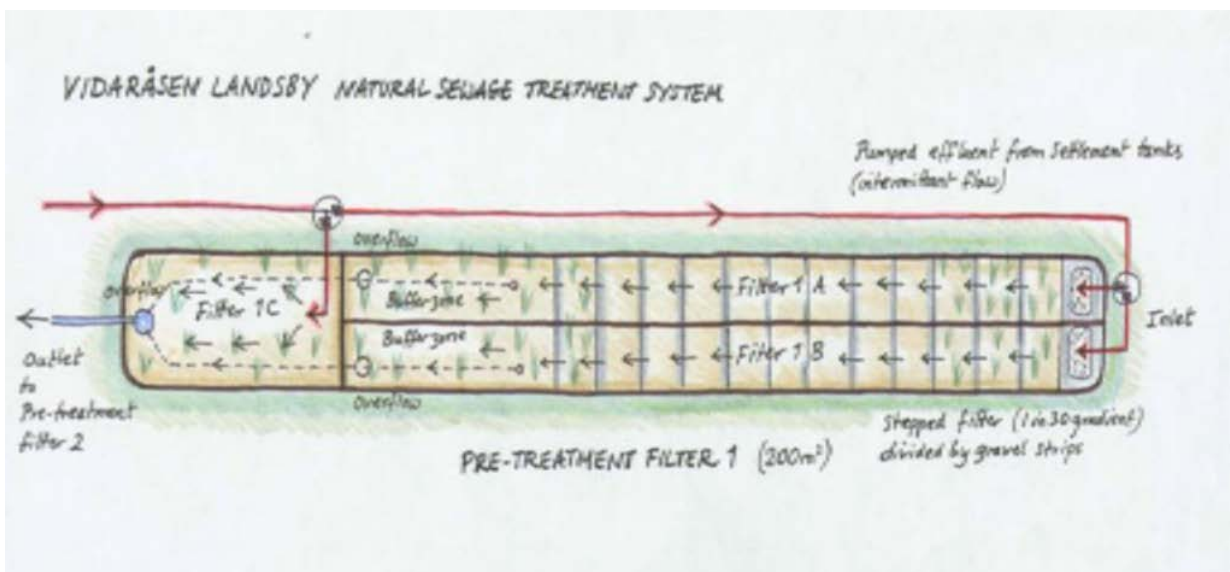


Figure 7 : Detailed layout plan of pre-filter 1

The plants grown in pre-filters are *Phragmites australis*, *Scirpus sylvaticus* and *Urtica dioica* (Browne and Jensen 2005).

4.2.3 Advanced facultative pond

The wastewater from the pre-filter flows to the advanced facultative pond by gravity (Figure 9). AFP has been designed based on the concept of Oswald (Oswald 1990). The feature of the AFP has been described in the earlier section. The pond center is designed with square shaft of ca.100m² and is 3 meter deep. The pit has the sludge capacity of 100 m³. The pit is surrounded by 0.5m high still ring to ensure that no oxygen rich water flows into the anaerobic zone. Total depth of pond in the middle is 5 m. The surface area of the AFP is 360 m². A gravel filter of 1

m deep and the 3m wide runs around the edge (Figure 9). In order to increase the DO content the wastewater is recirculated into the pond by pumping through the flow forms, which consists of five identical concrete basin of the Vortex model, which has a capacity of 300 lit/min. Aim of installing flow forms is to increase the dissolved oxygen (DO) concentration in the upper zone of the AFP.

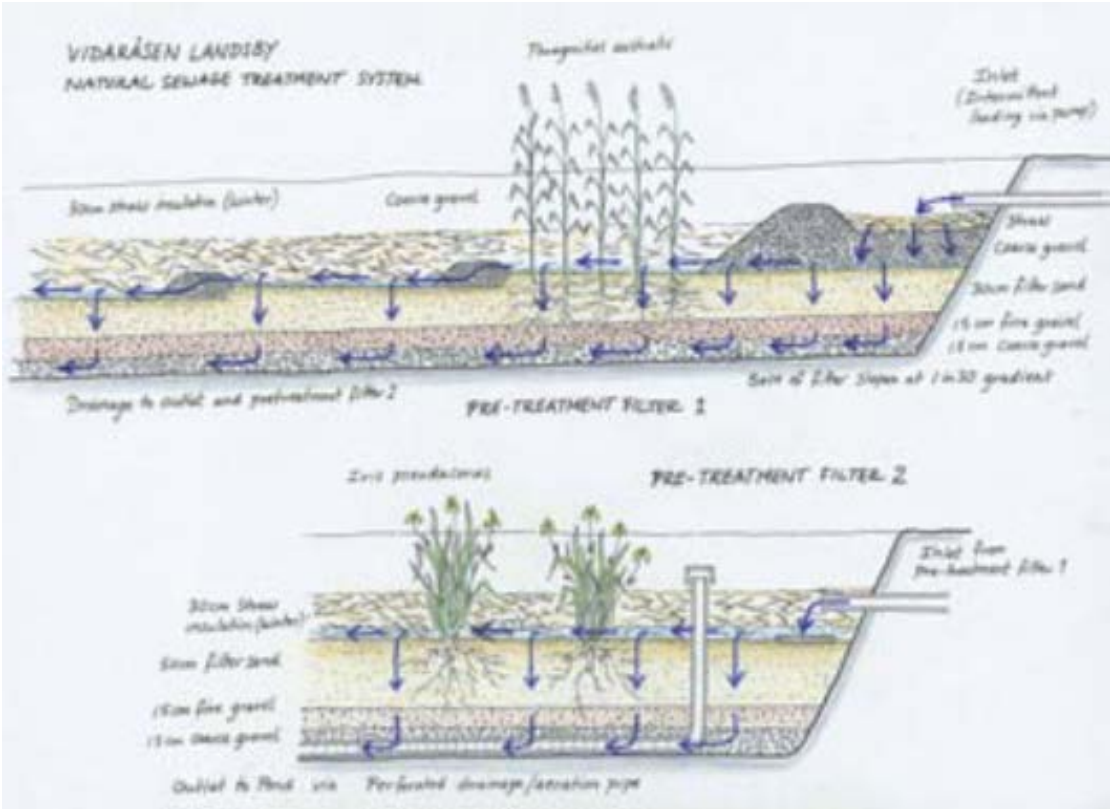


Figure 8: Cross sectional view of pre-filter 1 and pre-filter 2

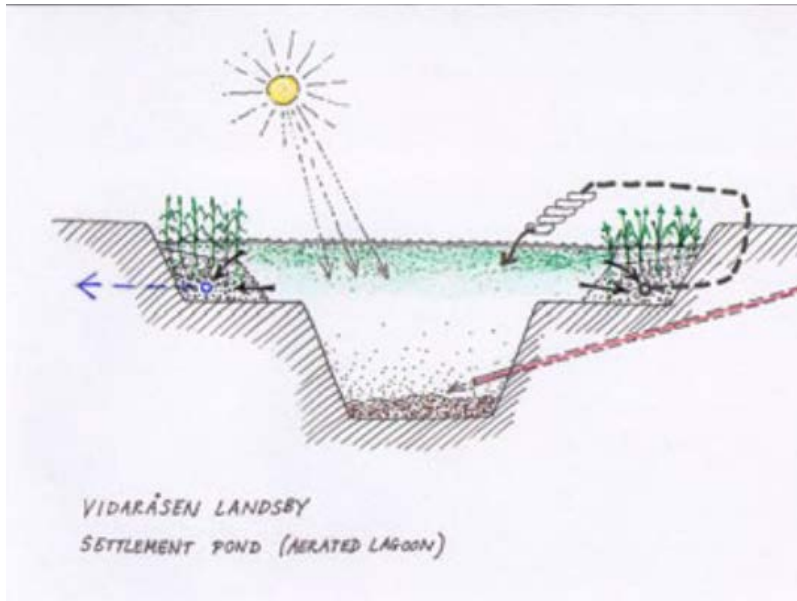


Figure 9: Cross sectional view of advanced facultative pond (AFP)

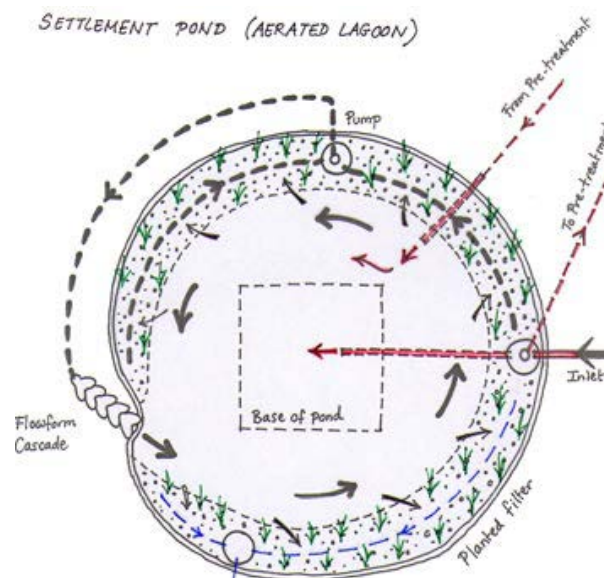


Figure 10: Plan view of AFP

The perforated pipe is placed at the bottom of the gravel filter (running around the edge) through which the water exits from the pond and goes to the stabilization pond. This arrangement prevents any escape of particulate matter from the AFP. During summer, the dominant species in the pond is Duckweed (*Lemna minor*). Duckweed starts growing at a temperature of 7°C. They grow rapidly and therefore require frequent harvesting. The plants grown in the gravity filter are *Phragmites australis*.

4.2.4 Stabilization ponds

The wastewater from the pond flows to three-stabilization ponds arranged in series. The first pond has a surface area of 600 m² and is 1.2 m deep. It is L shaped. It is connected to the flow form with eleven cascades. Water is recycled into the pond by pumping through these cascades (Figure 6). The water is pumped from ca.90cm deep pool to the cascade. At the lower end part of the pond there are two planted filter dams consisting of 35cm of sand (now replaced by shell sand) over graded gravel. There is a pipe under the first pond for the sludge removal. The surface area of second pond is 250 m² and is 1.5 m deep. The pond has planted filter dam in the inlet and the outlet (Figure 6)

The third pond has surface area of 200m² and is 1.5m deep. The third pond is connected to a planted filter dam at the inlet and HF constructed wetland at the outlet. Both the filter dam (sand now replaced by shell sand) and the wetland has an area of 90m² each.

Variety of plants are used along the edges of the ponds viz: *Typha latifolia*, *Carex*, *Sparganium erectum*, *Butomus umbellatus* and *Glyceria maxima* (Browne and Jenssen 2005). The purpose of establishing filter dams in the ponds are to achieve satisfactory cleaning effect after the pond system.

4.2.5 Horizontal flow Constructed wetlands

The system consists of two horizontal flow constructed wetlands. The first one is after the third stabilization pond (Pond 3). It is 18m wide 5m long and 1m deep. The effluent from the first HF CW discharges into the second CW. The second HF CW is 5m wide, 20m long and 1m deep. The first and the second wetland is connected with a 50m long pipe. The bottom of the wetland is sealed with bentonite and the sides are lined with dense clay. The filter material originally used in the wetland is Light weight aggregate (LWA), commercially known as Filterlite P.

The inlet zone of the HF CW has perforated distribution pipe which runs across the entire width. In the area, surrounding the distribution pipe coarse gravels are used which helps to distribute the water evenly through the filter beds. The outlet zone has also perforated pipes which is covered with coarse gravel so that the water flows evenly through the filter width and out to the drain. The distribution pipe lies down at the bottom of the filter bed. The pipe through which the water flows out from the distribution pipe lies approximately at the middle of the filter width. The wetland outlet goes via the flow meter so it is possible to control the level and withdraw proportional amount for sampling.

4.3 Operation and maintenance

The natural wastewater system to require operation and maintenance but the level of operation and maintenance required is low in comparison to conventional system. The activities performed for the operation of Vidaråsen systems are:

- Alternating flow application in the pre-filters on weekly basis
- Controlling the outlets from ponds during high rainfall and snow melting

The regular maintenance activities are:

- Maintenance of the pumps and flow meters – In 2012 the pump to pre-filter was replaced
- Removal of sludge from the pond- In 21 May 2008 sludge was removed
- Removal of duckweed and algae during summer
- Cleaning of the filter media in the beds- In October 2011 pre-filter was decommissioned for 8 weeks; in 2012 the filter dam in the AFP was cleaned
- Changing of filter media in the beds- As per the information received the media was changed in the following period:
 - In September 30th 2004 sand in pre-filter 2 was replaced by shell sand
 - In September 28th 2006 LWA in the HF constructed wetlands was replaced by shell sand
 - In September 18 2008 the gravel filter in pond 1 was replaced by shell sand
 - In December 3 , 2013 the filter sand in pre-filter 1 was replaced by shell sand
 - In October 2014 shell sand in the HF CW was changed
- Removing the algae and other deposits in the flow forms

The water from the groundwater stream is drained into the pipe under all the ponds. As per the information received, in 26 May 2009 and 14 October 2011 the outlet side filter dam in pond 3 was clogged by the slimy layer of iron bacteria. This slimy layer was observed in the outlet after the third pond, which flows out, in the open canal before it enters into the river. The slimy layer of iron bacteria was formed as a result of the oxidation of (Fe²⁺) in the ground water; which is in the dissolved state, into Fe³⁺ , because of contact of ground water with oxygen rich pond water.

4.4 Field visit and treatment performance data

The treatment site was visited in the fall 2014 . The purpose of the visit was to get a first-hand information of the Vidaråsen Camphill system. The field visit helped to understand the construction and the operational details of the treatment units. Mr. Browne explained the operational and maintenance aspect of the systems. Mr. Browne is the responsible person for the operation and maintenance of the system. Reports and monitoring data were also collected during the visit. The samples were collected several times a year both in warm and cold months. The grab samples from the influent (outlet of the septic tank), final effluent (outlet of HF constructed wetland) are analyzed for BOD, COD and TP. SS, and TtC was only analyzed for the final effluent. Influent and effluent from each treatment stages were analyzed only for TP.

The system has been continuously monitored since its commissioning in the year 1998. The performance of the system during its test status period (September 1998 to May 1999) is reported in Hensel (1999). The five year performance (1998 to 2003) is reported in Browne and Jenssen (2005). In this study the performance data from the year 2004 up to 2014 have been analyzed.

4.5 Data analysis

Quantitative data collected and compiled from the year 2004 to 2014 is analyzed with Minitab 16, with Statistical ANOVA tests. The variability in the results is presented as scattered plots and standard deviation.

5 Results and Discussion

The treatment performance of the Vidaråsen system with regard to SS, BOD, COD, TN, TP and TtC, for the past 11 years (2004-2014) is presented and discussed in the following section. The data to evaluate the performance of the individual units with respect to SS, BOD, COD, TN and TtC was not available for this study. Therefore while discussing the performance of the individual units for SS, BOD, COD, TN and TtC, Browne and Jenssen (2005) and Hensel (1999) has been extensively referred.

5.1 Suspended solids removal

The yearly average concentration of SS in Vidaråsen system is presented in figure 11. The outlet concentration is well below the 10 mg/l throughout the eleven-year period. The yearly average SS outlet concentration is 2.5 mg/L (SD±1.5). The average five year SS concentration in the effluent from septic tank as reported in Browne and Jenssen (2005) is 130 mg/l. Therefore overall removal of the of SS from the system with respect to effluent from septic tank is 98%. Such high removal of SS is achieved because of long retention time of about 75 days (Table 3) and repeated limited filtration (Browne and Jenssen 2005). This is higher than the standalone CW or the pond systems.

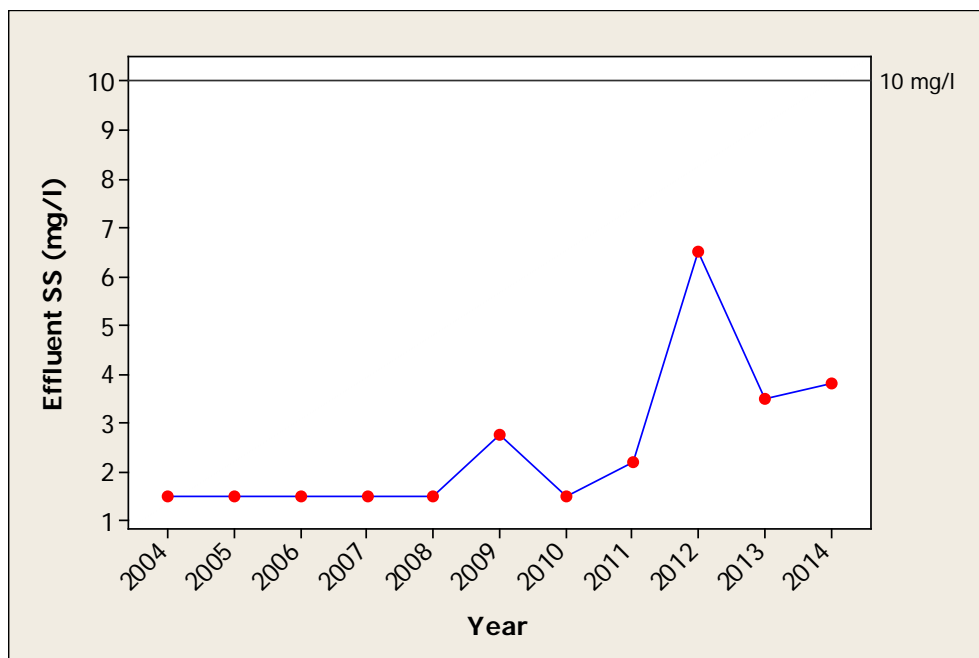


Figure 11: Yearly average concentration of suspended solids (SS)

The effluent SS is stable throughout the period from 2004 to 2011 and most of the time the average yearly outlet concentration of SS is below 2 mg/l. In the year, 2012 there is slight increase in the outlet SS concentration. This was probably because of the poor performance of the AFP. In 2012, after the filter dam in AFP was cleaned overall performance for SS removal was improved.

5.2 BOD and COD removal

The Norwegian discharge limits of the organic content in the effluent from the wastewater treatment systems is 10 mg/L of total organic carbon (TOC) or 20 mg/l of BOD (Browne and Jenssen 2005). The yearly average influent and effluent BOD and COD for the Vidaråsen system is shown in figure 12 and figure 13 respectively. The yearly average influent BOD and COD (effluent from the septic tank) is 203 mg/l (SD±59) and 386 (SD±104) mg/l respectively. The yearly average final effluent BOD and COD is 2 mg/l (SD±0.6) and 15 mg/l (SD±5.2) respectively. The BOD and COD removal efficient of the system is 99% and COD is 95 % respectively.

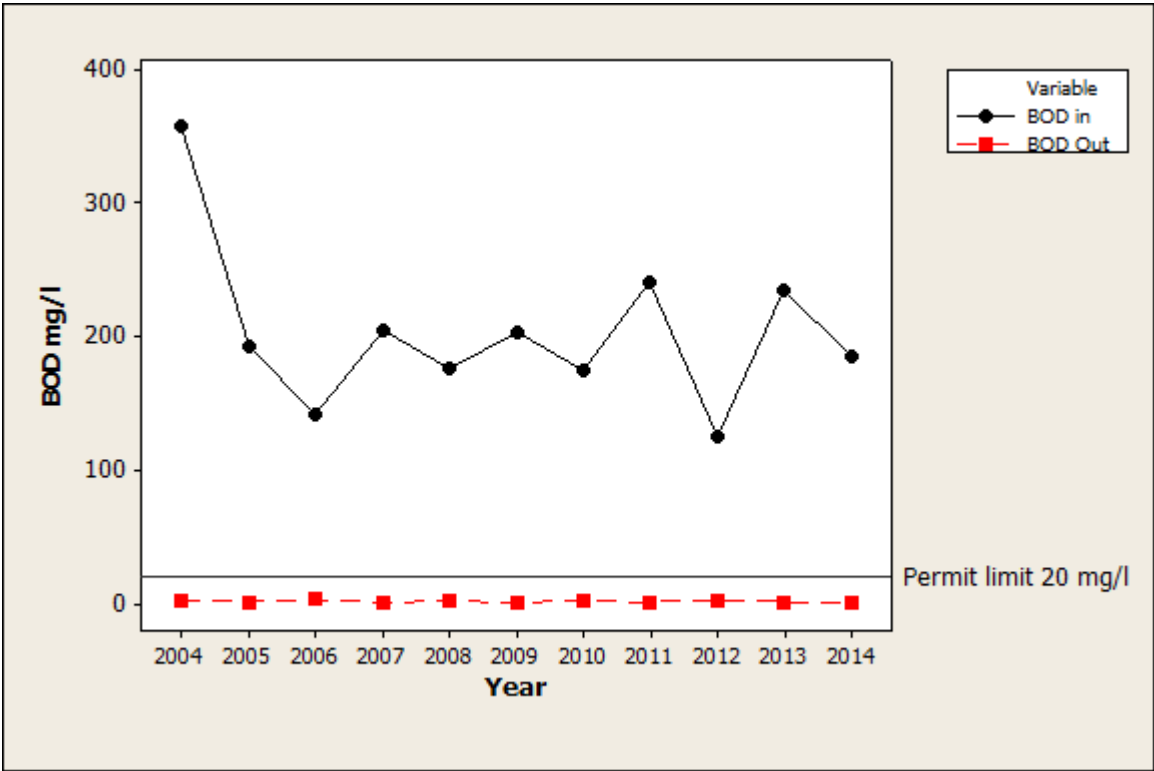


Figure 12: Yearly average influent and effluent concentration of biological oxygen demand (BOD)

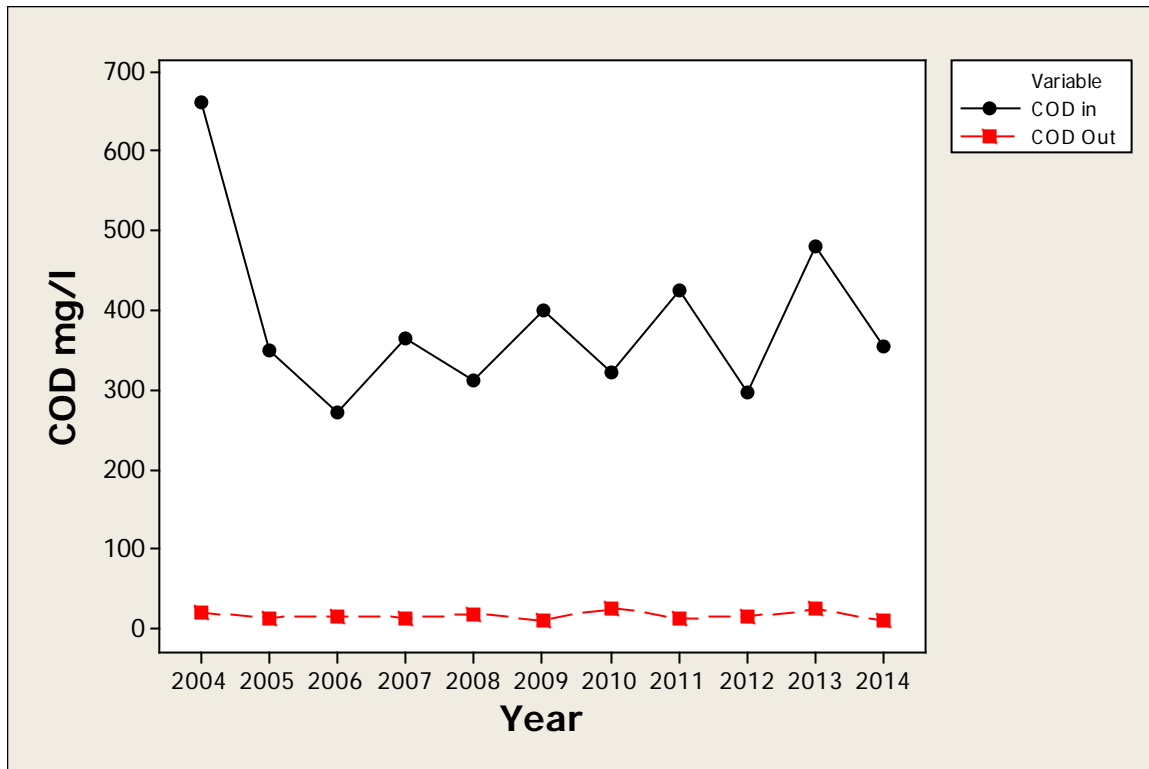


Figure 13: Yearly average influent and effluent concentration of chemical oxygen demand (COD)

Figure shows that the final effluent concentration of both BOD and COD is stable throughout the 11 years period. The combination of the AFP and the constructed wetland produced the high reduction in the organic matter without generating much solids for disposal. Such a high level of organic matter removal efficiency cannot be achieved by the stand alone pond or a wetland system. BOD removal efficiency of facultative pond and vertical flow constructed wetland operating in cold climates are in an average 60% and 75% respectively (Jenssen et al. 2010, Finney et al. 1980)

The organic matter removal in terms of TOC in the individual units has been reported in Browne and Jenssen (2005). Browne and Jenssen (2005) have shown that 78% of incoming BOD load in terms of (g/day) is removed in the pre-filter. The removal in AFP is 12 % of the incoming load. High BOD elimination was achieved by the pre-filter and progressively reduced in the subsequent units. Since pre-filter receives, the highest load therefore has higher elimination. Higher elimination at higher loads is a known feature of natural wastewater treatment systems (Kadlec and Wallace 2009).

The high organic removal rate in pre-filters is also because of the operational regime of intermittent dosing followed by a weekly rest periods. This intermittent dosing and a weekly resting period allows the pre-filter to operate in a mode of unsaturated flow, which allows the introduction of air in to the bed (Kadlec and Wallace 2009). This provides enough oxygen to accomplish aerobic degradation of organic matter. Moreover, the normal sand was replaced by the shell sand in pre-filter 2 in 2004. Shell sand has high porosity (30% to 50%) (Roseth 2000). High porosity means larger pore volume available for the accretion of particulate matters. Higher pore volume also means more air entrapped in the unsaturated layer which is available for aerobic degradation. This is probably also the reason of higher organic removal in the pre-filters. In the facultative pond the organic matter is removed both by aerobic and anaerobic degradation. The flow forms help induce the oxygen in the top layer of the pond and enhances the biological oxidation of organic matter. However, the availability of biomass in the suspended growth process reactors like pond systems are less therefore high organic matter removal is not achieved. The effluent from the standalone pond systems have high amount of algae solids in the effluent, which may give rise to TSS in the effluent (Kadlec and Wallace 2009). Treating post pond effluent in the CW will reduce the SS because of algae. Pond system cannot meet the secondary effluent standard of 20 mg/l of BOD as seen from the result of Hensel G. R. (1999).

5.3 BOD removal rate constant

The organic matter removal in ponds and constructed wetland is believed to follow first order removal kinetics (Kadlec and Knight 1996, Steen 2003). The BOD removal rate constant for the overall system is calculated using equation 1 (Section 3.3.2). The monthly final influent and effluent data has been used to estimate the average BOD removal rate constant of the system. The hydraulic loading rate is calculated using equation 3 (section 3.3.2). Average flow rate of 30 m³/day and the total surface area of 1990 m² are used for the hydraulic loading rate calculations. The frequency distribution of the kinetic removal rate constant is presented in figure 14. As observed in the figure the average BOD removal rate constant of 0.06 m/day is low in comparison to BOD removal rate constant reported in the other studies in cold climate. This shows that with respect to the large area used the overall organic matter transformation (microbial transformation) had not been so efficient in the system

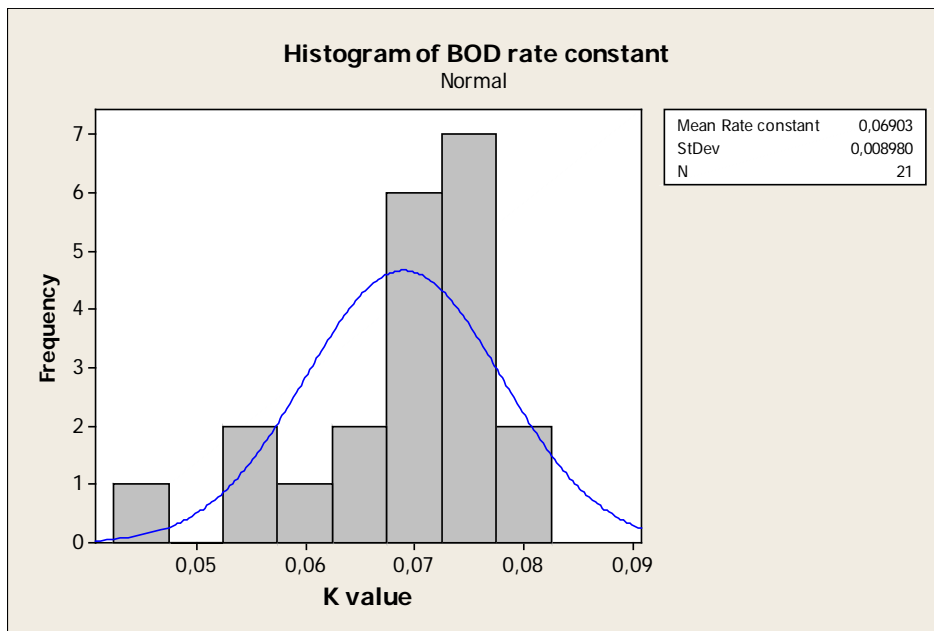


Figure 14: Frequency distribution of overall BOD removal rate constant

5.4 Nitrogen removal

The overall performance of Vidaråsen system for total nitrogen removal is presented in figure 15. The yearly average value of effluent TN over the 11 years period is 4.7 TN/mg/l ($SD \pm 3.3$). The average five year SS concentration in the effluent from septic tank as reported in Browne and Jenssen (2005) is 49 mg/l. Therefore overall removal of the of SS from the system with respect to effluent from septic tank is 89%. In comparison to the standalone constructed wetland and pond system, such removal is relatively very high. The study of constructed wetland operating in the cold climatic condition have shown the removal efficiency for TN is about 58% (Jenssen et al. 2010). In pond system, the removal efficiency is about 50% (Finney and Middlebrooks 1980). It shows that the stand-alone pond or CW cannot remove the total nitrogen to the extent removed by Vidaråsen system.

The high removal of TN indicates that nitrification and denitrification capability of the system is high. The study of Browne and Jenssen (2005) and Hensel (1999) shows that about 42 % of the TN load (in g TN/day) is removed in the pre-filter and 30 % in AFP.

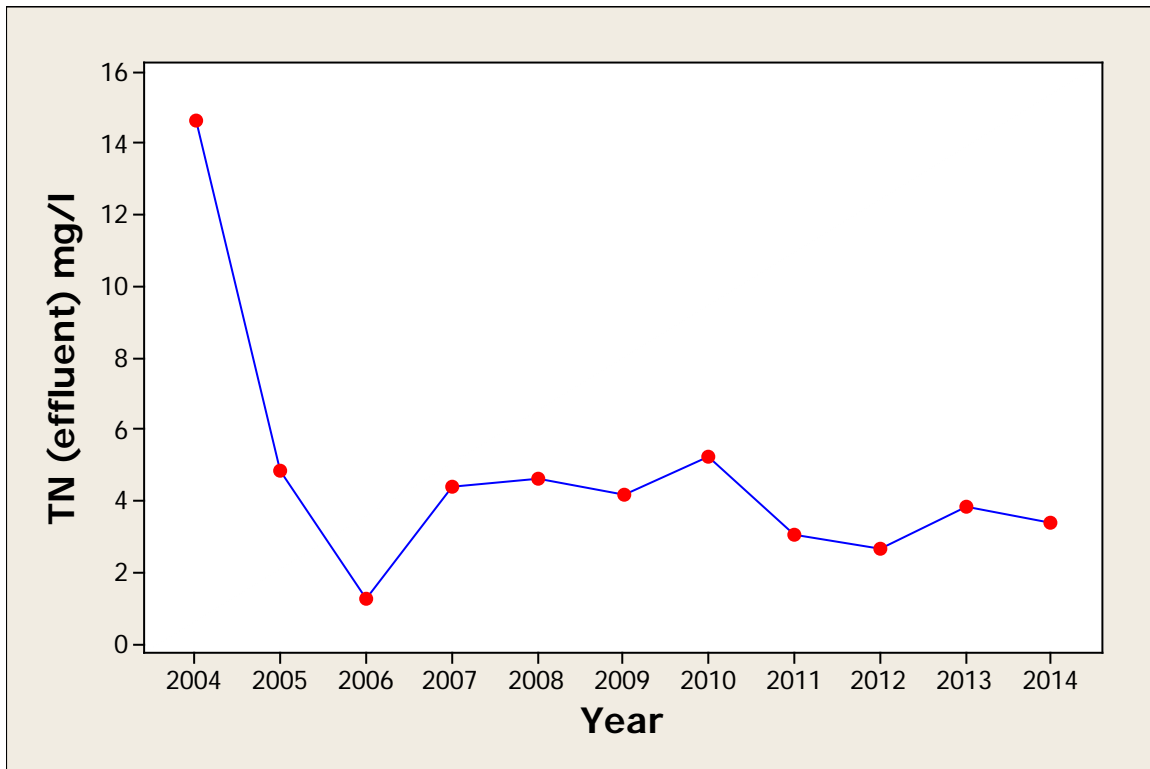


Figure 15 : Yearly average effluent of total nitrogen (TN)

The high removal of TN can be expected in the pre-filter because of the availability of oxygen in the pre-filter bed to meet the demand for both nitrification and carbonaceous oxidation. After the replacement of normal sand by shell sand in pre-filter 1 the overall TN removal performance of the system improved. As mentioned earlier the diffusion of oxygen into the bed is enhanced by alternate loading and resting of the bed and by the vertical application of the wastewater. Planted vertical flow beds with intermediate dosing have both high ammonia and BOD removal efficiency (Vymazal 2007). In cold climate the major pathway of ammonification is biological transformation (Mæhlum and Stålnacke1999). The biofilm that grows in the media contains the nitrifiers that uptake the dissolved nitrogen in the water phase (Kadlec and Wallace 2009). The rate of uptake (nitrification rate) depends on the availability of the oxygen, temperature and other environmental factors (Kadlec and Wallace 2009). In cold climate where plant are mostly dormant the nitrogen uptake by plant does not contribute significantly in the total nitrogen elimination from the system (Mæhlum and Stålnacke1999, Jenssen et al. 2010, Kadlec and Wallace 2009). The supply of oxygen by plant roots in cold climate is also limited and does not have significant contribution to the total oxygen demand of the bed (Kadlec and Wallace 2009).

In Norway to increase the availability of oxygen both for carbonaceous oxidation and nitrification the compact filter beds are built with Sprinklers and dosed in the unsaturated filter media bed intermittently (Jenssen et al. 2010). As mentioned earlier the shell sand was put into the pre filter 2 in 2004. Shell sand have higher pore volume than normal sand therefore have more nitrification potential.

The facultative pond provides condition for both nitrification and denitrification. In the deep pit of the facultative pond where the anoxic condition prevail, the nitrified effluent from pre-filter gets denitrified (Browne and Jenssen 2010). During warmer season, the top layer is rich in oxygen, which is supplied by the macrophytes (Duckweed and algae) and by the aeration in the flow forms. This provides good condition for nitrification. The studies of pond system, however have shown that the volatilization of ammonia is the major pathway of nitrogen removal in the pond systems in cold climates. The pH is high in the AFP both in the warm and cold season. High pH can be expected in warmer season because of Duckweed and algae bloom (Steinmann et al. 2003). The pre-filter with shell sand containing Calcium increases the pH of the effluent. At higher pH the presence of nitrogen in the form of Ammonia (NH_3) is high (Kadlec and Wallace 2009) resulting in the elimination of nitrogen by volatilization. The removal in the subsequent units (pond1, pond 2 and pond3 and the constructed wetland is in total about 30%. Nitrogen removal in the HF CW is probably because of denitrification in the available anoxic sites (Vymazal 2007).

The effluent TN for warmer and colder months for the year 2004 to 2014 are plotted in figure 16. Nitrogen removal is affected by temperature (Kadlec and Wallace 2009). At higher temperature nitrogen, removal rates are higher. From figure 16, it can be observed that the effluent TN concentration decreased during the warmer months. The combination of factors viz. higher rate of diffusion of air into the pre-filter; beds without snow cover, higher plant uptake in ponds, high rate of ammonia volatilization in AFP; may have increase the nitrogen removal efficiency of the bed in warmer months.

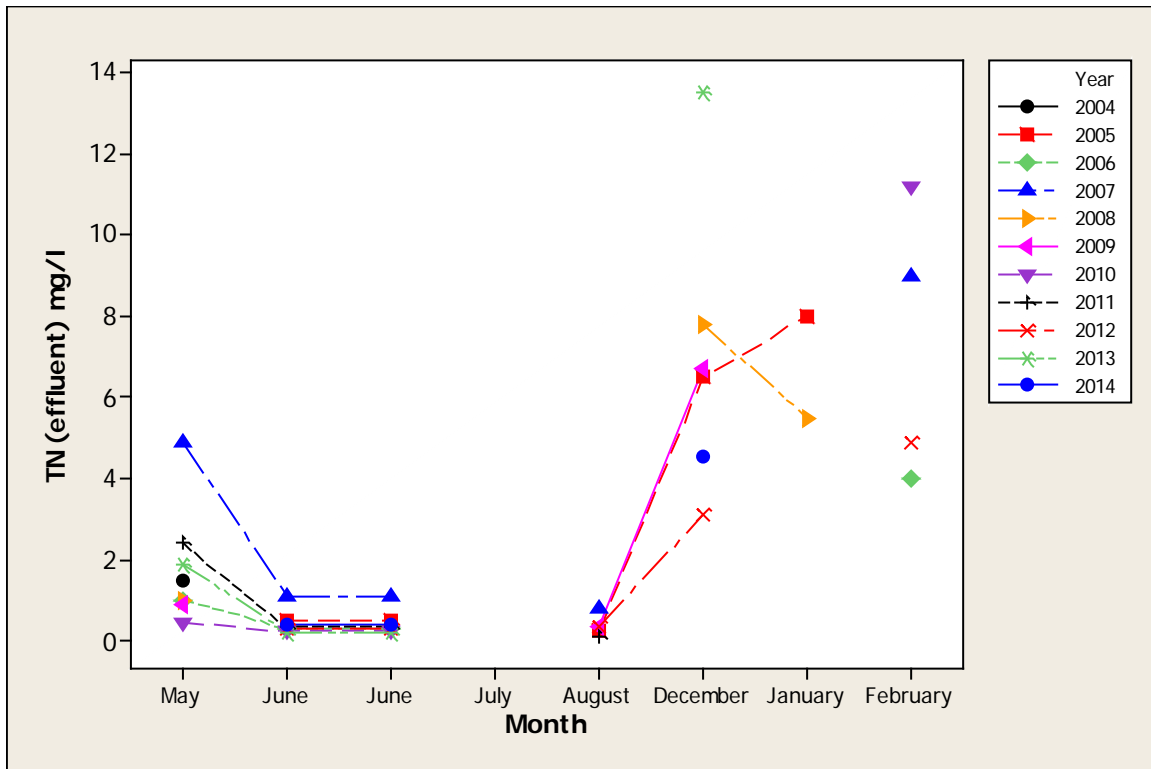


Figure 16: Scatter plot of average effluent of total nitrogen (TN) during winter and summer months

5.5 Phosphorus removal

Phosphorus is the most important parameter in Vidaråsen system. The treatment system has to meet effluent P of 0.4 mg/l. The scattered plot of the monthly outlet concentration of TP from 2004 to 2014 is shown in figure 16. The frequency distribution analysis of the effluent TP concentration using histogram (Annex 3) shows that effluent TP value below the permit requirement of 0.4 mg/l is 75 percentile. This indicates the stable and consistent performance of the system for TP removal.

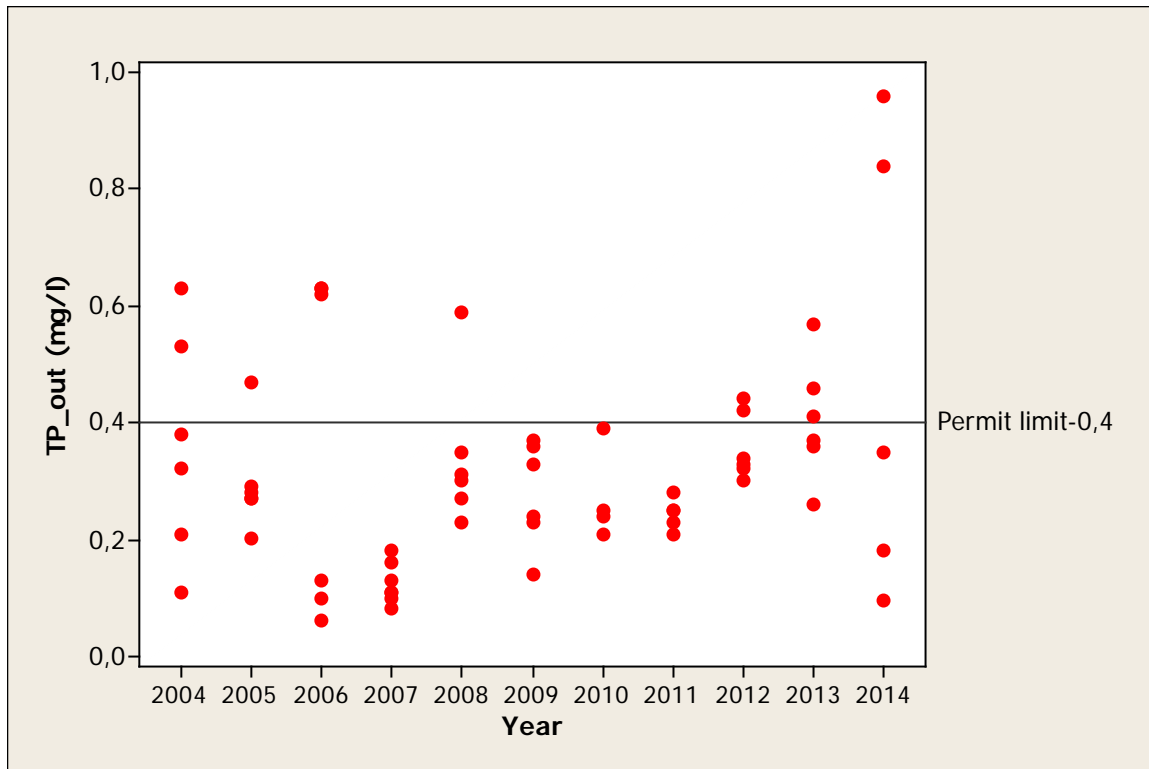


Figure 17: Scatter plot of average effluent of total phosphorus (TP) during winter and summer months

Over the 11 years period modification in the system has been carried out primarily to improve the phosphorus removal performance of the system. The media in the pre-filters and HF CW has been replaced by shell sand. Shell sand has high calcium content and therefore has high phosphorus adsorption capacity (Roseth 2000). The yearly average outlet phosphorus concentration for the period 2004 to 2014 is shown in figure 18. The outlet TP concentration is stable and below the permit limit of 0.4mg/l.

The phosphorus removal at different stages is shown in figure 19. About 44% of the total incoming Phosphorus load (in terms of g TP/day) is removed in pre-filter and AFP. After the replacement of sand filter by shell sand in the pre-filters, the phosphorus removal efficiency of the bed increased. The mechanism for P removal in constructed wetland is by accretion, adsorption and plant uptake. P removal by plant uptake is not very significant in comparison to other mechanisms (Mæhlum & Stålnacke 1999 and Jenssen et al 2010) particularly for the systems in cold climate.

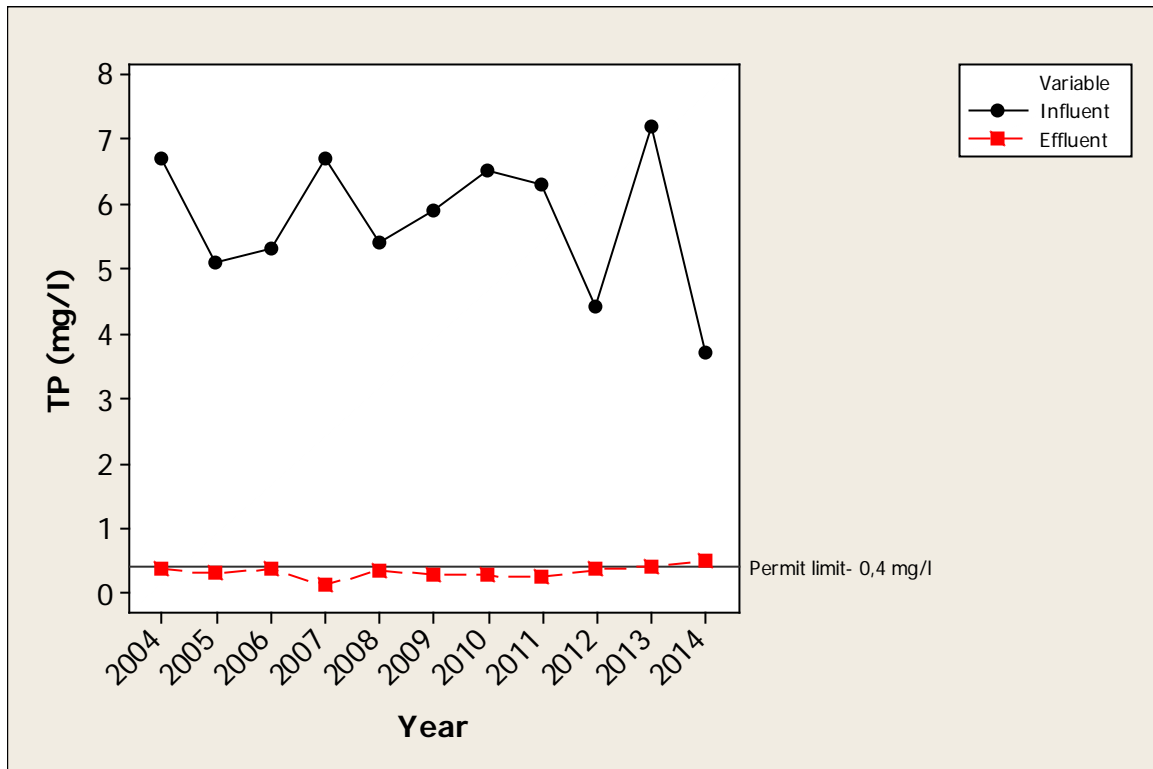


Figure 18: Yearly average influent and effluent concentration of total phosphorus (TP)

The major pathway of P removal in wetland is removal by adsorption in the wetland media (Kadlec and Wallace 2009, Jenssen et al. 2009). The batch experiment has shown that the P adsorption of the shell sand is higher than the sand media (Ganesh. & Nabelsi 2013). Even after the replacement by shell sand P adsorption in the pre-filters are not high as it should have been probably because of the major organic load of the incoming stream is taken up by the prefilter, Therefore the available site for P adsorption are utilized for biofilm growth and therefore less site is available for the P adsorption. In facultative pond 27% of incoming phosphorus load (in g TP/day) is removed. The main removal mechanisms of P in the pond is by plant uptake and accretion with the settling sludge. Plant uptake is during warm season. During winter, this is mostly by settling of particulate P in the sludge. The planted filterbed (which is now replaced by shell sand) in the bed periphery also helps to reduce the phosphorus content by adsorption or accretion. 13% of the incoming load is removed in CW.

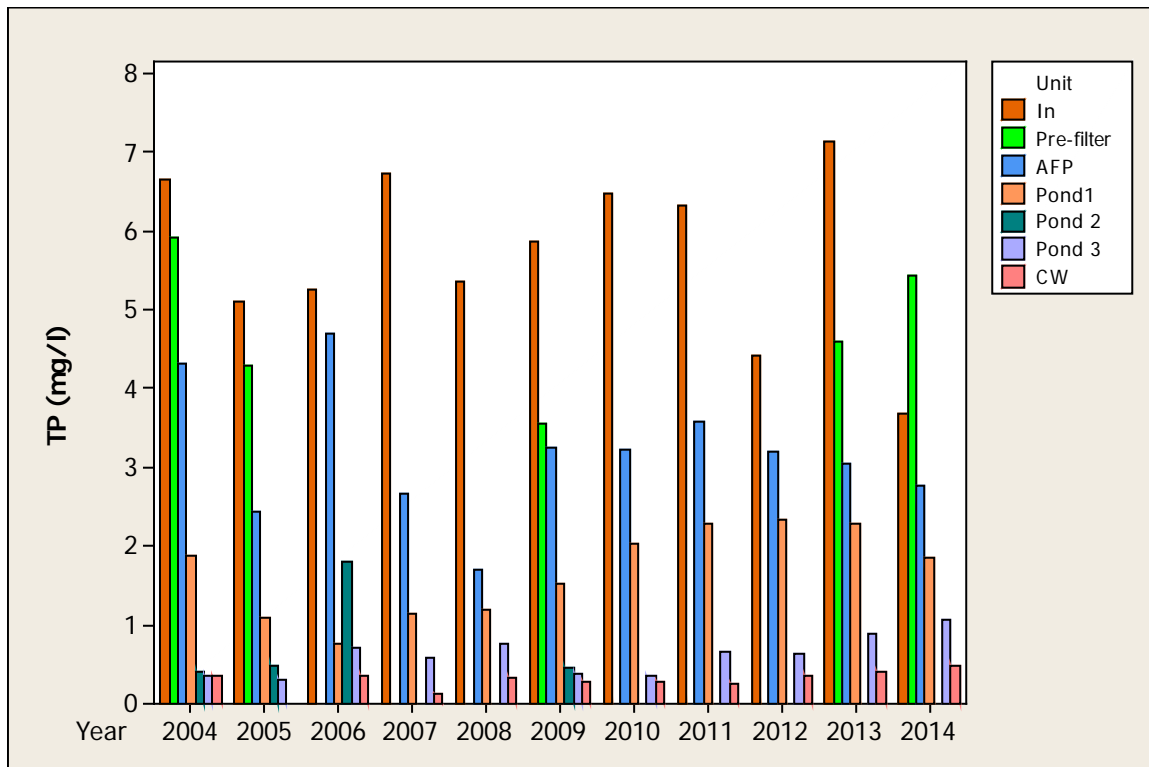


Figure 19: Concentration of total phosphorus at different stages of the treatment plant

5.6 Thermotolerant Coliform removal

The yearly average outlet concentration of TtC for the period from 2004 to 2014 is shown in figure 20. The yearly average performance data shows that the TtC is below the Norwegian permit limit of 100 TtC/100 ml. The TtC in domestic wastewater is in the range of log 6 to log 8 (Tchobanoglous 1991). Assuming the inlet TC concentration of log 6 (log 2 removed in the septic tank) the Vidaråsen system with an average yearly final effluent concentration of log 0.7 (6 TtC/100ml) has TtC removal capacity of log 5 (99.9%). The total coliform removal at different stages of the treatment in Vidaråsen system is reported in Browne and Jenssen (2005). Majority of the TtC removal is achieved in pre-filter unit (99%) at a theoretical retention time of 2 days (Table 3). The main removal pathway of pathogens in the attached growth process reactor like pre filter is by entrapment and adsorption to media; grazing by other microorganism and natural decay. Retention time is an important parameter for the removal of pathogen in CW. In cold climate a retention time of 7 to 10 days is recommended to achieve the effluent TtC that meets the permit limit (Jenssen et al. 2010). Since the retention time in the pre filter is short (2 days) the probable dominant mechanism of removal could be the adsorption to the media. The

bacteria may have been disinfected because of the rise in water pH in the pre filter with shell sand. The facultative pond has less than 1 log removal of coliform (60%). The stabilization pond 1, 2 and 3 removed 95% of TtC (2 log units). The pathogen removal mechanism in pond system is primarily exposure to ultraviolet rays and endogenous respiration as a result of long retention time (Tchobanoglous 1991).

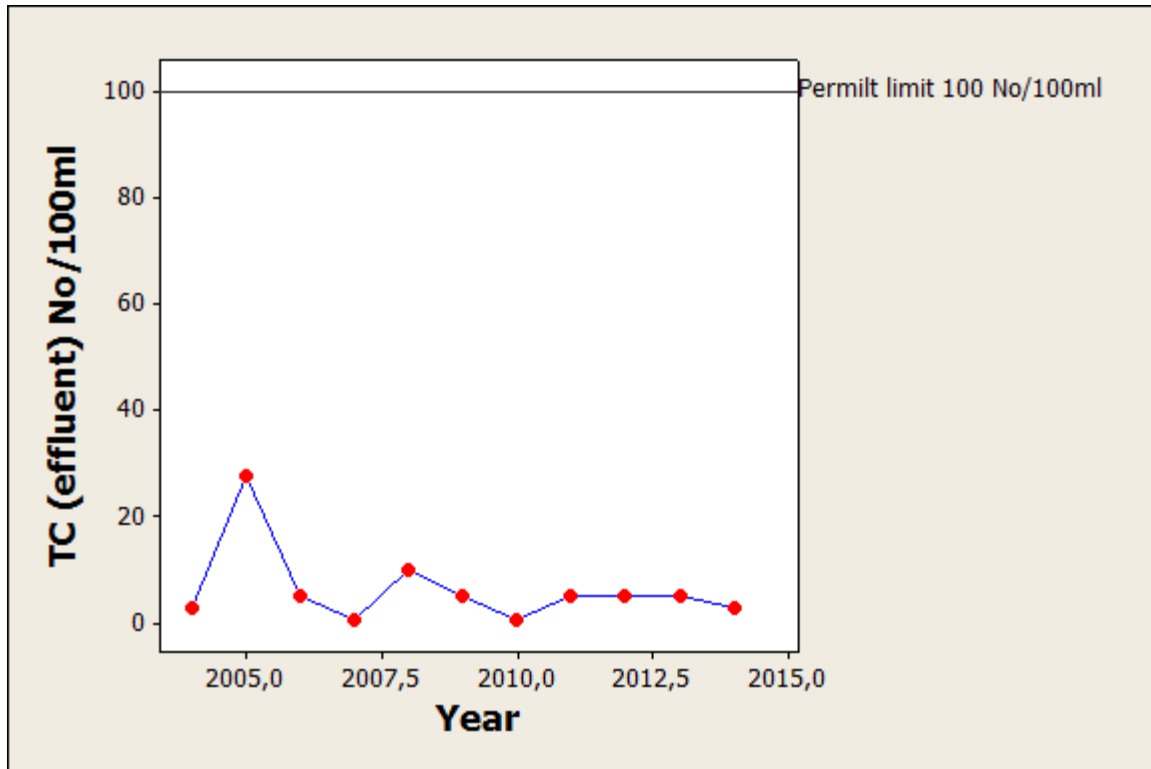


Figure 20: Yearly average outlet concentration of thermotolerant coliform (TtC)

6 Conclusion

The 11 years performance study of the Vidaråsen have shown that the combination of the constructed wetlands and the pond system is able to achieve high degree of the pollutant removal in cold climate. From this study, it can be deduced that the given combination of vertical flow wetlands followed by an advanced facultative pond (AFP) that is succeeded by three consecutive ponds and finally horizontal flow wetlands is an appropriate configuration to achieve an excellent removal in cold climate conditions. A key component for nitrogen and organic matter removal is the AFP. To fully utilize potential of the AFP the sludge from the septic tank can be taken via pipe to the AFP and discharge in batches into the anaerobic deep section of the pond. The sludge will be digested anaerobically and this will reduce the disposal

cost of septic tank sludge. The sludge will also supply required carbon for denitrification of the nitrated effluent from the vertical flow wetland pre-filter. The most remarkable feature of the Vidaråsen system is that it is able to achieve a very low effluent TP concentration of 0.4 mg/l. Such low concentration of phosphorus removal is difficult to achieve even by use of chemical precipitation. The P outlet data shows that for the last 16 years the P concentration in the outlet is consistently below 1 mg/l.

The Vidaråsen system has total area of 1990 m² and the total retention time of 75 days. The per capita area is 11 m². The land area requirement of the system in comparison to other decentralized systems (wetland filter beds and infiltration system) in Norway is high. The performance evaluation of the system shows that the pre-filter, the enhanced facultative pond and the terminal constructed wetland seems to be enough to achieve the current performance. This means that the two ponds in series following the AFP are redundant. Therefore, there is a possibility of the area optimization of the system if it is to be replicate elsewhere.

There is a growing interest to investigate overall sustainability of the wastewater systems including environmental, technical, economical and the social aspects. Performance analysis of the Vidaråsen system compared to a conventional system in terms of environmental impact and life cycle cost is therefore recommended. The TtC removal of the pre-filter system is found to be higher than the other units. The mechanism of the coliform removal in the pre-filter is not well understood. The bacteria and virus removal in the system with particular focus on the pre-filter is recommended for a follow-up study.

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Annex 1: Raw Data

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analysert av VestfoldLAB AS Tonsberg år 2004																	
Uke	Dato	Total P mg/l						BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l		T. Koll. /procent		Merknader
		Inn	FF1	FF2	EFP	D1	K10	Ut	Inn	Ut	Inn	Ut	Ut	Inn	Ut	Ut	
22	jan	5,6	5,1	3,9	1,7		0,32	0,32				1,50	49,40	11,70			
27	feb	2,4	7,3	5,5	2,7		0,53	0,53	24,1	4,5	130,1	44,0	1,50	12,90			
29	mar	7,0	5,4	5,2	1,8	1,0	0,52	0,63	372,0	3,0	731	17,0	1,50	1,50			Sand in prefilter switched to scd
30	sep	9,1						0,38	273,0	2,0	55,1	12,5	1,50	51,10	5,00		Sand i forfiltrene byttet til skjellsand
17	nov	4,0		2,7	1,3	0,51	0,28	0,11	234,0	1,5	39,5	12,5	1,50	3,00			
21	des	6,7						0,21	168,0	1,5	337	12,5	1,50	7,60	0,50		
Middel		6,7	5,9	4,3	1,9	0,71	0,4	0,36	358,2	2,5	663,4	19,70	1,50	49,40	14,63	2,75	
Kilo per år																	

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analysert av VestfoldLAB AS Tonsberg år 2005																	
Uke	Dato	Total P mg/l						BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l		T. Koll. /procent		Merknader
		Inn	FF	EFP	D1	D1f	K10	Ut	Inn	Ut	Inn	Ut	Ut	Inn	Ut	Ut	
28	jan	3,0	4,3	1,8	1,1		0,27	246,0	1,5	487	12,5	1,50	40,30	8,0			
30	mar			3,1			0,28		2,0		12,5	1,50	13,2				Terma koll EFP 600
29	apr	6,2					0,20	305,0	1,5	504	12,5	1,50	0,5	50,00			
11	aug	5,0		2,4			0,48	0,29	187,0	1,5	338	15,0	1,50	0,3			
20	okt	5,1					0,27	141,0	1,5	287	12,5	1,50	0,6				
14	des	6,3					0,47	82,0	2,0	138	12,5	1,50	6,5	5,00			
Middel		5,1	4,3	2,4	1,1		0,5	0,30	192,2	1,7	350,8	12,92	1,50	4,84	27,50		
Kilo per år																	

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analysert av VestfoldLAB AS Tonsberg år 2006																	
Uke	Dato	Total P mg/l						BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l		T. Koll. /procent		Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Inn	Ut	
8	feb	5,0						0,63	164,0	13,0	301	27,0	1,5	4,0	5,00		
13	feb	4,0			0,27			0,62	159,0	1,5	302	12,5	1,5	1,0	5,00		
19	feb			4,70			1,80	0,72	0,63	100,0	1,5	217	12,5	1,5	0,3	5,00	
28	sep	7,8						0,13	180,0	1,5	335	16,0	1,5	0,3	5,00		Filtremedia byttet i siste vårmåned til skjellsand
25	okt	6,4						0,10	173,0	1,5	325	12,5	1,5	0,8			
14	nov	3,1						0,06	71,0	1,5	154	12,5	1,5	3,8			
Middel		5,3		4,70	0,77	1,80	0,72	0,36	141,2	3,4	272,3	15,50	1,50	1,24	5,00		
Kilo per år																	

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2007																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	13 feb.	8,8						0,63	0,08	164,0	1,5	302	12,5	1,50	9,0		
	28 mar.	6,1							0,13	220	1,5	336	12,5	1,50	8,7		
	19 apr.	7,9		2,10					0,11	240,0	1,5	397	12,5	1,50	4,9	0,50	
	19 apr.	9,4		3,10	0,79			0,54	0,11	226,0	1,5	435	12,5	1,50	1,1		
	19 apr.	4,3		2,60	1,50				0,16	157,0	2,0	281	12,5	1,50	0,8		
	11 okt.	5,9		2,60					0,10	234,0	1,0	442	12,5	1,50	0,2		
	14 nov.	4,8		2,50					0,18	193,0	1,0	363	12,5	1,50	5,9		27,5 N i EFP dammen
	Middel	6,7		2,66	1,15	#DIV/0!		0,59	0,12	204,9	1,4	365,1	12,50	1,50	4,38	0,50	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2008																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	22 jan.	4,9						0,67	0,23	196,0	2,5	370	32,0	1,5	5,5		
	27 mar.	4,3							0,59	185	1,5	339	12,5	1,5	6,8		
	21 mai	9,2							0,27	117,0	3,0	200	32,0	1,5	1,0		Slamtomning dam 1
	18 sep.	4,5			1,0	0,15	0,85	0,30		213,0	1,5	366	5,5	1,5	2,0	10,00	Skjellsand eller lagd i dam 1
	13 nov.	4,6		1,7	1,4	0,09		0,31		187,0	1,5	317	12,5	1,5	4,5		
	23 des.	4,7						0,04		157,0	2,0	284	13,0	1,5	7,8		
	Middel	5,4		1,7	1,2	0,1	0,8	0,34		175,8	2,0	312,7	17,92	1,50	4,60	10,00	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2009																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	2 feb.	7,5						0,34	0,37	219,0	1,5	444,0	5,0	1,5			
	26 mar.	3,8				0,24			0,36	152	2,0	352	9,0	1,5	12,50		
	26 mar.	5,7	1,40	2,80	2,80	0,23	0,21	0,39	0,23	180,0	1,5	377	18,0	9,0	0,88		Oransje bakterie tettet utløp kum 10
	31 apr.	5,2	5,30	3,80	0,48	0,43	0,67	0,56	0,33	194,0	1,5	333	5,0	1,5	0,37	5,00	
	22 okt.	5,8	4,00	3,20	1,30	0,19		0,19	0,24	140,0	1,0	332	11,0	1,5	0,25		
	23 des.	7,2								336,0	1,5	569	5,0	1,5	6,70		
	Middel	5,9	3,6	3,3	1,5	0,3	0,5	0,4	0,28	203,5	1,5	401,2	8,83	2,75	4,14	5,00	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2010																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	18. feb.	6,6						0,39	176,0	2,5	330	5,0	1,5	11,20			
	9. mar.	6,7		3,40				0,21	0,25	1,65	2,5	250	5,0	1,5	8,90		
	26. mar.	5,7		3,50	1,80	0,98		0,46	0,24	218,0	1,5	405	45,0	1,5	0,45		
	18. jun.	7,0		3,30	2,40	0,98		0,40	0,21	139,0	1,5	307	45,0	1,5	0,23	0,50	
	21. sep.			3,30		0,58											
	16. nov.			2,60	1,90	1,20											
	Middel	6,5		3,22	2,03	0,94		0,36	0,27	174,5	2,0	323,0	25,00	1,50	5,20	0,50	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2011																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	29. mar.	7,4		2,6				0,25	317,0	1,5	563	29,0	1,0	12,10			
	13. april	8,5		3,5	1,7	2,1		0,72	0,28	240	1,5	397	5,0	6,0	2,40		
	2. jun.	6,7		3,7	2,1			0,43	0,21	209,0	1,5	386	5,0	1,0	0,33	5,00	
	11. aug.	2,6		3,3	1,2			0,87	0,23	150,0	1,5	260	12,0	1,0	0,12		
	14. okt.	6,5		4,8	3,7	2,1		0,58	0,25	291,0	1,5	520	5,0	2,0	0,27	5,00	forfiltrene ut av drift i 8 uker Oranjs bakteriaslim fra dam 2 til utløp
	Middel	6,3		3,58	2,30	1,85		0,65	0,24	241,4	1,5	425,2	12,20	2,20	3,04	5,00	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analyser av VestfoldLAB AS Tonsberg år 2012																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	10. feb.	5,9		2,10				0,45	0,30	160,0	1,5	397	5,0	2,0	4,90		
	25. apr.	3,2		2,30	1,40	1,10		0,65	0,33	164	9,0	360	22,0	19,0	5,80	5,00	
	29. jun.	4,2		4,10	2,30	1,70		0,46	0,32	54,0	2,5	137	5,0	11,0	0,29		
	30. aug.			5,20	3,80	2,30		1,40	0,34		1,5		5,0	1,0	0,37		
	30. okt.			2,80	1,90	1,20		0,27	0,44		1,0		20,0	1,0	1,40	5,00	Filter EFP dammen renses
	20. des.			2,70		1,50		0,58	0,42		2,0		29,0	5,0	3,10		Pumpen til forfiltrene byttet ut
	Middel	4,4		3,20	2,35	1,56		0,64	0,36	126,0	2,9	298,0	14,33	6,50	2,64	5,00	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analysert av VestfoldLAB AS Tonsberg år 2013																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	26. apr.			2,40	1,90	2,10		1,10	0,36	189,0	1,5	286,0	11,0	4,0	5,10	5,00	
	28. mai	7,3		3,70		1,60		0,80	0,37	150,0	1,5	376,0	28,0	4,0	1,90		
	19. jun	10,2		2,30	0,57	2,80		0,64	0,26	309,0	1,5	769,0	52,0	1,0	0,22		
	13. sep.	7,0		4,70	3,60			0,70	0,46		1,5		19,0	7,0	0,03		
	18. okt.	6,7	4,60	3,00	3,10	1,50		0,64	0,41	207,0	2,0	424,0	15,0	4,0	2,10		
	3. des.	4,6		2,20		1,50		1,40	0,57	320,0	2,0	549,0	16,0	1,0	13,50		Byttet skjellsand forfilter 1
	Middel	7,2	4,60	3,05	2,29	1,90		0,88	0,41	235,0	1,7	480,8	23,50	3,50	3,81	5,00	
	Kilo per år																

Vidaråsen Landsby Naturbasert Kloakkrensning																	
Prøver Resultater Analysert av VestfoldLAB AS Tonsberg år 2014																	
Uke	Dato	Total P mg/l								BOF ₇ mg/l		KOF mg/l		SS mg/l	Total N mg/l	T. Koli. /100ml	Merknader
		Inn	FF	EFP	D1	D1f	D2	k10	Ut	Inn	Ut	Inn	Ut	Ut	Ut	Ut	
	18. mar.	3,0		1,70				0,99	0,84	173,0	1,0	289	12,0	1,0	7,0	0,50	
	12. jun	7,2	5,44	4,60	2,00	2,40		0,73	0,96	163	1,5	368	14,0	15,0	0,4	5,00	
	1. okt.	1,2		3,30		2,30		1,60	0,10	197	1,0	392	5,0	1,0	0,3		Byttet skjellsand siste filter
	17. des.	3,4		1,50	1,70			1,40	0,18	207,0	2,0	372	5,0	1,0	5,5		Byttet pumpen til flowform dam 1
	29. des.							0,64	0,35		2,0		5,0	1,0	3,60		Byttet pumpen til flowform EFP
	Middel	3,7	5,44	2,78	1,85	2,35		1,07	0,49	185,0	1,5	355,3	8,20	3,80	3,36	2,75	
	Kilo per år																

ANNEX 2: Photographs



Vidaråsen Camphill



AFP during construction phase



Advance facultative pond



Pre-filter bed



Observing ponds and the installations (seen in photograph are Supervisor Prof. P. Jensen and Mr. Will Browne)



HF Constructed wetland

ANNEX 3- Data compilation

Yearly Average influent and effluent concentration of the parameters investigated in this study

Year	Total P		BOD		COD		SS	Total N		Total coliform/100m	
	Inn	Out	Inn	Out	Inn	Out		Out	Out	Out	
2004	6,7	0,36	358,2	2,5	663,4	19,7	1,5	14,63	2,75		
2005	5,1	0,3	192,2	1,7	350,8	12,92	1,5	4,84	27,5		
2006	5,3	0,36	141,2	3,4	272,3	15,5	1,5	1,24	5		
2007	6,7	0,12	204,9	1,4	365,1	12,5	1,5	4,38	0,5		
2008	5,4	0,34	175,8	2	312,7	17,92	1,5	4,6	10		
2009	5,9	0,28	203,5	1,5	401,2	8,83	2,75	4,14	5		
2010	6,5	0,27	174,5	2	323	25	1,5	5,2	0,5		
2011	6,3	0,24	241,4	1,5	425,2	12,2	2,2	3,04	5		
2012	4,4	0,36	126	2,9	298	14,33	6,5	2,64	5		
2013	7,2	0,41	235	1,7	480,8	23,5	3,5	3,81	5		
2014	3,7	0,49	185	1,5	355,3	8,2	3,8	3,36	2,75		
Mean Value	5,745455	0,320909	203,4273	2,009091	386,1636	15,50909	2,522727	4,716364	6,272727		
Standard Deviation	1,025461	0,091994	59,02882	0,625888	104,5932	5,252183	1,502629	3,314651	7,160858		

Frequency distribution analysis of monthly outlet TP concentration over the period of 2004-2014 (in Minitab)

TPcode	Count	Percent	CumCnt	CumPct
0,06:0,17	10	32,26	10	32,26
0,18:0,29	9	29,03	19	61,29
0,30:0,41	5	16,13	24	77,42
0,42:0,53	2	6,45	26	83,87
0,54:0,65	5	16,13	31	100,00
N=	31			



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