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A five year performance evaluation of on-site wastewater treatment at Høyås farm, Ås, Norway

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A FIVE-YEAR PERFORMANCE EVALUATION OF ON-SITE WASTEWATER TREATMENT AT HØYÅS FARM, ÅS, NORWAY

A Thesis submitted in partial satisfaction of the requirements for the degree
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in

Environment and Natural Resources - Specialization Sustainable Water and Sanitation, Health and Development.

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ABSTRACT

To prevent contamination of surface and groundwater sources, municipalities in Norway maintain strict regulations to control the discharge of treated wastewater. Municipalities with local codes set phosphorus (P) effluent discharge limit of 1 mg/l for wastewater treated with On-site waste wastewater treatment systems (OSWWTs) such as the constructed wetland/filter bed system in use at Høyås farm in Ås municipality. The system has been in operation for 5 years. The system component includes a septic tank and biofilter for pre-treatment. This is followed by two P filter units installed parallel to each. One unit is filled with P filter Filtralite-P (PFFP) while the other with P filter Filtramar (PFFM) also known as Shellsand. The last treatment units are two sand filter units installed parallel to each other to polish the effluent. One sand filter (SFFM) receives effluent from PFFM and the other sandfilter (SFFP) receives PFFP effluent.

The treatment system has been under study to monitor the performance since start of operation. This work evaluates the operation performance of the system for 5 years. This is done by taking Wastewater samples from effluent in each treatment components, analysing for P in form of total P (TP), and establishing time-series trend from data collected since start of operation.

Treatment performance parameters other than TP were evaluated by analysing for ortho-phosphate (Ortho-P), nitrogen (N) in form of total nitrogen (TN), ammonium ions (NH_4^+), nitrates (NO_3^-), conductivity, pH’ as well as 5-day biochemical oxygen demand (BOD5). Time series report was made for each parameter to establish changes in effluent quality over time. After the 5th year, the Høyås system has a removal efficiency of 60% for TP, 60% for Ortho-P, >50% for TN, 92%-94% for NH_4^+, and >97% for BOD. Effluent pH is in range 7-8.

The final effluent using time series data has mean TP effluent concentration of 0.79mg/l and 1.08mg/l from SFFP and SFFM respectively and mean BOD concentration of 14.23mg/l and 7.23mg/l from SFFM and SFFP respectively. The treatment system meets the discharge limits of 1mg/l for P in the SFFP effluent. The SFFM effluent slightly exceeds the limit 1mg/l (mean final effluent still under 1mg/l). A time series forecast predicts the TP mean effluent to exceed limit within the next 5 months. The effluent BOD meets the 20mg/l for BOD set by the Ås municipality.

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Abbreviations

A – Surface area

BF – Bio-filter

BOD$_5$ – 5-day biological oxygen demand

Cin – Concentration in the inlet

COD – Chemical oxygen demand

Cout – Concentration in the outlet

CW – Constructed wetland

DS - Dissolved solids

E. coli – Escherichia

coli EU – European

Union Fig. – Figure

FWS – Free water surface

GEMS – Global Environmental Monitoring

System HLR – Hydraulic loading rate

k – Constant

K – Hydraulic conductivity

N – Nitrogen

NE – Nonexistent

NH_4^+ - Ammonium

NO_3^- - nitrate

Ortho-P – Orthophosphate

OSWWT - On-site waste wastewater treatment system

P – Phosphorus

Pe – Person equivalent

PFFM (FM) - Phosphorus filter

Filtramar® PFFP (FP) - Phosphorus filter

Filtralite® P Q – Volumetric flow rate

SF – Sand filter

SFFP – Sandfilter Filtralite® P

SFFP – Sandfilter Filtramar®

SS - Suspended solids

ST – Septic tank

Std.Dev – Standard deviation

STE – Septic tank effluent

TN – Total nitrogen

TP – Total phosphorus

TSS – Total suspended solids

VSB – Vegetated submerged bed

WWTS – Wastewater treatment system

WW – Wastewater

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1. INTRODUCTION

1.1. Research background

It is important to treat wastewater before discharging it into the environment. In Norway, as well as in most Nordic countries, most homes and facilities in the rural areas use on-site (decentralized) systems to collect and treat wastewater generated. In these areas, it is often difficult to collect wastewater through sewer network and treat it in wastewater treatment plants like the usual practice in most cities of the world. Connecting these houses to the network is very difficult and economically not viable (Jenssen et al. 2010), due to long distances over which pipes would need to be laid through rough terrains, forests or even bedrock. Therefore, it is expected that houses in rural areas are not connected to sewage networks.

However, the increasing popularity of using on-site waste water treatment systems, demands efficient and sustainable systems. Major potential sources of water pollution in European countries have been identified as inadequately treated wastewater from rural households (Johansson & Johansson 2002; Vymazal et al. 1998). It is convenient for house owners to settle for cheap on-site wastewater treatment options in terms of installation and maintenance which often results in low performance (Westholm 2006). Factors such as soil properties, depth of water table, available space, topography of the area, affect the performance of on-site wastewater treatment systems when infiltration is used (Jenssen & Siegrist 1991). Many areas do not have natural conditions favourable for infiltration and package treatment plants or various filter-based systems (as investigated in this thesis) have to be used

On-site wastewater treatment systems, if properly set up, perform well in most regions, including in places with cold climate. Previous studies and experiences have shown that cold climate on-site treatment systems can meet effluent criteria for the most important treatment parameters (Wittgren & Maehlum 1997). In addition, there has been strict local guidelines and regulations on wastewater effluent quality in Norway (NKF and NORVAR 2001). These guidelines and regulations, necessitate for the use of high performance on-site waste water treatment systems. The overall national guidelines for wastewater effluent discharge can be modified and made stricter by each municipality. The guidelines demand high performance treatment systems to protect the environment and most importantly, the water bodies form nutrient contamination. Nutrient contamination from wastewater has been identified as a cause for eutrophication in water bodies.

Eutrophication is the promotion of the growth of plants, animals, and microorganisms in water bodies (Khan & Ansari 2005). It reduces water quality. It is a very slow, natural process which results in an extreme deficiency or even complete depletion of oxygen (anaerobic condition) in surface water if not disrupted. Consequently, aquatic organisms that survive in the presence of oxygen (aerobic condition) perish while anaerobic organisms are favored instead. Wastewater characteristics that could affect water quality and influence eutrophication are Phosphorus (P), Nitrogen (N), BOD_5, suspended solids (SS), dissolved solids (DS), pH, conductivity, alkalinity.

Phosphorus and Nitrogen are the major causes of eutrophication in surface water. While Phosphorus has been identified as cause of eutrophication in fresh water sources (Bennett et al. 2001), the major cause of eutrophication in salt water is Nitrogen (Vitousek et al. 1997). The required performance of the on-site systems is regulated by Norwegian local codes and Municipalities with local codes normally use 1.0mg/l effluent discharge limit for phosphorus (Heistad et al. 2006a). It was estimated by (Hinesly & Jones 1990) that, phosphorus concentrations exceeding 0.05mg/L may cause eutrophication in surface water bodies. This emphasizes the importance of having high performance wastewater treatment system for phosphorus removal.

P removal in filter based on-site wastewater treatment system is achieved by using P- sorbing filter materials or substrates. The substrates can be natural materials, industrial by-products and man-made products (Vohla et al. 2011). To be suitable for use in a small scale on-site system, the substrate must have high P sorption capacity, have adequate hydraulic conductivity as well as be available at reasonable cost (ÁdÁm et al. 2007b). Increasing numbers of P- filter materials have been proposed as suitable media for P removal in on-site wastewater treatment systems (Cucarella & Renman 2009). However, the longevity of the sorption capacity of phosphorous is still a major focal point for research (Herrmann 2014)

The small scale on-site wastewater treatment system installed at Høyås farm in Ås municipality, Norway uses P-filter materials with high P-sorption capacity (Mironga 2014). The system was constructed in 2012 was put into operation same year. The P-filter materials in use in the system are Phosphorus Filters: Filtrate-P (PFFP) and Phosphorus filter Filtramar

(PFFM). The system receives WW from an average of 8 people per day throughout a year and can treat WW from a maximum of 25 persons per day (Al Nabelsi & Ganesh 2013). It is based on the design of a Norwegian constructed wetland/filter bed system but the P-removing filter units are strongly downsized compared to the requirement in the Norwegian guidelines (VA-miløblad 49). A polishing step in a small sand filter, that is not required in VA-miljøblad 49, is added.

In addition to being a potential cause of eutrophication, wastewater effluents may cause loss of species and habitat as well as increasing the turbidity of receiving water. Wastewater effluents may also pose a health risk to drinking water sources by spreading of pathogens. This may occur if inadequately treated wastewater effluent is discharged into surface water bodies or groundwater. Therefore, top performance wastewater treatment system is vital to achieving environmental sustainability as well as to safeguarding human health.

1.2. Research Objectives

The specific objectives of the study are to;

- Compare phosphorus sorption capacities of Filtralite-P and Filtramar materials
- Establish, and to what extent does the individual treatment components reduce the contaminant concentration.
- Determine whether the system meets the discharge limits of 1mg/l for P and 20mg/l for BOD.
- Estimate life time for the P-filters as well as, identify probable causes of variation in the effluent concentration over time.
- Assess ways to improve general treatment performance of the treatment

1.3. Research Questions

In fulfilling the stated objectives, the following research questions will be discussed:

- What is the current situation of the Høyås wastewater treatment system in term of system design and functionality of the system components?
- What is the Characteristics of wastewater been treated?

- How efficient are the FP and FM p-filter materials and how efficient is the general treatment performance?
- Does the system still meet the discharge limit set for Phosphorus and BOD and how has the system performance changed over time?

1.4. Significance of the study

This study is beneficial to the environment especially the receiving water bodies. The Ås municipality may use results from this study to evaluate whether Høyås system still maintains discharge limits for Phosphorus and BOD. This study may also be beneficial to the system owner. Findings and recommendations from this study may provide help in maintaining or retaining a high-performance system. Furthermore, system engineers may use this study to evaluate and choose P-filter medium with better P-sorption capacity when constructing on-site wastewater treatment systems with Phosphorus medium for P-sorption.

In the next chapter, a background to the study is presented. chapter 3 shows the materials and methods used in the study. chapter 4 presents the results and chapter 5 discusses the results. The last chapter, chapter 6, presents the conclusion. Recommendations are also made in the 6th chapter.

2. BACKGROUND INFORMATION

This chapter will present a literature review on the topic of local wastewater treatment plants in Norway, regulation of water quality after the wastewater treatment system, and descriptions of the main water pollutants that come from domestic wastewater into water bodies.

2.1. Small scale wastewater treatment in Norway

Small-scale water supply systems include private or individual facilities and installations, usually providing one house or a small number of houses with water for domestic and / or commercial needs. These systems administered by the local community, and public systems under the management of a public organization that usually supply water to farms, villages, towns and suburban areas (Rickert et al. 2016). These can be systems with or without water supply through pipes. They may or may not include water treatment, storage and distribution of water.

Small-scale sanitation technologies include a whole range of systems - from simple local ones, such as latrine toilets, flush toilets, to septic tanks or collective sewer systems with or without wastewater treatment. These systems can be managed by organized utility companies, but many local systems are run by communities or individuals.

Small-scale water supply systems are determined based on such criteria as the number of served population, the form of management, the amount of water supplied, as well as the presence or absence of a pipeline for water supply, centralized or decentralized water supply, location in rural areas or in a city. Likewise, small-scale systems can be classified by the number of wastewater being treated, the number of connections to maintenance or the type of technology used.

As is known from the work of Paruch and others, about 17% of the population of Norway use small decentralized water treatment facilities. This is approximately 340000 operating local systems. The figure below shows the distribution of those small scale WWTS systems with different technologies (Paruch et al. 2011).

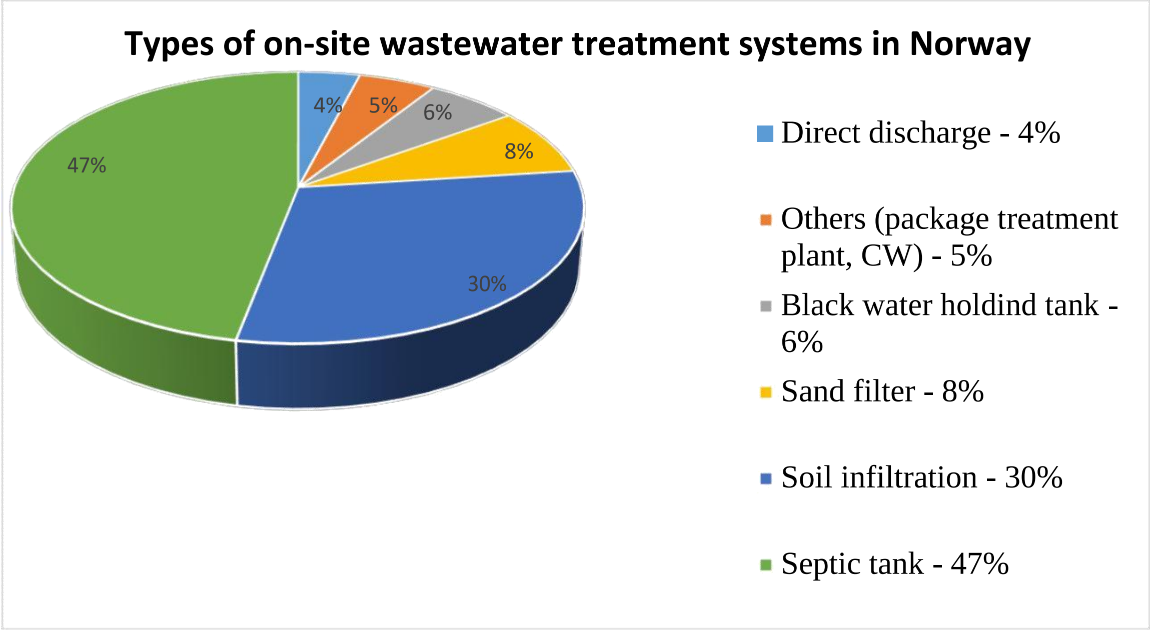


Fig. 2.1: *Distribution of on-site wastewater treatment technologies in Norway (Johannessen 2012).*

2.2. Issues of wastewater treatment performance of wetland systems in cold climate

In recent years, the development and use of alternative, small-scale, environmentally and economically acceptable wastewater treatment technologies have been actively promoted in the world. The most promising of them are those whose action is based on the use of natural processes occurring in aquatic ecosystems with the participation of higher aquatic vegetation. There is a number of options for solving the problem of wastewater treatment, in particular using the constructed wetlands technology.

Constructed wetlands are ecologically designed marsh ecosystems that integrate physical, chemical and biological processes involving marsh vegetation, soils and associated microbial communities in the process of wastewater treatment. Systems are created that, under the condition of low cost and minimum maintenance requirements, are governed primarily by natural energy, as sun and gravity. And they are capable of self-sustaining processes occurring in them. At the same time, they are reliable and highly efficient in the transformation and removal of pollutants of sewage, regardless of the season of the year.

Constructed wetlands are divided into two types depending on the location of the hydraulic design line (Vymazal 2008). These types are:

- Free water surface (FWS) wetlands (or surface flow wetlands);
- Vegetated submerged bed (VSB) systems (subsurface flow wetlands).

Outwardly FWS are very reminiscent of natural bogs by the presence of standing water and aquatic plants, rooted in the soil layer on the bottom of the marsh. Wastewater in such systems pass through leaves, stems and plant bases. FWS CW is the most efficient facility for reducing the concentration of ammonium and nitrates in wastewater, which is explained by the extremely high level of nitrification in systems of this type (Jin et al. 2002). Also, due to the significant impact of sunlight on systems with surface flow, they are more effective in removing of *E. coli*.

Then VSB do not look like natural bogs in appearance: they do not have open water spaces, constant water level. Such systems are a bed of filter medium (such as crushed stone, small stones, gravel, sand or soil), which is planted with aquatic plants. With proper design and operation, the wastewater passes the system below the surface of the medium, in contact with the roots and rhizosphere of the plants. In addition, vertical flow wetland is separately distinguished. This type of constructed wetlands is a typical vertical sand or gravel filter planted with aquatic plants (Moshiri 1993).

In the northern regions, the main problem associated with the technology of constructed wetlands is its operation at low temperatures. The experience of the use of constructed wetlands in Norway, Sweden, Denmark, Canada and North America shows that artificially created wetlands as post-treatment facilities are effective even at low temperatures. However, the winter decrease in the activity of the such systems is insignificant in comparison with the warm season (Jenssen et al. 1993) .

Seasonal fluctuations play no small role in the functioning of the constructed wetlands for wastewater treatment. During the winter, the percentage of bacteria reduction is lower compared to all other seasons (Thullen et al. 2005). The maximum removal of bacteria is noted in conditions of high solar radiation and high temperature (Zdragas et al. 2002). Removal of ammonia varies cyclically for the seasons of the year in the constructed wetlands. However, a clear dependence on seasonal factors such as temperature, mass load and salinity of effluents for ammonia removal was not revealed in the constructed wetlands (Jing & Lin 2004).

Among the two types of constructed wetlands, systems of subsurface runoff have an advantage in a colder climate. Since purification occurs below the ground level, which means that bacterial communities are also isolated and protected from exposure to cold air. Temperature and other seasonal changes in climatic conditions affect both biological and physical activity within the system (Wittgren & Maehlum 1997).

It was revealed that the constructed wetlands remain fully functional in conditions of low temperatures. The experience of including wetlands in the water treatment system has shown a high efficiency of the method in Norway. Moreover, the purification processes were practically identical both in the summer and in the winter, with a rather high level of removal of organic matter (BOD, COD), phosphorus and nitrogen (Maehlum 1995).

2.3. Effluent standards

Water pollution has become a global problem in the present time. In this connection, the role of rationing of the maximum permissible impact on the environment is increasing. This will guarantee the ecological safety of the population and the preservation of the genetic fund. Ensuring rational and safe water use, excluding depletion of water resources and irreversible deterioration of the quality of the environment, is one of the urgent and key tasks of the socio-economic development of European countries. At the same time, the issue of normalizing the quality of wastewater treatment is one of the fundamental issues of the water sector, at least the part that is associated with the use of water for drinking and industrial water supply, which inevitably leads to the formation and discharge of sewage into the water receivers.

According to “TheRichest”, which makes the top-10 ratings in a variety of indicators, Norway ranks second in the quality of tap water in the world, second only to Switzerland (www.therichest.com, 2016). Surely this is one of the factors ensuring, the northern country for the past 14 years, the first place in the list of countries for the human development index, taking into account the life expectancy and health of the population (UNDP, 2016). This is all due to the fact that Norway allocates considerable intellectual and financial resources to the cleanliness of the environment and water resources.

Every year, 700 million cubic meter of water passes through the stations of water treatment and wastewater treatment. With the daily intake of about 200 liters of water per person, this makes it possible to provide 90% of the population with clean water. The remaining use private sources. Thus, most of the water resources are supplied by the state.

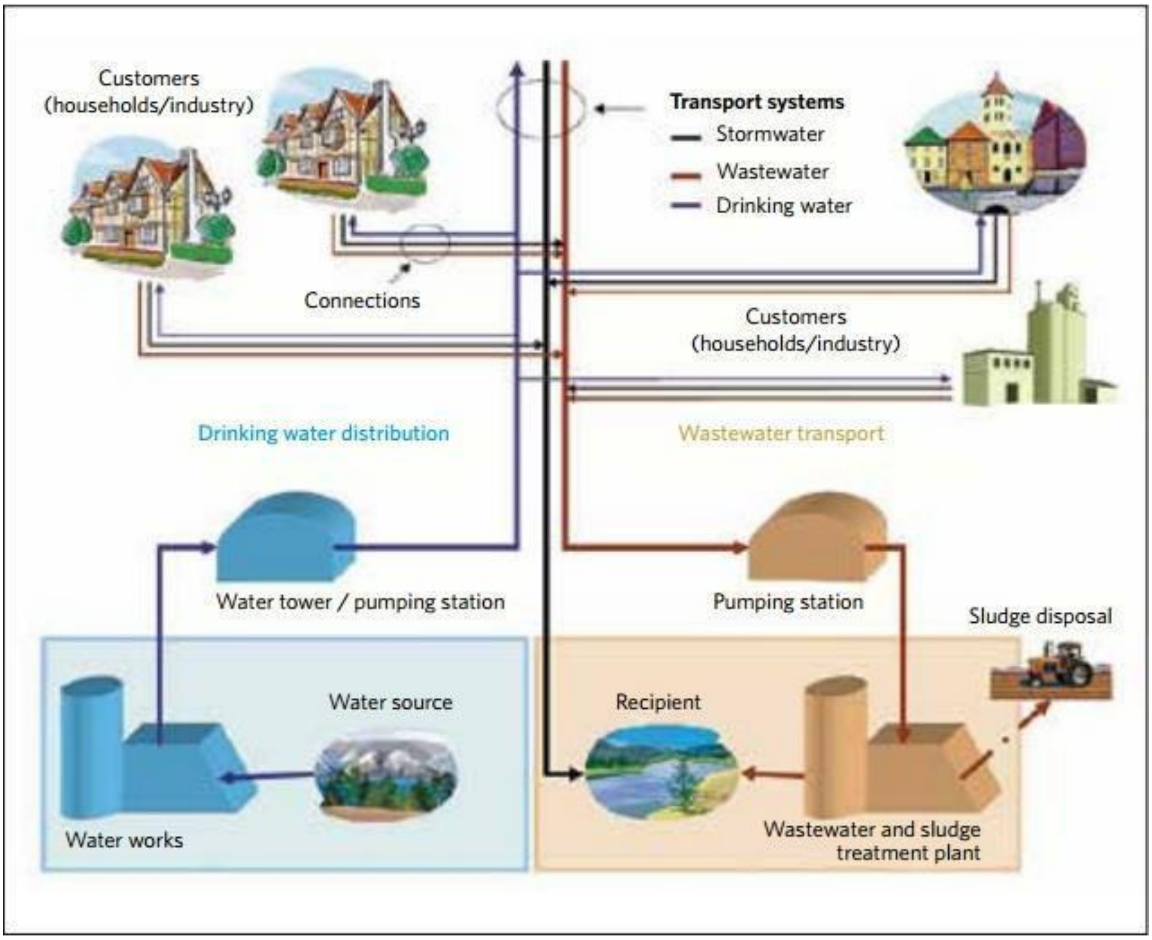
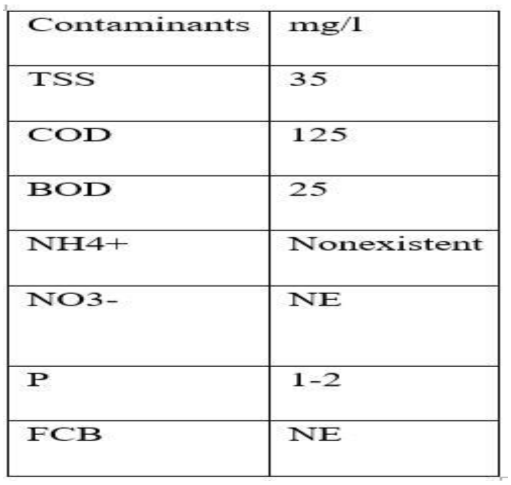


Fig.2.2: *Schematic diagram of the Norwegian water supply and wastewater infrastructure* (“Norwegian Water,” 2014).

The state provides access to a centralized water treatment complex for 84% of the population. The rest, 16% use local cleaning facilities. Such indicators are achieved due to the distribution of the population across Norway. Nevertheless, this approach provides a high-quality result of wastewater treatment and water supply, despite the difficulties in implementation.

Based on the EU standards - the system of global environmental monitoring - the level of phosphorus is the most important criterion in determining the quality of treatment in local water treatment systems. Determination of the saturation of total phosphorus (considering dissolved and suspended forms, organic matter and mineral compounds) has become a mandatory item in the program for monitoring the composition of water body.

Table 2-1: EU standards (Ellingsen, 2012).



Contaminants	mg/l
TSS	35
COD	125
BOD	25
NH4+	Nonexistent
NO3-	NE
P	1-2
FCB	NE

In Norway, there is a national requirement for the regulation of wastewater pollution after small-scale wastewater treatment systems. They should provide about 90% removal of total phosphorus and BOD_5 (Johannessen, 2012). Also, according to the rules of local municipalities, there are maximum permissible emission standards for phosphorus and biological oxygen demand in wastewater after such local plants. These limit levels are those:
P = 1 mg/l and BOD_5 = 25mg / l (Heistad et al. 2006b).

2.4. Contaminants in wastewater

2.4.1. Phosphorus

Phosphorus is the most important obligatory chemical element necessary for living organisms and has the highest bioaccumulation coefficient, i.e. acts as a fertilizer (Litke 1999).

This element serves as a powerful biogenic agent. In natural reservoirs, it is often the total content of mineral-organic phosphorus that becomes a factor restraining the further growth of productivity. The ingress of excess volumes of phosphorus-containing compounds into natural sources triggers mechanisms of uncontrolled growth of plant biomass. Low-flow and non-current objects are more prone to changes in the trophic status, which are accompanied by a complete rearrangement of the entire structure of the reservoir: the concentration of bacteria and salts increases, putrefactive processes begin to prevail, and the water becomes turbid.

When phosphorus enters water bodies, it causes rapid growth of algae, especially blue-green (cyan bacteria), which disrupt the natural bio-system, extract dissolved oxygen from the water, avoid sunlight, create anaerobic conditions and lead to the death of many living organisms and accumulation of bio-toxins. Water in such reservoirs is not suitable for water consumption by the population and dangerous for human health and life (Köhler 2006).

One of the likely aspects of the eutrophication process is the growth of blue-green algae (cyanobacteria), many of which are toxic. The substances released by these organisms belong to the group of phosphorus- and sulfur-containing organic compounds, which belong to the nerve-paralytic poisons.

2.4.1.1. Sources of Phosphorus

The main source of additional intake of phosphates in natural waters is domestic wastewater containing phosphates of detergents and final products of animal and human vital activity (Kundu et al. 2015). Washing powders and detergents, as well as many water softeners, are "suppliers" of sodium polyphosphate phosphate salts of complex composition, which can be converted into orthophosphates during hydrolysis. In addition, phosphates are an integral part of the compositions that reduce the formation of scale when using water in heat exchange processes. In an even greater quantity, phosphates enter natural reservoirs with fertilizers washed off from fields, from drainage systems, urban storm sewage.

Many researchers have analyzed the ways of phosphorus intake and its content in surface water bodies. Thus, when studying the reserves and dynamics of phosphorus concentration in Lake Dong Hu (China) during the period from October 1997 to September 1999. The total supply of phosphorus to the lake from the outside was from 3.1 to 3.2 g/m3 in one year during the indicated period. At the same time, 80% of phosphorus came from sewage, and the rest - from atmospheric precipitation. The laboratory of the University in Hanover (Germany) also studied the ways of phosphorus entering the natural waters. According to their data, about 38% of phosphorus compounds enter water bodies with domestic wastewater.

It should be noted that inorganic compounds of phosphorus make up only 10% of the total amount of phosphorus contained in the water of surface water bodies, and the bulk of its reserves are in organic form, for example, in sexton, and, naturally, settles to the bottom.

Phosphorus in waste water is represented as organic, inorganic and mixed contaminants, as well as bacteria and microorganisms present in varying degrees of dispersion, in the form of suspended solids, colloids, and soluble substances.

Soluble phosphates include alkali metal and ammonium salts; the remaining metals form insoluble precipitates. The properties of phosphates include their ability to sorb on the surface of other substances.

2.4.1.2. Phosphorus forms in wastewater

By total phosphorus is meant the sum of mineral and organic phosphorus. Just as for nitrogen, the exchange of phosphorus between its mineral and organic forms, on the one hand, and living organisms, on the other hand, is the main factor determining its concentration. In natural and waste waters, phosphorus can be present in different forms. In the dissolved state (sometimes referred to as the liquid phase of the water being analyzed), it can be in the form of Ortho-Phosphoric acid (H_3PO_4) and its anions ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}

) in the form of meta-, pyro- and polyphosphates (these substances are used to prevent the formation of scale, they are also part of detergents). In addition, there are a variety of organophosphorus compounds - nucleic acids, nucleoproteins, phospholipids, etc., which can also be present in water, being the products of vital activity or the decomposition of organisms. Some organic pesticides also belong to organophosphorus compounds.

Phosphorus can also be present in the undissolved state (in the solid phase of water), being present in the form of slightly soluble phosphates suspended in water, including natural minerals, protein, organic phosphorus-containing compounds, remains of dead organisms, etc. Phosphorus in the solid phase in natural reservoirs is usually found in benthic Sediments, but can occur, and in large quantities in wastewater and polluted natural waters.

In accordance with the requirements of the global system for monitoring the state of the environment (GEMS), the determination of the content of total phosphorus (dissolved and suspended, in the form of organic and mineral compounds) is included in the compulsory observations of the composition of natural waters. Phosphorus is the most important indicator of the trophic status of natural water bodies. The main form of inorganic phosphorus at pH values of the water body is more than 6.5 is the HPO_4^{2-} ion (about 90%) (McCray et al. 2005). In acidic waters, inorganic phosphorus is predominantly in the form of $H_2PO_4^-$.

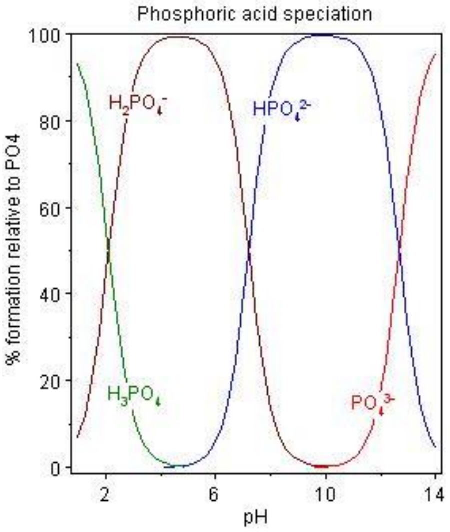


Fig. 2.3: *Complexation of phosphoric acid as a function of pH (Brothers 2014).*

2.4.2. Nitrogen

2.4.2.1. Total Nitrogen

The water of open natural water bodies contains a certain percentage of nitrogen-containing compounds, which are either dissolved in it, or are present as a suspension or in a colloid form. Under the influence of biochemical processes occurring in water bodies, as well as under the influence of physical and chemical factors (Oakley et al. 2010), they are transformed, passing from one state to another. The TN indicator shows the total saturation of the water of a natural source with both mineral and organic nitrogen compounds.

The total index of water saturation with nitrogen of mineral origin reflects the aggregate volume of its nitrate (NO_3^-), nitrite (NO_2^-) forms and ammonium (NH_4^+). The high content of nitrites and ammonium nitrogen is a very reliable indicator of recent pollution, and a large amount of nitrates may indicate that the water has been contaminated long enough. The ability to interconversion is inherent in both gaseous nitrogen compounds and all its other forms (Harrison 1998), that are shown in figure below (Fig.2.3.).

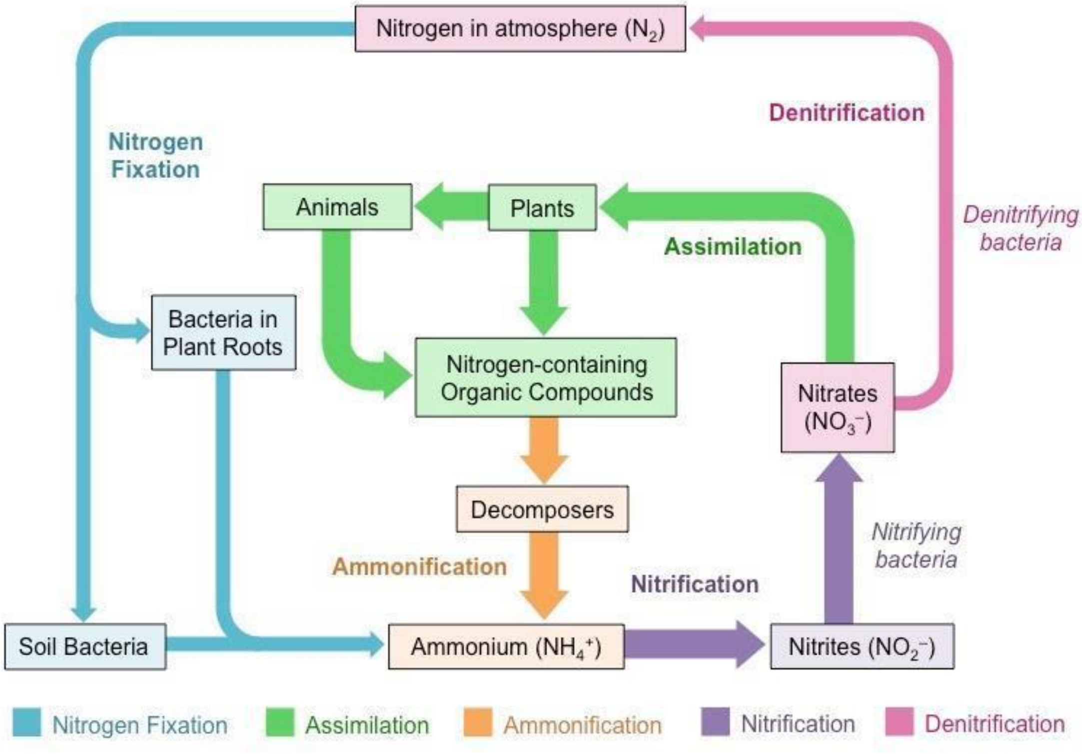


Fig. 2.4: *Transformation and cycle of Nitrogen in the environment.*

2.4.2.2. Ammonium

The water saturation by ammonium ions (in terms of nitrogen) varies between 10-200µg/l. Their main natural suppliers to uncontaminated water bodies are the following reactions:

- Biochemical degradation of protein compounds;
- The process of amino acid deamination;
- Decomposition of urea, occurring with the participation of urease.

Come ammonium ions with runoff from livestock farms, household discharges and farmland. In Norway, the use of ammonium fertilizers is popular. Over-saturation with ammonium ions reflects the deterioration of the sanitary situation in the water body. This is an effective indicator of pollution, both for underground and for natural water bodies located on the surface. First of all, this indicator demonstrates the presence of domestic and agricultural impurities.

In domestic sewage contains up to 2-7mg/l ammonium; there are around to 10 grams of ammonium nitrogen (per capita) is fed every day to the WW system from the household sewage.

2.4.2.3. Nitrate

There are several sources of nitrate ion penetration into water bodies:

- Nitrification of ammonium nitrogen. The process takes place in the water column with the participation of oxygen and nitrifying bacteria;
- Precipitation coming from the atmosphere. They are saturated with nitric oxide, formed from electrical discharges;
- Domestic sewage;
- Irrigated fields and other farmlands. Hence, nitrates are due to the active use of nitrogen supplements.

Nitric acid salts – nitrates (NH_4^+) - are the final products of mineralization of organic nitrogen-containing substances. The presence in water of nitrates without ammonia and nitrous acid salts indicates the completion of the mineralization process and at a high content in the water indicate an ancient contamination of it. Simultaneous content of all three components in the water - ammonia, nitrites and nitrates - indicates the incompleteness of the mineralization process and the epidemiological contamination of water.

The increased content of nitrates at the outlet from the water treatment plant leads to the overgrowth of the water outflow. Nitrogen, as a biogenic element, promotes the growth of algae and bacteria. This is called the eutrophication process. This process is very dangerous for water reservoirs. Since the subsequent decomposition of plant biomass will consume all the oxygen in the water.

2.4.3. pH

The hydrogen index pH is the negative decimal logarithm of the concentration of hydrogen ions in water. It is one of the important characteristics of water, which determines the chemical and biological processes that take place in it. The pH depends on the degree of dissolution of various elements, their toxicity, and the effectiveness of water purification methods. In an aqueous solution with a pH level of 7, H^+ and OH^- ions are in equal concentrations, and this solution is called neutral. Waters with pH less than 7, where the concentration of H^+ ions exceeds the concentration of OH^- ions, are acidic, and with pH more than 7 - alkaline. The pH level in waste water must be between 6 and 9.

Table 2-2: Classification of waters by pH:

Water group	pH value
Strongly acidic	< 3,0
Acidic	3,0-5,0
Weak acid	5,0-6,5
Neutral	6,5-7,5
Weak alkaline	7,5-8,5

Alkaline	8,5-9,5
Strongly alkaline	>9,5

Water with a low pH level has increased corrosive activity, and at a high pH level, there is an increase in the intensity of formation of iron deposits and salts of stiffness is observed.

Water dissociates (decomposes) into hydrogen ions H^+ and hydroxyl OH^- by the equation:

$H_2O \leftrightarrow H^+ + OH^-$

But the same number of water molecules simultaneously formed again. Consequently, the composition of water at a certain temperature and in the absence of impurities does not change.

$K_w = (H^+)\,(OH^-) = 10^{-14}$

The product of the concentrations of these ions is a constant value and is called the ion product of water - K_w. Since a small amount of water molecules breaks down, the concentration of H^+ and OH^- ions is small, then small is their product. At a temperature of 24.8°C, $K_w = 10^{-14}$.

An increase in the concentration of hydrogen ions causes a corresponding decrease in hydroxide ions and vice versa.

For a neutral stage:

$[H^+] = [OH^-] = \sqrt{10^{-14}} = 10^{-7}$

To assess the acidity and alkalinity of the medium, it is convenient to use not the concentration of hydrogen ions, but the hydrogen pH. It is equal to the decimal logarithm of the concentrations of hydrogen ions, taken with the opposite sign.

If any substance dissolved in water, which is itself the source of H^+ and OH^- ions (for example, the acids: HCl, H_2CO_4, HNO_3, etc.; alkalis: NaOH, KOH, $Ca(OH)_2$, etc.), the H^+ and OH^- will not be equal, but their product K_w will be constant.

2.4.4. Conductivity

Electrical conductivity of a water solution to conduct an electric current. The inverse of the electrical resistance. The electrical conductivity of water depends on the concentration of ions dissolved in it and the water temperature. The mineral part of the water is made up of Na^+, K^+, $Ca_2{}^+$, $Mg_2{}^+$, Cl^-, $SO_4{}^{2-}$, HCO^{3-} ions. These ions determine the electrical conductivity of natural waters. The presence of other ions, for example Fe^{3+}, Fe^{2+}, Mn^{2+}, Al^{3+}, NO^{3-}, $HPO_4{}^{2-}$, H_2PO^{4-}, do not greatly affect the electrical conductivity if these ions are not contained in water in significant amounts (for example, below releases of production or household waste water). With an increase in the mineralization of water, its electrical conductivity rises. The index of electrical conductivity is used to control the quality of reverse osmosis, distilled and deionized water. The electrical conductivity of distilled water should not exceed 5µS/cm.

2.4.5. BOD

Biochemical oxygen demand (BOD) is an indicator determined by the oxidation of "organic" not with the help of chemical substances, but by biochemical effects under aerobic conditions (Von Sperling & de Lemos Chernicharo 2005). Biochemical oxygen consumption is more often determines for five days (BOD_5) and, as a rule, this index in surface waters is in the range of 0.5-4.0 mgO2/l (Du Toit 2006).

3. MATERIALS AND METHODS

In this chapter, the wastewater treatment system at the Høyås farm will be introduced, including the design and components of the system. Wastewater sampling procedures and methods used in wastewater analysis will also be described.

3.1. Design of the water treatment system

The wastewater treatment system, is located in Høyås farm with geographical coordinates 59° 38' 5.5''N and 10° 47'13''E (Jenssen & Siegrist 1990). The farm's address is Brekkeveien 120 in Ås municipality, Akershus region in Norway. The farm is close to a location known as "marine limit", it means that around 10,000 years ago, right after the last glaciation period, this area was covered by sea (UMB K, 2012).

Soil research has shown that the soil on the site of the water treatment system consists mainly of silty clay, although fragments of sand and gravel may be encountered. Therefore, it can be concluded that in the case of leakage of untreated water from the treatment system, the possibility of groundwater contamination is reduced (Mironga 2014).

The Høyås small scale wastewater treatment system was built in September 2012 for the average of 8 people, but the system can work at a maximum load of 25 Pe/day. Main parts of the system are septic tank (ST), bio-filters (BF), phosphorus filters (PFFM, PFFP) and sand filters (SFFM, SFFP). Layout of the system is shown on the figure below.

The most important thing should be noted in this system is that after the bio-filter the system is divided into two parallel branches of water purification. Namely, two types of phosphorus-removal materials Filtramar and Filtrate-P were installed in parallel, and each of the P-filters were followed by sand filters separately. Water after treatment flows into a creek.

This system serves two houses (main and guest) and two small apartments that are rented. It is estimated that approximately 8 people always live on the farm. But, the system was designed taking into account the fact that in certain periods the guests can come to the farm and therefore the number of people who can live on the farm can be 25 people.

So, according to the data the volumetric flow rate could be calculated

(Q): Q = 150l/Pe. day * n Pe

$Q = 150 * 8 = 1200$ l/day = 1,2 m^3/day

Or $Q * 365 = 438$ m^3/year

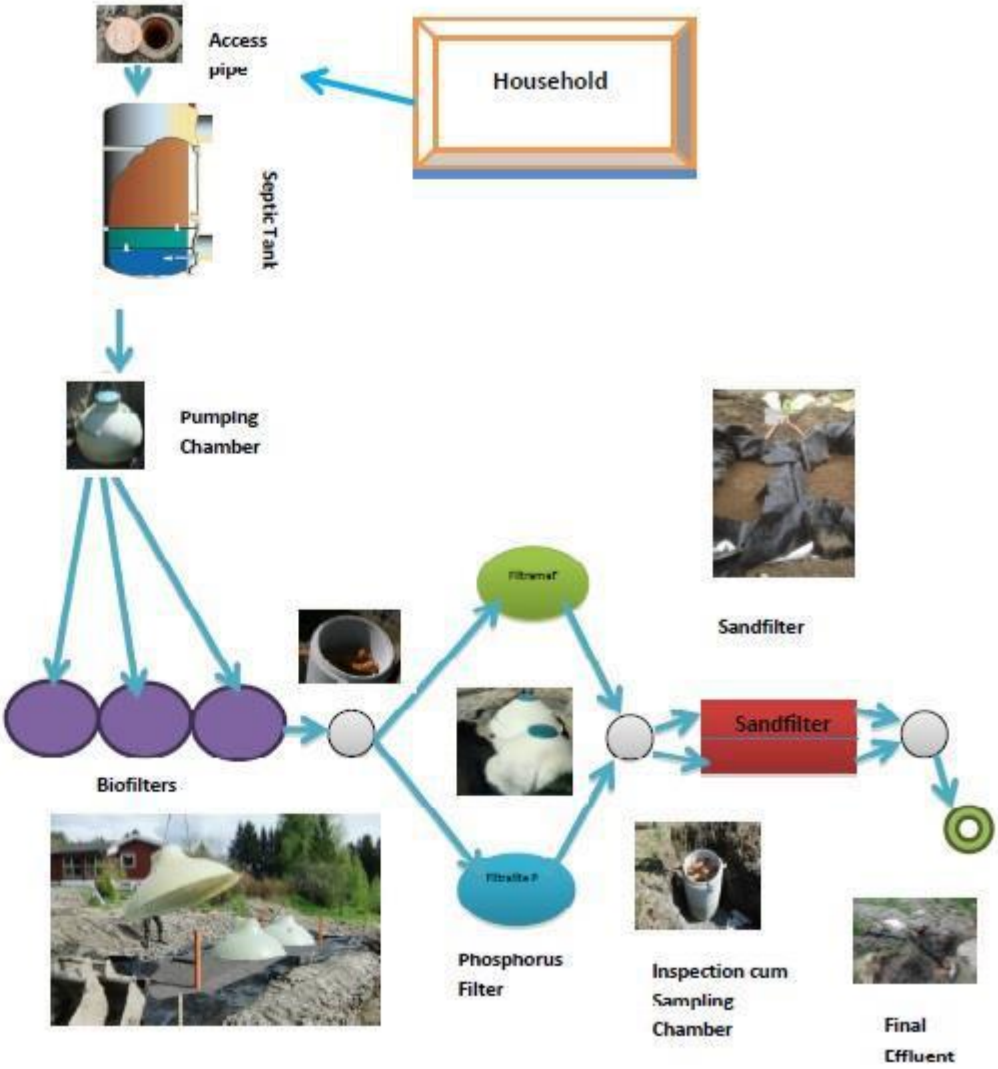


Fig. 3.1: *Layout of Høyås SSWWTS (Al Nabelsi & Ganesh 2013)*

3.1.1. Septic tank

A septic tank (ST) is an installation in which the effluents pass through several stages of purification. The main principle of the septic tank is the protection of waste water and the processing of organic inclusions by anaerobic bacteria. To achieve a better cleaning quality, septic tanks are made multi-chamber. The main part of solid waste settles in the first chamber, in the subsequent parts flows the previously purified water (Busch, 1958). The process of eliminating impurities is realized by a biological method, by fermenting the sewage without oxygen access. The septic tank is capable of eliminating about 30-60% SS, 25-35% BOD, 5-10% TN and TP, which is a fairly high indicator for such treatment systems (Jenssen et al. 2006). The fluid gradually moves from one chamber to another. In each tank, mechanical and anaerobic cleaning takes place. Purified liquid is discharged into the upper layers of the soil. Twice a year there is removing of rotted residues and sludge with the help of special installations with pumps or sewage machines.

There is fiberglass septic tank, which consists of three chambers with a total volume 9.5m^3 and volumes of each chamber is 6.9m^3, 1.3m^3, 1.3m^3 respectively in the Høyås farm. Wastewater flows by gravity from the tank to the pumping chamber.

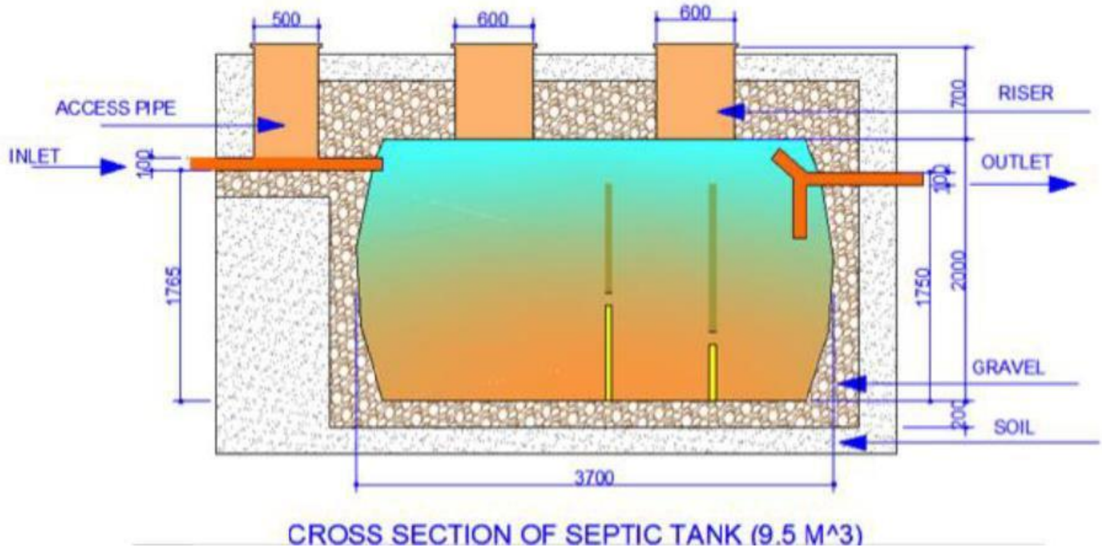


Fig. 3.2: *Cross-sectional size specification of a septic tank (Al Nabelsi & Ganesh 2013).*

This kind of ST is a little oversized corresponding only for 8 Pe with actual Q value of 1.2m^3/day. But it was done for proper treatment for 25 Pe at the time of diverse activities in the farm. Actually, this volume of the tank corresponds to 3 residential units (Jenssen et al. 2006).

3.1.2. Bio-filter

Any septic tank supplemented with a bio-filter (BF) works 20-25% more efficiently, decomposing the organic matter without the use of filtration fields.

A BF for wastewater is especially necessary if soils have low filtering capacity (loam, clay soil) or groundwater level lies close to the surface of the ground.

The bio-filter design consists of five main parts:

- the container in which the filter elements are located, while the walls of the reservoir can be either watertight or moisture-permeable;
- filter body or filter load;
- device-water distributor, whose task is to uniformly irrigate the entire filter surface by wastewater;
- a drainage device that removes clarified waters;
- an air distributor, by means of which the air necessary for the normal flow of oxidizing processes enters the bio-filter for sewage.

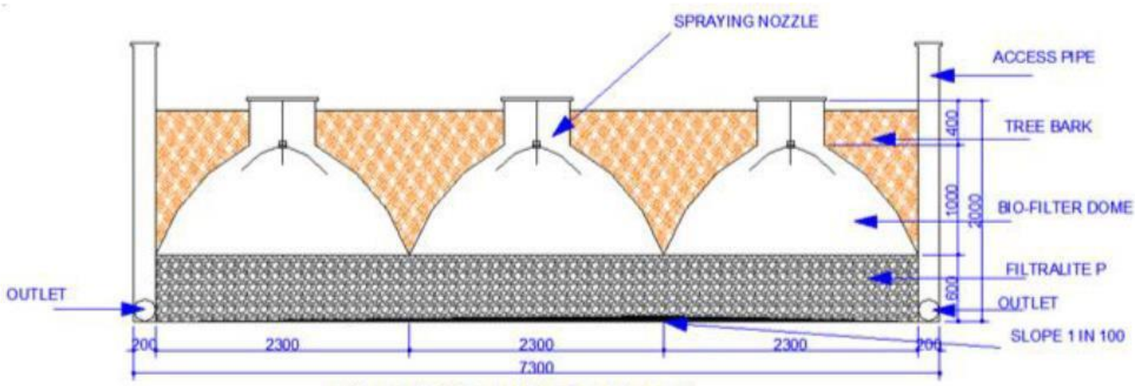


Fig. 3.3: *Cross section of bio-filter treatment component at the Høyås farm (Al Nabelsi & Ganesh 2013).*

The bio-filter consists of three domes with diameter 2.3m and 12.5m^2 filter bed. Already pre-cleaned from various solids, wastewater enters a BF filled up to 60cm with Filtralite HC 2.5-5mm grains (Annex 08) filter material. Here WW is evenly distributed by nozzles over the whole surface of the charge (Brady & Weil 1990), after which their aerobic oxidation takes place, followed by biological after-treatment of aerobic bacteria.

Passing through the filtering material, the wastewater forms on its surface such a unique film consisting of many microorganisms. These microorganisms are destructively affecting the organic matter contained in the waste water, and thereby purify this water (NKF and NORVAR, 2001).

Since aerobic microbes cannot exist without oxygen, for this purpose, drainage pipes are provided in the bio-filter design. This makes it possible for oxygen to enter both the lower and upper zones of the bio-filter and create favorable conditions for the life of the aerobes. Also, these pipes are drainage for clarified water as they pass along the bottom of the filter bed.

When the system was building in 2012, the top of the filter bed was concealed with isolating tree bark. But in August 2013 the bark was replaced with LWA Leca ISO 10-20mm (Annex 11).

Estimating of hydraulic loading rate (HLR) for the bio-filter:

HLR = Q/A,

Q – flow;

A – surface area of the filter bed;

HLR = 1200 l/day ÷ 12.5 m^2 = 96 l/m^2.day = 9.6 cm/day

The BF is a little oversized comparing to hydraulic loading rate of 20 cm/day from VA-Miljøblad nr.49 in the same reasons as a ST (Al Nabelsi & Ganesh 2013).

3.1.3. Alternative phosphorus removal units

As already mentioned above, the main attraction of this system is that after the bio-filter the system is divided into two parallel lines of water treatment. These lines are almost identical to each other: the size of the domes (2.3m), the flow of the same amount of sewage through the nozzles, after each subdivision of the phosphorus-trapping filter there are sand filters for each one. The only thing that distinguishes them is the filling of the domes: one of them is filled with 4 m^3 of Filtramar 0-7mm of grain size (PFFM) for more detailed information Annex 10, the other is filled with 4 m^3 of Filtralite-P of 0.5-4mm grains (PFFP) (Annex 09). That was done to compare the performances of two P-filer materials PFFM and PFFP, its P-removal quality and longevity of work.

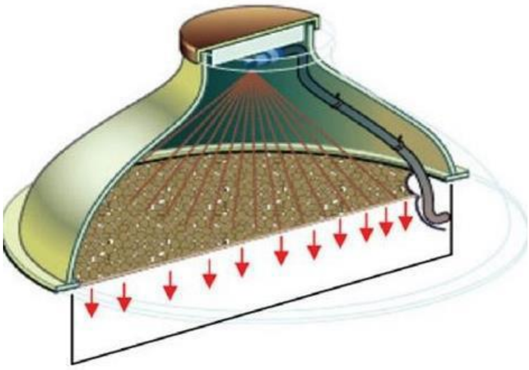


Fig. 3.4: *The appearance of wastewater distribution in the phosphorus filter components* (Jenssen et all., 2006).

3.1.4. Sand filters

Filtration through a layer of sand is an economical way to remove suspended particles and other impurities in water treatment and wastewater treatment. Passage of water through a sand layer, which delays various impurities. Sand filters are the construction of soil's purification of wastewater under artificial filtering loading and are arranged in combination with septic tanks - for complete biological treatment (post-treatment) of sewage.

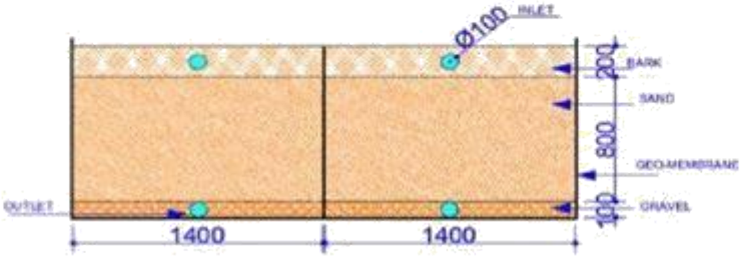


Fig. 3.5: *The appearance of sand filters in cross-sectional view located at Høyås farm (Al Nabelsi & Ganesh 2013).*

The water after the phosphorus filters by the gravitational flow enters the sand filters SFFM and SFFP, respectively. Each of the sand filters has an area of 7m2 (10m - length, 0.7m width and 0.7m depth). The bottom of the sand filters is covered with an impenetrable membrane, and on top of SFFM and SFFP was strewn with bark of a tree. But, at the time when the bark of the tree was changed to the LWA on the top of bio-filter component in 2013, at the same time, on the sand filter, the bark was replaced by the LWA as well.

3.2. Water sampling procedure

Sampling was carried out twice this year on 15th February and 19th April. Sampling took place from each stage of water treatment: septic tank, bio-filter, both phosphorus-removing filters (PFFM and PFFP), also, after each of sand filters (SFFM, SFFP). Approximately 1 liter samples were taken from each part of the water treatment system, so that the volume of sewage samples was sufficient for all analyzes.

3.3. Wastewater analysis

Analyzes of water samples taken from the water treatment system at the Høyås farm were analyzed in the days following the fence, respectively. In the interval between the analyzes, if any of the measurements were taken the next day, the samples were stored in the refrigerator in the laboratory.

It should be mentioned right away that most of the samples before the analysis had to be diluted, since the maximum limit of this or that polluter could exceed the threshold for one of the measurements in the method.

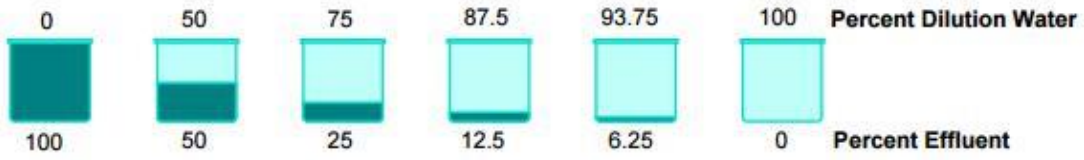


Fig. 3.6: Example of typical dilution series (States Environmental Protection Agency, n.d.).

All necessary analyzes and measurements were carried out in the laboratory of the Department of Environmental Sciences (IMV) in Norwegian University of Life Sciences (NMBU).

3.3.1. Phosphorus analysis

All selected wastewater samples were also analyzed for quantitative content of total phosphorus (TP) and Ortho-Phosphorus (Ortho-P).

3.3.1.1. Total Phosphorus measurements

TP was determined with the help of LCK 349 with the limiting limits of 0.05-1.5mg/l PO_4-P and 0.15-4.5mg/l PO_4. As it was known from previous studies, the approximate content of TP and Ortho-P in wastewater, it was found that for TP analysis samples must be diluted in order to fall within the permissible concentration for LCK 349. So, samples from ST, BF and PFFP were diluted 20-fold, and for PFFM, SFFP, and SFFM, the samples were diluted 10-fold. The analysis was carried out according to the instructions indicated on the LCK 349 (Fig.3.7). The principle of this kit is that after the reaction between PO_4^{3-} ions with molybdate and antimony ions an antimonil-phosphomolybdate complex is formed in an acidic solution, which is then reduced to phosphormolybdenum blue by ascorbic acid (HACH, n.d.-b). All these actions take place in cuvettes with barcodes, after which they are placed in a special spectrophotometer (Fig.3.10), that reads the barcode (to establish the type of analysis) and obtains the results.

Fig. 3.7: *Kit LCK 349 with work steps.*

3.3.1.2. Ortho-Phosphorus measurements

Ortho-P was determined by the spectrophotometric method. The analyzed samples were diluted exactly as for the determination of TP. The principle of the method is: during the interaction of orthophosphate ions with molybdate in an acidic medium, a yellow heteropoly-cite-lot is formed, which under the action of ascorbic acid, which acts as a reducing agent, turns into an intensely colored blue compound. The reaction is carried out for 20 minutes at room temperature, the intensity of the color increases. The results show only the content of orthophosphate ions in the sample. Then, the results of the samples were obtained using a spectrophotometer (Gilford Stasar II Spectrophotometer w/sipper) at a wavelength of 700 nm, showed in figure 3.8.

Fig. 3.8: *Gilford Stasar II Spectrophotometer w/sipper.*

3.3.2. Nitrogen analysis

Water samples taken from the Høyås water treatment system were analyzed for the total content of nitrogen (TN), ammonium (NH_4^+) and nitrates (NO_3^-).

3.3.2.1. Total Nitrogen measurements

To determine the TN for the samples taken on February 15, a set of LCK 338 (Laton) with limiting concentrations of 20-100mg/l was used. The analysis was carried out in accordance with the methodology presented on the package LCK 338 (Fig.3.9). The principle of TN analysis is that peroxo-disulfate ties all types off Nitrogen in the solution an oxidize them to nitrate. After that these ions react with 2,6-dimethylphenol and generate nitro-phenol in the presence of sulfuric and phosphoric acid solution (Koroleff Digestion) (HACH, n.d.-a). After that, the data was read by a special apparatus Lange Hach DR2800 (Fig 3.10).

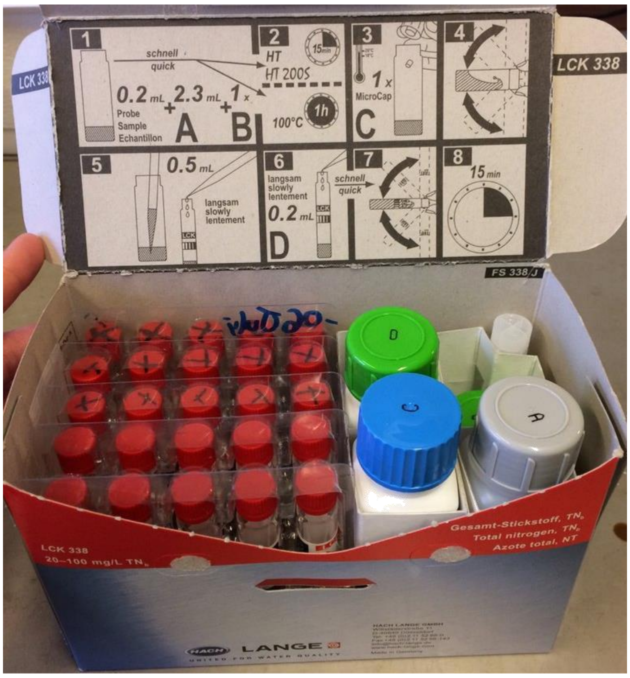


Fig. 3.9: *Kit LCK 338 (Laton) with work steps*.

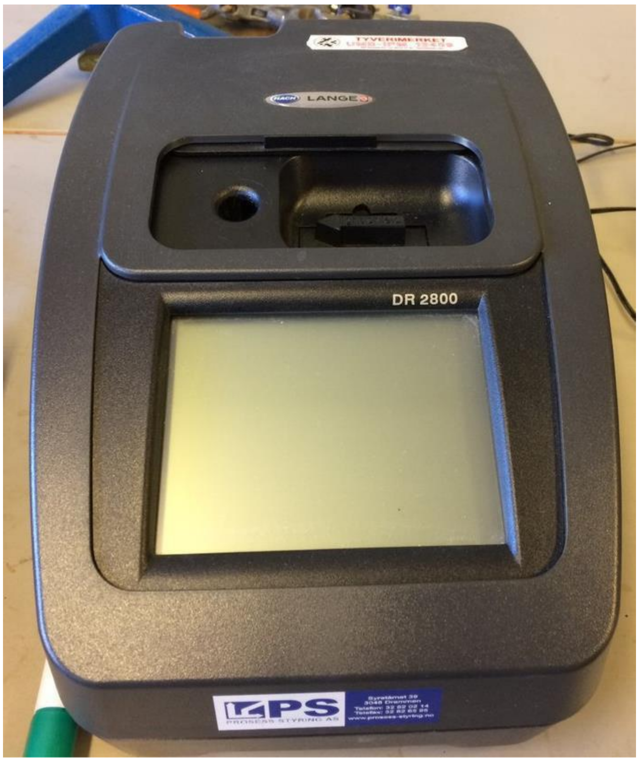


Fig. 3.10: *Spectrophotometer Lange Hach DR2800.*

Samples taken on April 19, unfortunately, could not be analyzed on the TN in the same way as the previous series of samples, as at that time the reagents of LCK 338 had ended, and the order of the new kit takes a long time. Therefore, these samples were analyzed by an employee of the laboratory of the IMV department - Oddny Gimmingsrud by the method described in Annex 12.

3.3.2.2. Ammonium measurements

For the analysis of NH_4^+ in the samples of all treatment components, LCK 304 was used with a range of 0.015-2.0mg/l NH_4-H and 0.02-2.5mg/l NH_4. For this analysis, the samples were diluted in this order: 1:20 for ST, BF and PFFP, and 1:10 for PFFM, SFFP, and SFFM. The analysis was then carried out according to the principle indicated for the LCK 304 (Fig. 3.11). To determine the amount of ammonium in the sample, it should be converted to indophenol-blue. It happens when $NH4^+$ ions interact with ions of hypochlorite and salicylate in the presence of catalyst, which is a sodium nitroprusside at pH=12.6 (HACH, 1998).

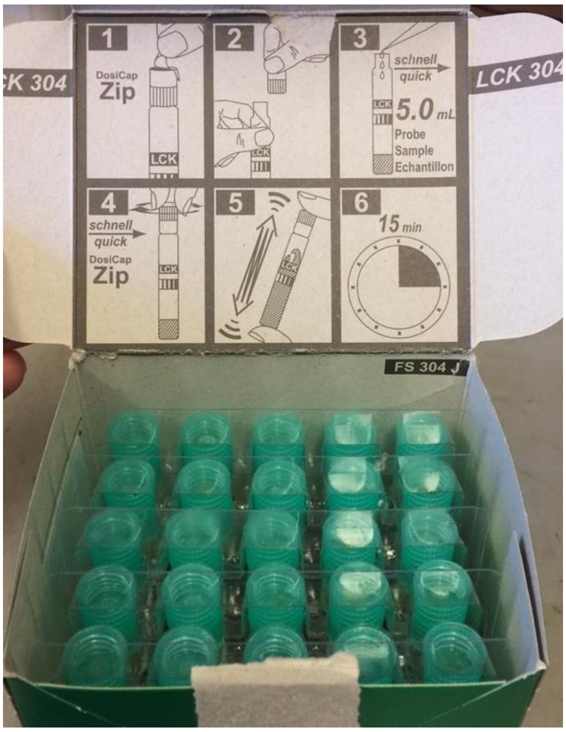


Fig. 3.11: *Kit LCK 304 with work steps.*

3.3.2.3. Nitrate measurements

Also, all water samples were analyzed for the quantitative content of nitrates using the Lange Hach LCK 339 kit (0.23-13.50mg/l NO_3-H, 1-60mg/l NO_3). In this assay, the samples were also diluted in the ratios: 1:2 for the bio-filter, 1:3 for the PFFP; 1:5 for the PFFM, SFFP, SFFM. Samples from the septic tank did not need dilution. The analysis process was also performed according to the procedure of the Lange Hach indicated for this kit (Fig. 3.12), in which after reaction of Nitrate ions with 2,6-dimethylphenol, produces 4-nitro-2,6-dimethylphenol in the presence of sulfuric and phosphoric acid solution (HACH LANGE, 2016).

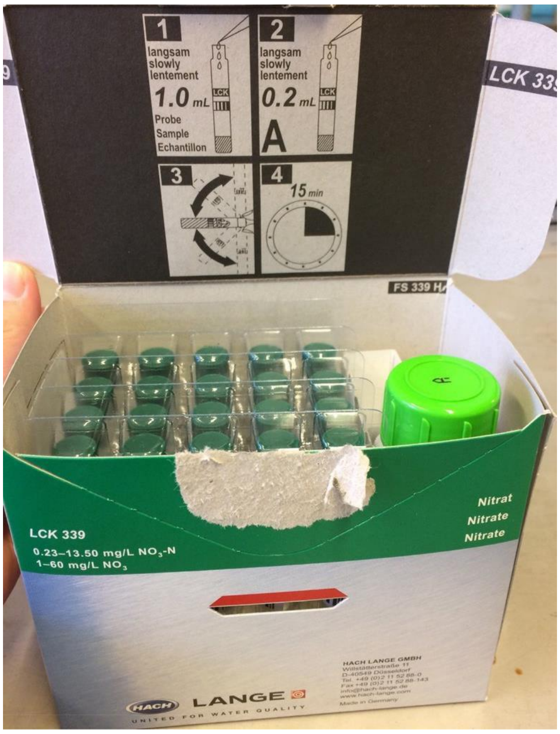


Fig. 3.12: *Kit LCK 339 with work steps.*

All the data were recorded in time-series for the analysis of the operation of the water treatment system from the moment it was launched to the present.

3.3.3. pH measurements

The pH of the samples taken on the farm was measured with a pH meter "PHM210 standard pH meter MeterLab TM" (Fig. 3.13), which allows the pH values to be directly obtained -

the negative decimal logarithm of the activity (concentration) of the cation or anion to be analyzed.

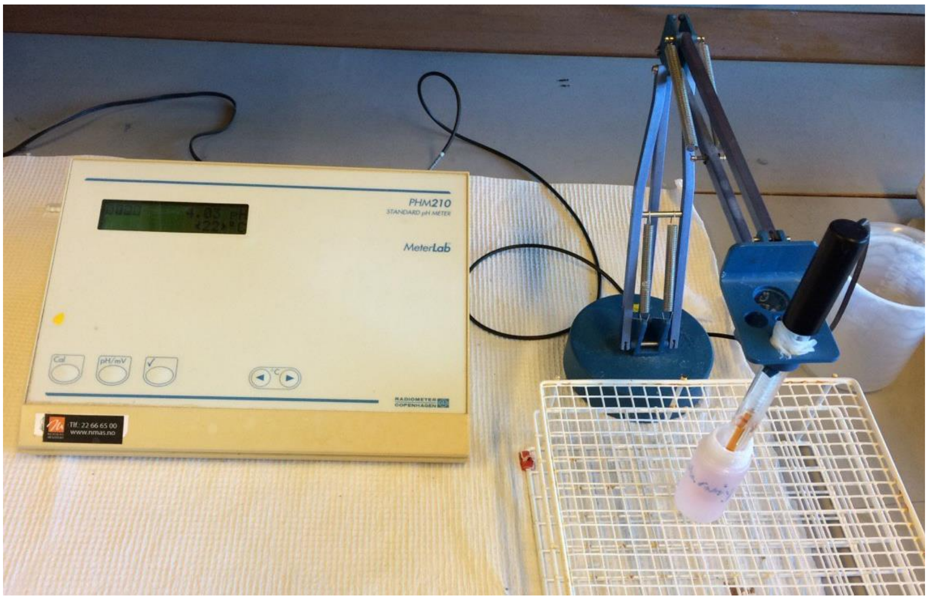


Fig. 3.13: *pH meter "PHM210 standard pH meter MeterLab TM".*

All pH meters require periodic adjustment. For this, the measuring electrode is immersed in a buffer solution with a precisely known pH and the instrument is adjusted so that the meter readings show the exact pH of the buffer. After adjusting the pH meter, samples of sewage samples were analyzed. The electrode must be thoroughly rinsed with distilled water before immersion in the solution to be analyzed, and carefully remove the remaining water from it with a help of clean paper towel.

3.3.4. Conductivity measurements

The electrical conductivity was measured by means of a special meter of conductivity meter "712 Metrohm Conductometer" (Fig. 3.14). The principle of the conductometer is based on the direct dependence of the electrical conductivity of the solution (current in a constant electric field created by the electrodes of the device) on the amount of substances dissolved in water. The data was displayed on the screen in a measurement unit µS/cm.

Fig. 3.14: *Conductivity meter "712 Metrohm Conductometer".*

3.3.5. BOD measurements

BOD5 measurements were not carried out in sewage samples taken this year. But, since in this graduation work the data on the measured BOD under laboratory conditions are used from previous years, it should be mentioned that it was measured on the instrument "WTW OxiTop OC100" (Fig. 3.15). The methodology to these measurements is included in Annex 13.

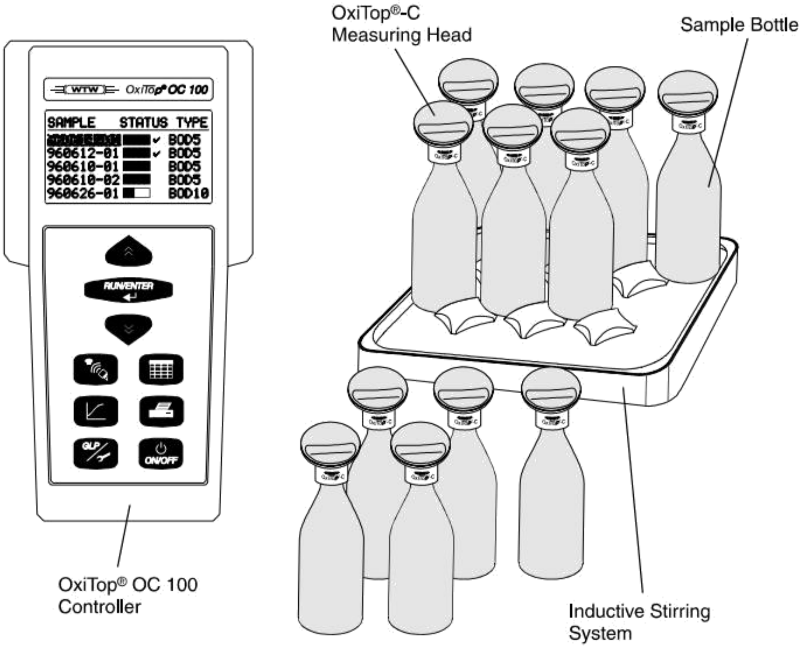


Fig. 3.15: *System for measuring biological oxygen demand (BOD5) "WTW OxiTop OC100".*

3.4. Time Series analysis

The water analysis data from the previous studies (Nabelsi and Ganesh, 2013), (Mironga, 2014) and unpublished master thesis data (2015) have been used in this study to examine the change of pollutant concentration with time. This data is required to assess the quality of the reproduced water and the state of work of the small-scale water purification system in general. The data obtained are the main parts of this study. All time-series are presented in the next chapter and the tables presented in the appendices to this paper. Prediction for TP final effluent limit was done using forecast function on Microsoft office excel.

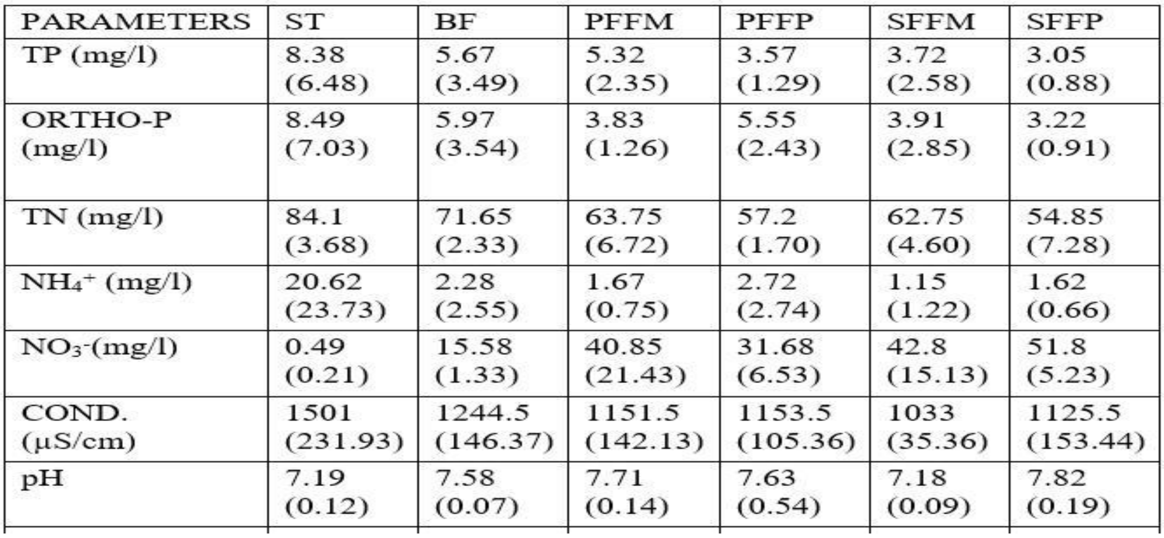
4. RESULTS AND DISCUSSION

This chapter presents results from the performance study of Høyås farm treatment system conducted. The results of the sampling campaign conducted from February to April 2017 for this study is combined with the performance study conducted by Ganesh and Nabelsi (2013) and Mironga (2014) to evaluate how each parameter has changed in treatment system over time since it was constructed.

4.1. General Results

Effluent concentrations and levels as well as descriptive statistics of analysed parameters for WW effluent from treatment components septic tank (ST), biofilter (BF), phosphorus filter filtramar (PFFM), phosphorus filter filtralite-P (PFFP), sand filter filtramar (SFFM) and sand filter filtralite-P (SFFP) FFP are shown in (Annexes 01-06). Table 1 below shows the mean concentration values of parameters for treatment component obtained from test of two samples each during this study period (February 2017- April 2017).

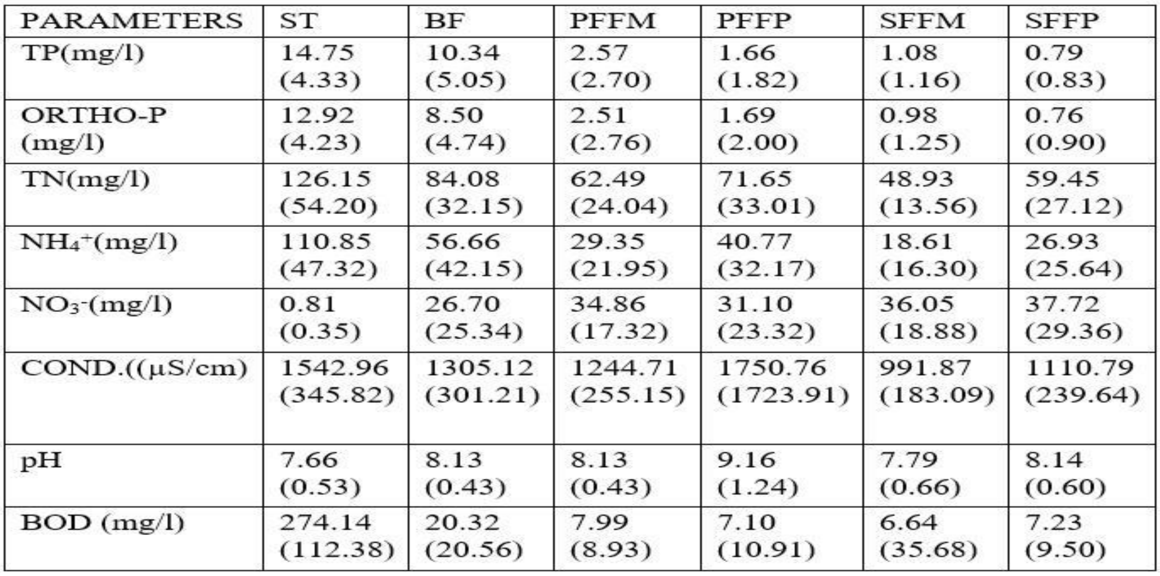
Table 4-1: Mean Effluent Concentrations and levels of Parameters in Treatment Components in the Study Period February 2017 to April 2017.



PARAMETERS	ST	BF	PFFM	PFFP	SFFM	SFFP
TP (mg/l)	8.38 (6.48)	5.67 (3.49)	5.32 (2.35)	3.57 (1.29)	3.72 (2.58)	3.05 (0.88)
ORTHO-P (mg/l)	8.49 (7.03)	5.97 (3.54)	3.83 (1.26)	5.55 (2.43)	3.91 (2.85)	3.22 (0.91)
TN (mg/l)	84.1 (3.68)	71.65 (2.33)	63.75 (6.72)	57.2 (1.70)	62.75 (4.60)	54.85 (7.28)
NH_4^+ (mg/l)	20.62 (23.73)	2.28 (2.55)	1.67 (0.75)	2.72 (2.74)	1.15 (1.22)	1.62 (0.66)
NO_3^-(mg/l)	0.49 (0.21)	15.58 (1.33)	40.85 (21.43)	31.68 (6.53)	42.8 (15.13)	51.8 (5.23)
COND. (µS/cm)	1501 (231.93)	1244.5 (146.37)	1151.5 (142.13)	1153.5 (105.36)	1033 (35.36)	1125.5 (153.44)
pH	7.19 (0.12)	7.58 (0.07)	7.71 (0.14)	7.63 (0.54)	7.18 (0.09)	7.82 (0.19)

As shown in (*Table 4-1)*, based on the measured parameters in this current study period, Høyås OSWWTS has exceeded the discharge limits for P 1mg/l. Mean inlet TP concentration of 8mg/l is reduced to final mean TP effluent concentration of 3.72mg/l and 3.05mg/l from SFFM and SFFP respectively (*Table 4-1)*. However, this is the mean of two samples in 2017, whether or not the mean over all the years of operation has exceeded the discharge limit of 1mg/l is discussed in later parts of this chapter. Mean inlet Ortho-P concentration is reduced from 8mg/l to final mean effluent concentration of 3mg/l in both the SFFM and SFFP. Also, mean inlet TN was reduced from 84.1mg/l to final mean effluent concentration of 62.75mg/l and 54.85mg/l from SFFM and SFFP respectively. Mean final effluent was pH7.18 from SFFM and pH7.82 from SFFP. The mean inlet conductivity level of 1501 µS/cm is reduced to final effluent level of 1033µS/cm and 1113µS/cm from SFFM and SFFP respectively.

Table 4-2: Mean Effluent Concentrations and levels of Parameters in Treatment Components since the system started operation in October 2012 to April 2017. The numbers in brackets are Standard Deviation values.



PARAMETERS	ST	BF	PFFM	PFFP	SFFM	SFFP
TP(mg/l)	14.75 (4.33)	10.34 (5.05)	2.57 (2.70)	1.66 (1.82)	1.08 (1.16)	0.79 (0.83)
ORTHO-P (mg/l)	12.92 (4.23)	8.50 (4.74)	2.51 (2.76)	1.69 (2.00)	0.98 (1.25)	0.76 (0.90)
TN(mg/l)	126.15 (54.20)	84.08 (32.15)	62.49 (24.04)	71.65 (33.01)	48.93 (13.56)	59.45 (27.12)
NH_4^+(mg/l)	110.85 (47.32)	56.66 (42.15)	29.35 (21.95)	40.77 (32.17)	18.61 (16.30)	26.93 (25.64)
NO_3^-(mg/l)	0.81 (0.35)	26.70 (25.34)	34.86 (17.32)	31.10 (23.32)	36.05 (18.88)	37.72 (29.36)
COND.((µS/cm)	1542.96 (345.82)	1305.12 (301.21)	1244.71 (255.15)	1750.76 (1723.91)	991.87 (183.09)	1110.79 (239.64)
pH	7.66 (0.53)	8.13 (0.43)	8.13 (0.43)	9.16 (1.24)	7.79 (0.66)	8.14 (0.60)
BOD (mg/l)	274.14 (112.38)	20.32 (20.56)	7.99 (8.93)	7.10 (10.91)	6.64 (35.68)	7.23 (9.50)

Comparing the two sets of data (*Table 4-1* and *Table 4-2*), the mean final effluent concentration TP and Ortho-P have increased. Also, mean TN concentrations in the current study from the SFFM has increased compared to the previous studies while a reduction in TN was recorded in the SFFP mean effluent. In this current study, the mean final effluent level of $N0_3^-$ increased in both the Filtramar and Filtralite-P lines. Consequently, significant decreases were recorded for final mean NH_4^+ effluent concentration in both treatment lines. The mean effluent conductivity levels in the previous studies were higher in all treatment component except in the final effluent (SFFM and SFFP). The mean pH levels from the current study are reduced in all treatment components compared with mean effluent pH recorded in combined measurement up till the end of this current study.

To check the extent to which the current treatment components can remove contaminants influent concentration in each treatment component, removal efficiency in the BF was calculated using the formula:

$$\frac{\text{Mean Inlet concentration- Mean Effluent concentration}}{\text{Mean Inlet concentration}} \times 100$$

The efficiencies of each treatment component were calculated for TP, OP, TN and NH_4^+ and the performance are illustrated in the Fig. 4.1 below.

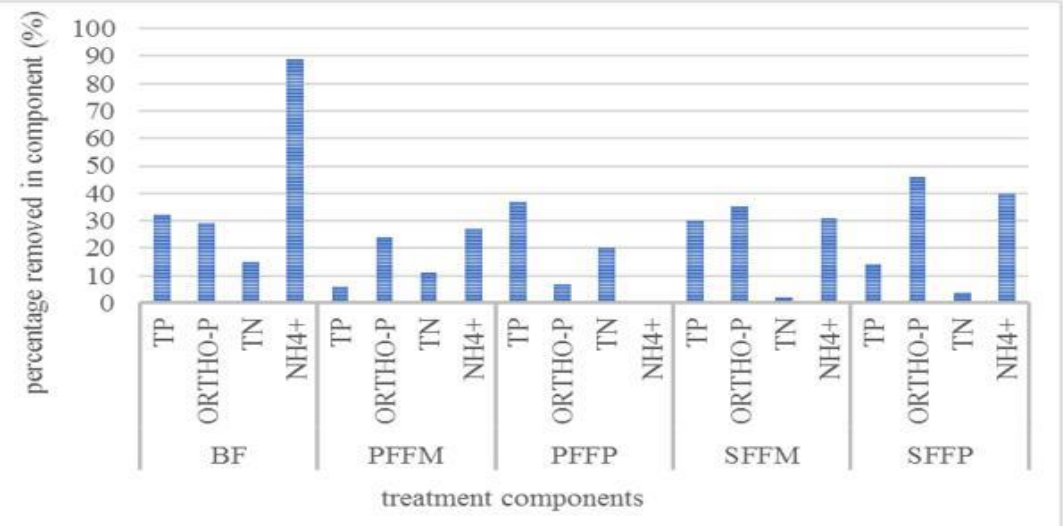


Fig. 4.1: *Chart showing (%) concentration removed in each treatment components for total phosphorus (TP), orthophosphate (OP), total nitrogen (TN) and ammonium ions (NH_4^+) (Feb – April 2017).*

4.2. Phosphorus removal

4.2.1. Total Phosphorus

The Høyås treatment system has been a well-tested system capable of removing phosphorus in wastewater. The mean inlet TP in the STE from 2012-2017 is 14mg/l with Std.Dev of 4mg/l (*Table 4-2*) and it is in the range 3-21mg/l (Annex1). Since the system was constructed, there has been changes in the STE concentration over time. The maximum STE concentration recorded was in March 2015 while the minimum recorded was 3mg/l in February 2017 (Annex1). TP concentration are reduced as WW flows through treatment components (BF, PFs and SFs) and. The PFFP removes a highest percentage of P as seen in figure 4.1. The change in concentration over time are illustrated in the time series curve in figure 4.2.

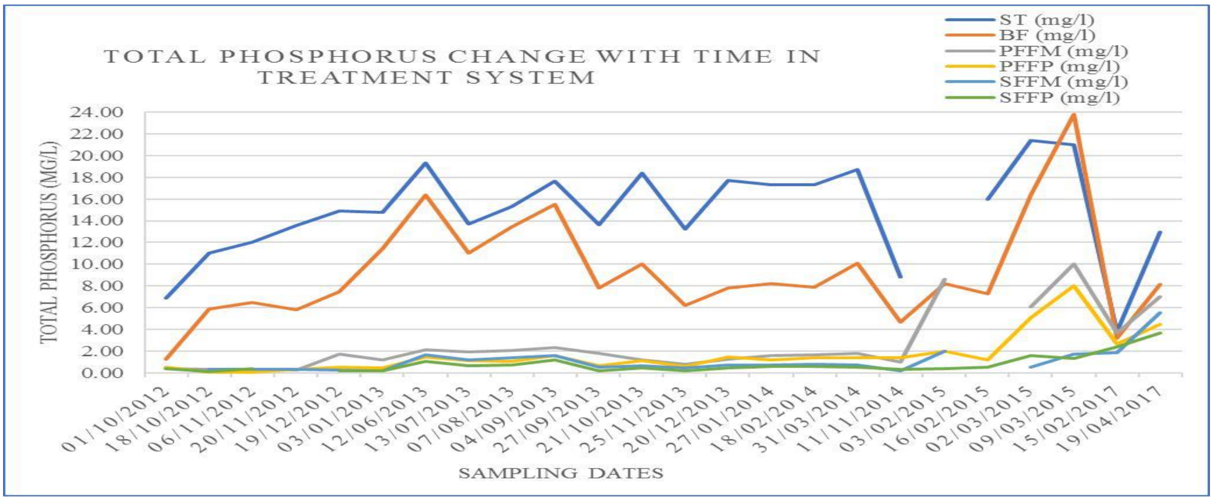


Fig. 4.2: *Time series curve showing changes in effluent concentration of TP in the treatment systems.*

As shown in the time series, the final TP effluent was low in the early months after the system has been in use. The curve also shows that P was removed mostly in the P-filters. This indicates a good TP removal especially at the start of operation. This claim is supported (Al Nabelsi & Ganesh 2013) as neither the daily nor final mean effluent crossed the 1mg/l limit throughout the 2012- 2013 study period. The first study on this treatment system documented a high TP removal efficiency of 97% and 98% respectively from the mean SFFM and SFFP final effluent (Al Nabelsi & Ganesh 2013). The subsequent study on the same system confirmed the reduction in the TP removal efficiency to 94% and 96% respectively from the mean SFFM and SFFP final effluent (Mironga 2014). Despite the slight reduction in the removal efficiency, the same study concluded that the treatment system was under the acceptable discharge limit of 1mg/l TP but alerted the increasing trend in the TP levels.

In further support to this claim of declining removal efficiency of TP, WW parameters analysed from the system in this current study period indicate lower removal efficiency. The mean final TP measured from the SFFM and SFFP effluents were 3.72mg/l and 3.05mg/l respectively from the initial inlet of 8.38mg/l in the ST (*Table 4-1*). This imply 56% and 63% removal respectively from the mean SFFM and SFFP final effluent. Nevertheless, the system still removes phosphorus to a considerable level even though it has been in operation for long. The reduction in the removal efficiency is not very surprising as the first study on this system predicted the lifetime of PFFP to be 2.45 years (Al Nabelsi & Ganesh 2013). The system removed phosphorus substantially for the first 2 years of operation indicating high sorption capacity of the P-filter materials. A similar study evaluating the performance of compact filter system for treating domestic wastewater in eastern Norway indicated that the treatment system maintained stable and high removal of P for the first 3 years (Heistad et al. 2006b). The same study predicted that the system will only be saturated with P in 5 years. Therefore, the longevity of the treatment system is dependent on the design parameter as well as on the ability of the P-filters to remove P in wastewater (Drizo et al. 2002). Both final effluents from Filtramar and Filtralite-P lines have been noticeably on an increasing trend since 2nd of March 2015 for SFFP and since 9th of March 2015 for the SFFM.

4.2.1.1. Performance estimate: first-order area-based removal rate constants (k)

First-order area-based removal rate constants (k) can be used in representing performance data for the system. k represents the rate of contaminant concentration reduction in the treatment system (Mæhlum 1998). The first order area based removal rate is given by the equation;

$\ln (C_{out}/C_{in}) = -k/q$……………………………………………………..……..…equation 1

Where k is the area-based first-order removal rate constant (m/d), q is the hydraulic loading rate (m/d), Cout is the outlet concentration (mg/l), Cin is the inlet concentration (mg/l).

Equation 1 can be re-arranged as; $k = \ln (C_{in} / C_{out}) * Q/A$……………………. equation 2

Where Q is average water flow (m^3/yr) and A is the wetland area (m^2). (Kadlec & Knight 1996)

The mean k value estimated for P is removal in the SFFM and SFFP final effluent is 34 m/yr and 43/yr respectively (see annex 07 for calculations). The mean k values are similar higher than k value (24m/yr) reported for Constructed wetland in similar climate in Tveter (Mæhlum & Stålnacke 1999).

4.2.1.2. Mean effluent TP discharge limit prediction

Estimation is made to determine the period when the mean TP final effluent exceeds the 1mg/l limit by interpolating and extrapolating values for TP concentration at equal date interval from the time series data. The data is the plotted using forecast tool on Microsoft office excel. The prediction is presented in Fig 4.3.

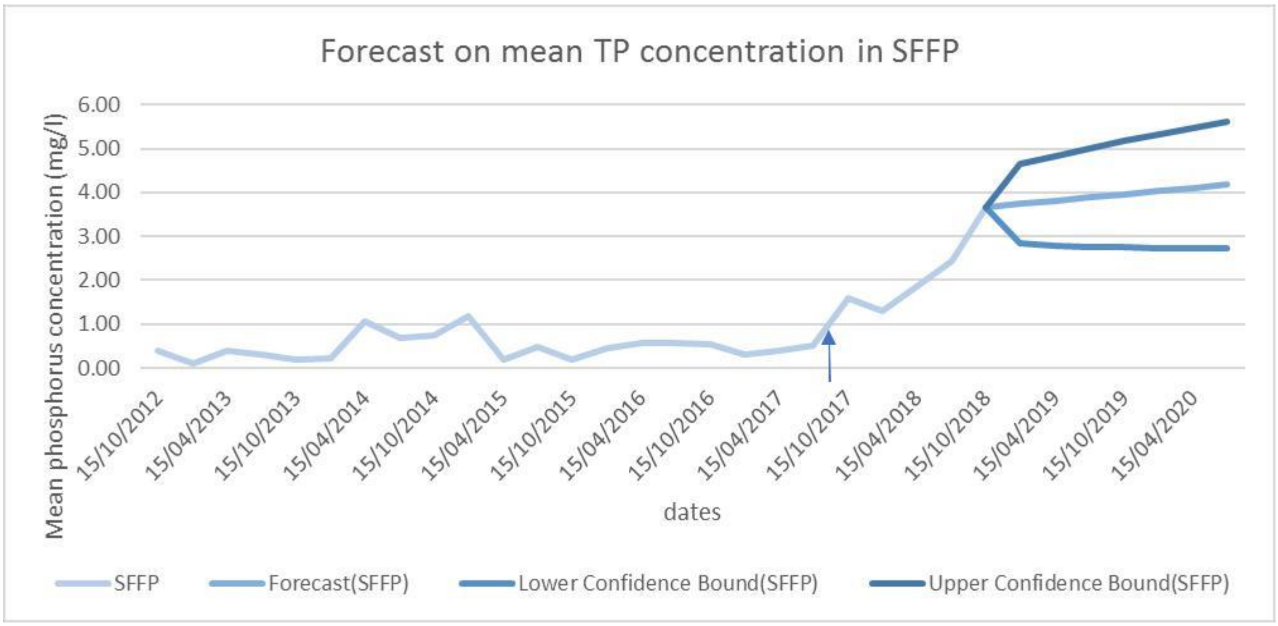


Fig 4.3: *Forecast curve of when mean TP effluent concentration crosses the 1mg/l in the SFFP.*

From the graph, the predicted date is October 2017.

Total Phosphorus effluent concentration curves in Filtramar and filtralite-P lines (2017):

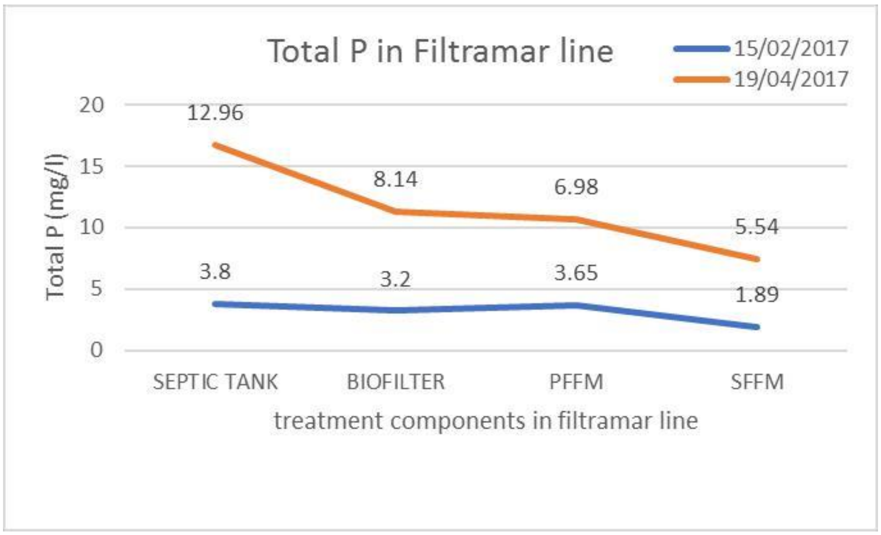


Fig. 4.4: *TP concentration curve in Filtramar line in this study period (2017).*

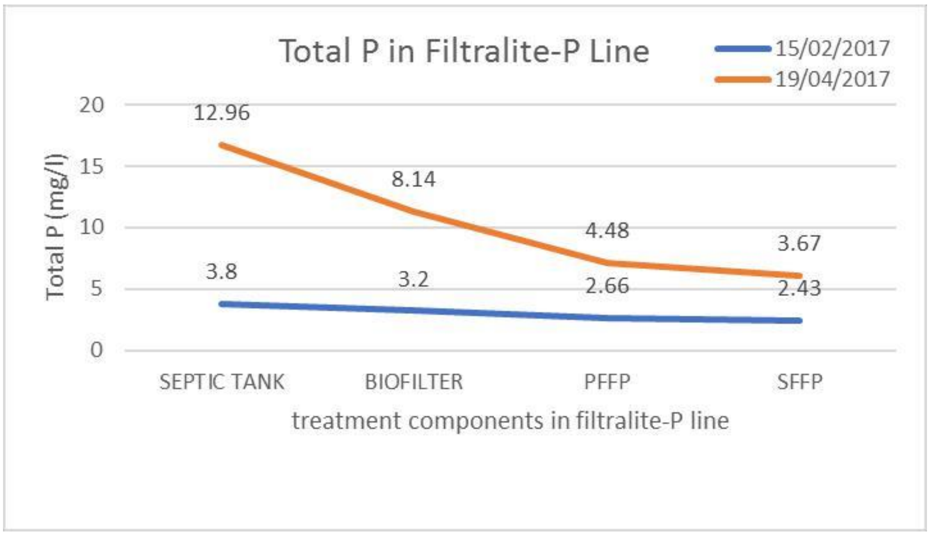


Fig. 4.5: *TP concentration curve in Filtralite-P line in this current study period (2017).*

After the second year, the BF seems to have lesser effect on P removal. Nevertheless, the biofilter still removes little P whenever the TP concentration in the system is not high.

In addition to the design parameter and p-sorption capacity of the P-filter materials, other factors might also have affected the reduction in the TP- removal efficiency of the treatment system.

There is a possibility that the working condition of the nozzles have some effects on the P removal as WW goes through the P-filters system very fast. This is in agreement with (Mironga 2014) the previous study which argues that there could be a lesser mean TP concentrations from P-filters if the nozzles could distribute WW evenly on the whole surface area of filter media.

4.2.2. Ortho-Phosphate

The mean influent concentration of Ortho-P (2012-2017) measured as STE is 12mg/l (*Table 4-2*). This is about 86% of the mean inlet TP given that mean TP influent is 14mg/l.

Ortho-P effluent concentrations from treatment components follow nearly the same trend as TP effluent concentrations. Identical to the time series curve of TP, Ortho-p concentrations are reduced from higher concentrations in the inlet to lower concentrations in the final effluents.

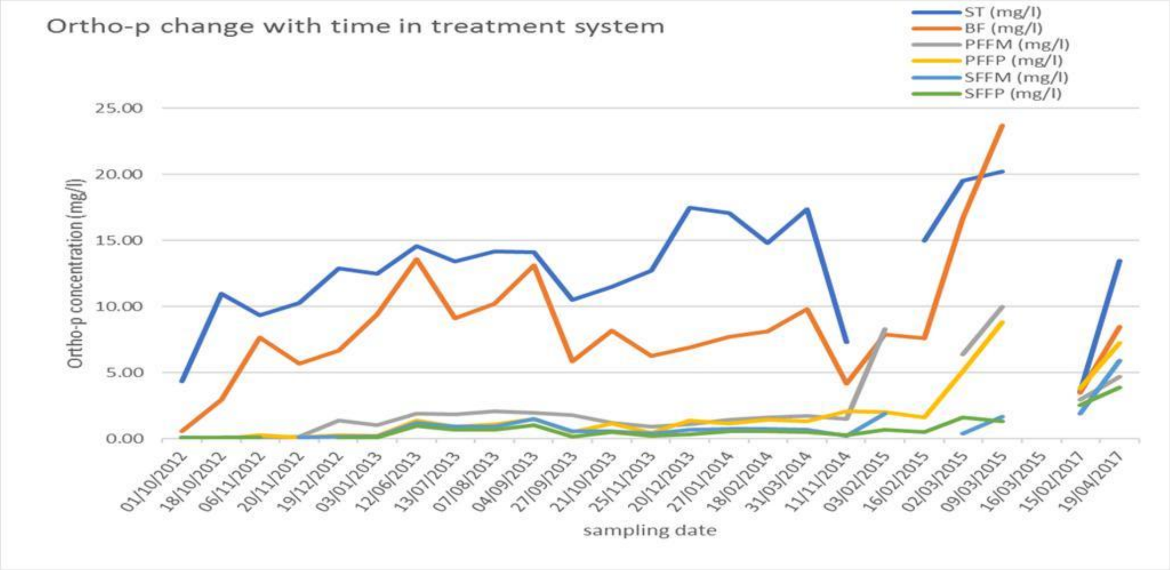


Fig. 4.6: *Time series curve indicating Ortho-P concentration change with time in the treatment components.*

Similar to the TP trend, major Ortho-P removal occurs in P-filters as indicated by the curve (Fig 4.6). The mean Ortho-P concentration (2012-2017) is 2.51mg/l and 1.69mg/l from PFFM and PFFP respectively (*Table 4-2*).

As shown in the time series curve (Fig. 4.6), the final effluent Ortho-P outlet concentration in the PFFM and PFFP was very low when the treatment system was new in 2012 and increases gradually as the system gets older. There is a noticeable decrease in the trend in September 2013 and in November 2014. Since then, the final effluent Ortho-P concentration in the treatment components has been on the rise resulting from increase in effluent PFFM and PFFP Ortho-P concentration. The removal efficiency of the system for Ortho-phosphate has reduced from 94% and 96% (Mironga 2014) to 62% and 53% in the SFFM and SFFP final effluents respectively final.

There is much difference in the Ortho-p concentration in the septic tank and bio-filter. However, the difference reduces through the P-filters treatment components resulting in almost the same final effluent concentration of Ortho-P and TP (Annexes 01 and 02).

4.3. Nitrogen removal

4.3.1. Total Nitrogen

TN, NH_4^+, and NO_3^- were analysed to monitor the ability of the treatment system to remove N in wastewater. TN concentration is higher in the influent and it reduced as wastewater passes through consecutive treatment components. Mean influent concentration of TN measured (STE) from 2012-2017 was 126 mg/l while final mean TN effluent measured from the SFFM and SFFP effluent was 48 mg/l and 59 mg/l respectively (*Table 4-2*). The removal efficiency for TN documented in the last study was 61% and 54% in the SFFM and SFFP respectively (Mironga 2014). However, the TN removal efficiency of the treatment system has reduced to 25% (SFFM) and 34% (SFFP) currently. This removal efficiency is still substantial even though not very high. The changes in the TN concentration in the system is shown in the time series curve in figure 4.7.

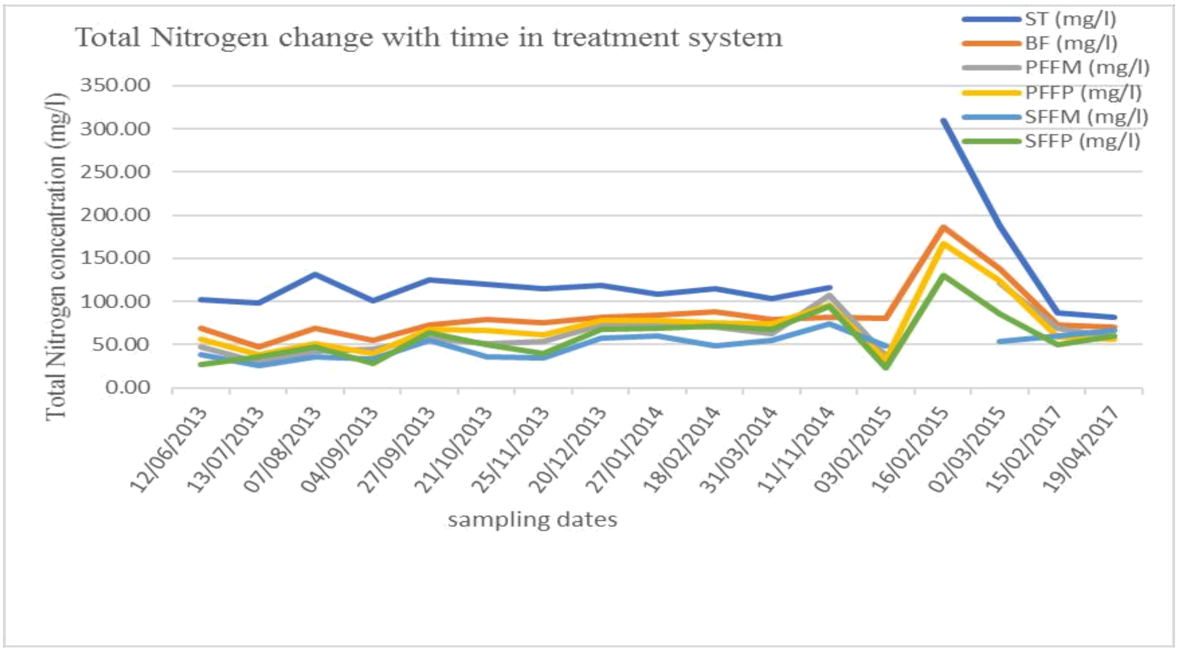


Fig. 4.7: *Time series curve showing the change in TN concentration in the treatment system from 2013-2017.*

As presented in the time series curve (Fig. 4.7), the TN concentration in the treatment system follows a quite steady pattern since it was first measured in June 2013. The concentration went to a high level (above 300mg/l) in February 2015. The increase is probably caused by factors such as fertilizer use on the farm, quantity of water use per person, use of detergent etc.

The measurement taken in this study period (2017) shows that the TN concentration is down to a lower level than it was before the increase (*Table 4-1*). This could be as a result of the new occupant moving-in on the farm assuming lower Nitrogen load in the toilet.

The majority of TN measured as STE is in form of NH_4^+, out of the 126mg/l mean influent concentration of TN, 110mg/l was in form of NH_4^+ (*Table 4-2*).

4.3.2. Ammonium

The inlet NH_4^+concentrations are reduced as WW flows through the treatment components. The mean final effluent of NH_4^+ in the study periods (2013-2017) is 18mg/l and 26mg/l from SFFM and SFFP respectively (*Table 4-2*). The mean effluent concentration of NH_4^+ is low in in the final effluent indicating good nitrification in the system. In this study period, the mean final effluent removal efficiency of NH_4^+ in the system increased to 92% (PFFP) and 94% (PFFM) from 69% and 79% respectively measured in the previous study (Mironga 2014).

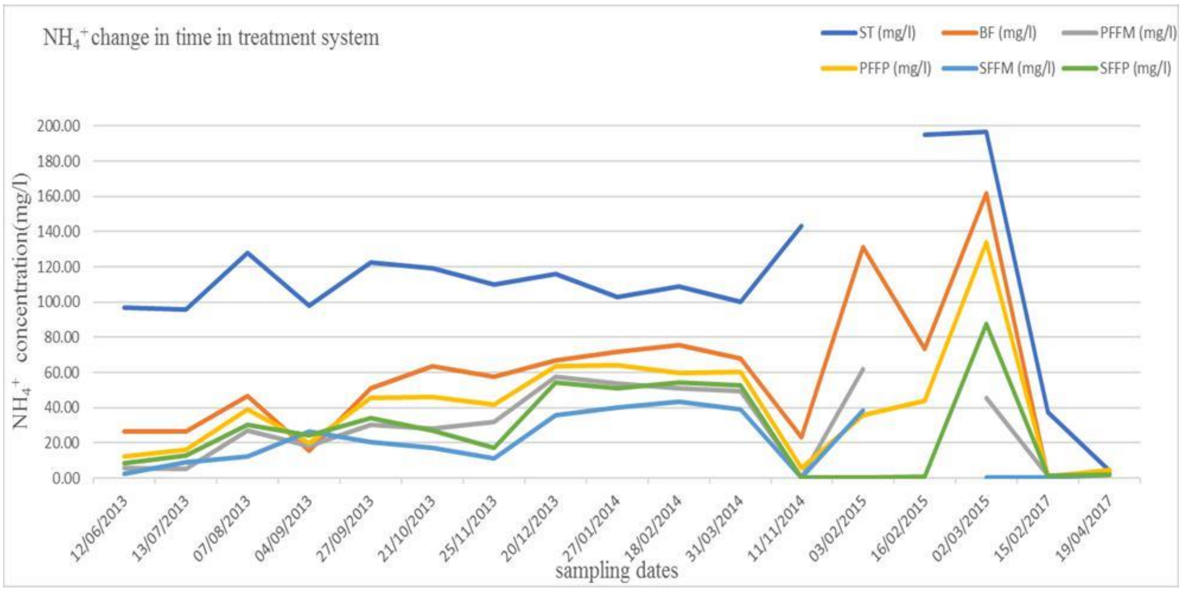


Fig. 4.8: *Time series showing the changes in* NH_4^+ *concentration in the treatment systems in the study period 2013-2017.*

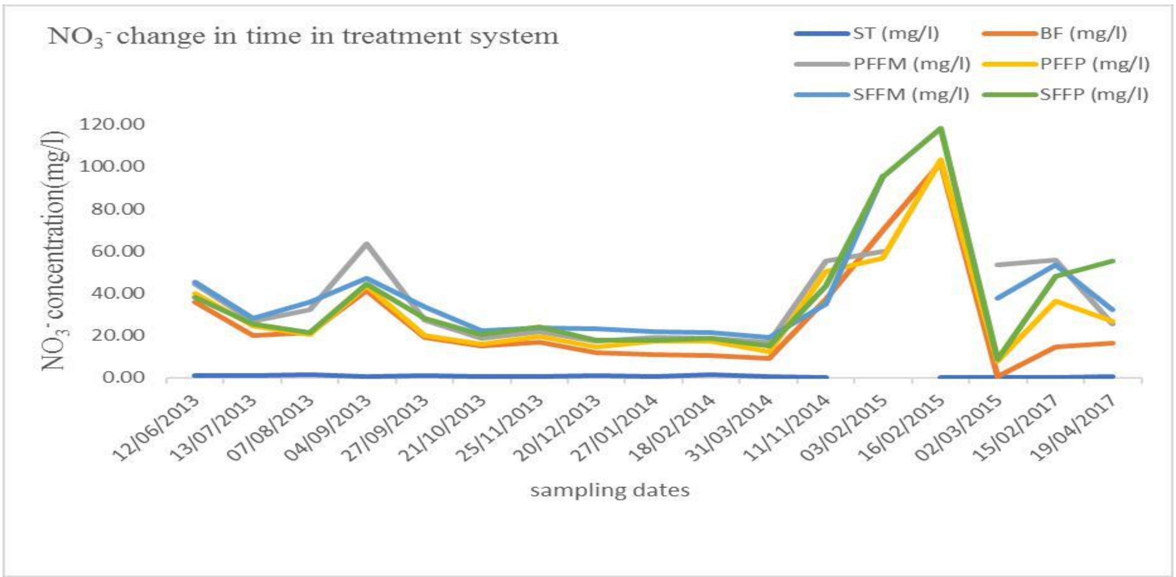


Fig. 4.9: *Time series curve showing changes in the* NO_3^- *concentration in the treatment components in the study period 2013-2017.*

The NO_3^- concentration along the treatment lines increases as the concentration of NH_4^+ decreases.

4.3.3. Nitrates

As presented in the time series curve, NO_3^- concentration is low in the beginning (STE line almost close to zero in (Fig. 4.9). The concentration increases in the subsequent treatment components and at the final effluent of SFFM and SFFP, NO_3^- concentration got close to the TN values (Annexes 05 and 06). This means that almost all the NH_4^+ in the system has been nitrified at the final effluent indicating good nitrification in the treatment system. It also shows that the NH_4^+ is down to very low concentration. The system works well as an aerobic system with increased nitrification in the system and in the Phosphorus filters. The sum of NO_3^- and NH_4^+ is almost half of the TN in the beginning and at the end of the system. At the end of the system, most of the TN is in form of NO_3^- . The Effluent concentrations of NO_3^-increase in the treatment components as a proof of biological nitrification process taking place in the treatment system. This is the process of oxidizing the ammonia to remove nitrogenous compounds present in the wastewaters in the presence of nitrifying bacterial (Ramalho 2012). Nitrification works very well to reduce NH_4^+ in the system resulting in more NO_3^- towards in the effluents. Subsequently, due to anaerobic conditions in the sand filters, the nitrate is denitrified and transformed to nitrogen gas (Isaacs & Henze 1995) with the help of heterotrophic bacterial. There is not enough denitrification in the system to remove NH_4^+ due to limited energy source for the anaerobic microsites. The limited energy source is because of the huge reduction in BOD after the BF. The reduction in the mean TN concentration (about 60% reduction in mean inlet TN concentration) is still very significant even though BOD has been removed.

4.4. Conductivity

The mean influent conductivity level (STE) measured in the study period (2012-2017) is 1542µS/cm (*Table 4-2*) while final effluent from SFFM is 991µS/cm and from SFFP is 1110µS/cm (Annexes 05 and 06). The maximum level of conductivity ever recorded in the treatment system was 8890 µS/cm (Al Nabelsi & Ganesh 2013) in the PFFP and it was at the beginning of operation in 2012 (Annex 04) .

The change in conductivity level measured in the system from start of operation in 2012 is shown in the time series curve in figure 4.10.

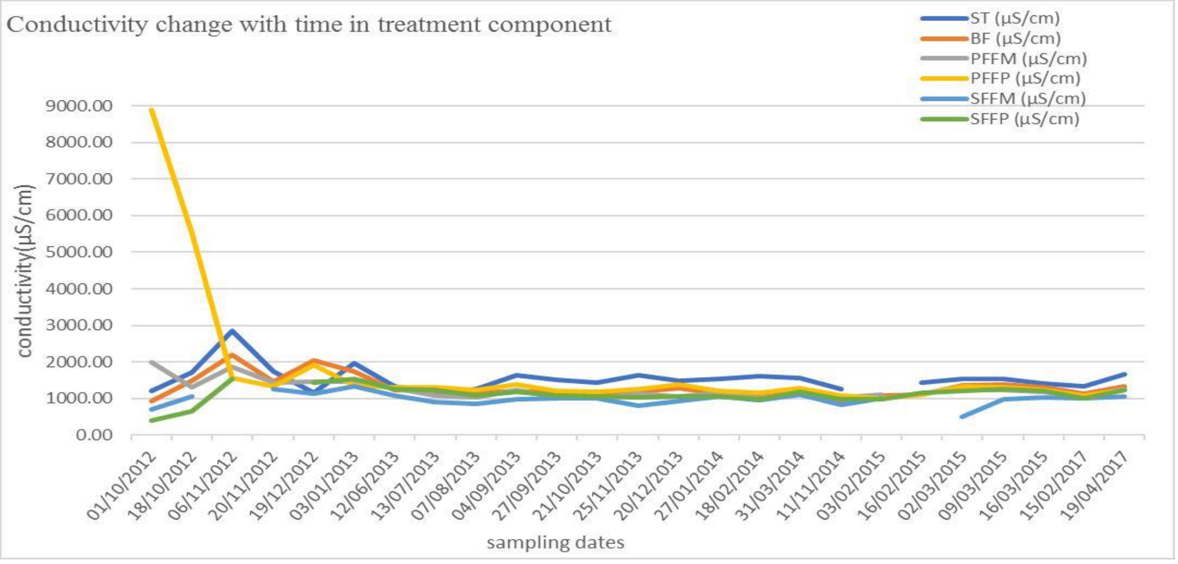


Fig. 4.10: *Time series curve showing the changes in conductivity level in the treatment system in the study period from 2012-2017.*

The high conductivity level in the PFFP in the beginning is because of calcium and magnesium leaching out of the Filtralite-P when it was still fresh. This is in accordance with a column experiment performed in a study to analyse the P retention in the filter materials shells and Filtralite-P (Ádám et al. 2007a). The column experiment result showed decrease in calcium and magnesium concentration in the effluent over time. Over time, Calcium and magnesium oxides into the system form dolomite which is calcium and magnesium carbonate (Rennesund et al. 2003), thereby resulting in the conductivity being almost at the same level in the system.

Similar conductivity trends were observed in previous study where inlet conductivity levels reduced in consecutive treatment components except for PFFP (Ganesh and Nabelsi, 2012).

4.5. pH

The mean influent pH measured(STE) is 8.1 and the final effluent has mean pH7.79 from SFFM and pH8.14 from SFFP effluent respectively (*Table 4-2*). The mean pH levels from both sand filters are within pH range of 7.5-8.5 set as “good for drinking water” in a nationwide survey of the chemical composition of drinking water in Norway (Flaten 1991).

The changes in the pH in the system is presented in the time series curve in Fig. 4.11.

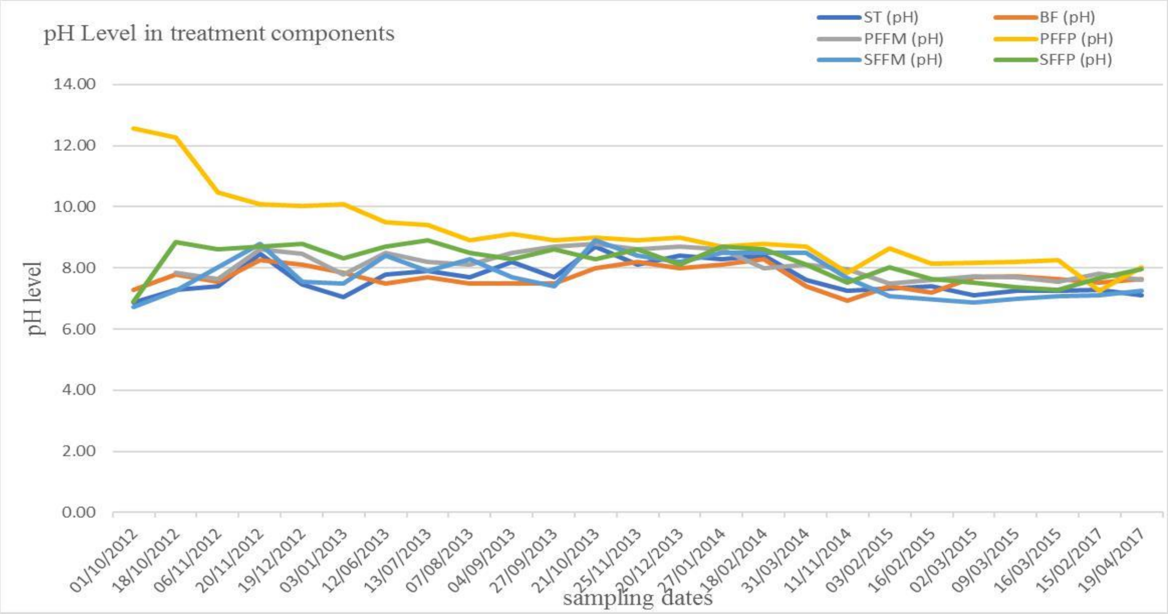


Fig. 4.11: *Time series curve showing pH changes in the treatment systems from 2012-2017*

Similar to the conductivity curve, highest pH is measured in the PFFP effluent is due to the presence of calcium ions in the beginning. At the beginning of operation, the pH was 12 and it reduced to 8. Over a period, loss of Ca_2^+ from the system introduces acidic P in wastewater, this results in drop in pH. If the pH was to drop to below 7, there is a risk of calcium bound phosphorus to leach into the system. The reduction in pH was also documented by (Adam et al. 2005) in a small-scale box experiment to estimate P-sorption of Filtralite P.

4.6. BOD removal

From the result from previous studies presented in table 2, the Høyås treatment system functions well in removing BOD in the wastewater. The first study on the system recorded a maximum BOD removal of 90% and 95% in the BF and PFs mean effluent concentrations (Al Nabelsi & Ganesh 2013). However, the same study observed a lesser removal efficiency of 87% in the SFs because of Organic matter leaching into the treatment component from the tree bark used for insulating it. Also, a broken nozzle in the biofilter might have affected the slight increase in BOD documented in January 2013 (*Figure 4.12*).

The subsequent study (Mironga 2014) done on the treatment system further confirmed the effect of the tree back on the BOD concentration by documenting decreases in the BOD concentration in the SFs concentrations immediately after replacing the tree back in August 2013(Annex 03 & 05).

Discussing the effect of temperature on BOD concentrations in the Høyås treatment system, the previous study on the system indicated increases in BOD concentration in the cold months (Mironga 2014) siting low microbial activity in degrading organic matter as the cause. However, a study evaluating the effects of temperature on WW parameters in constructed wetland (Akratos & Tsihrintzis 2007), explained that temperature has no serious effect on BOD removal. In the study, he statistical tests carried out on BOD value obtained at temperatures below and above 15 degrees Celsius showed that the BOD differences are not significant. This is in support of claims that constructed wetlands, if properly designed , can function well in places with cold climates (Jenssen et al. 2005). The mean final effluent BOD concentration is under the discharge limit of 20mg/l (*Table 4-2*).

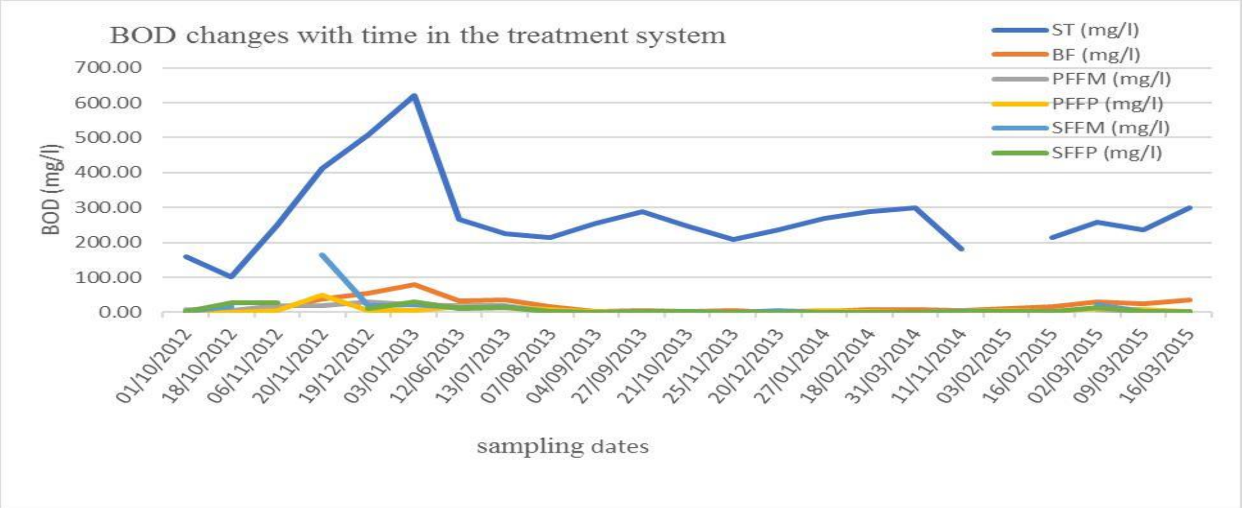


Fig. 4.12: *Time series curve showing BOD changes in all the treatment system (2012-2015 study period).*

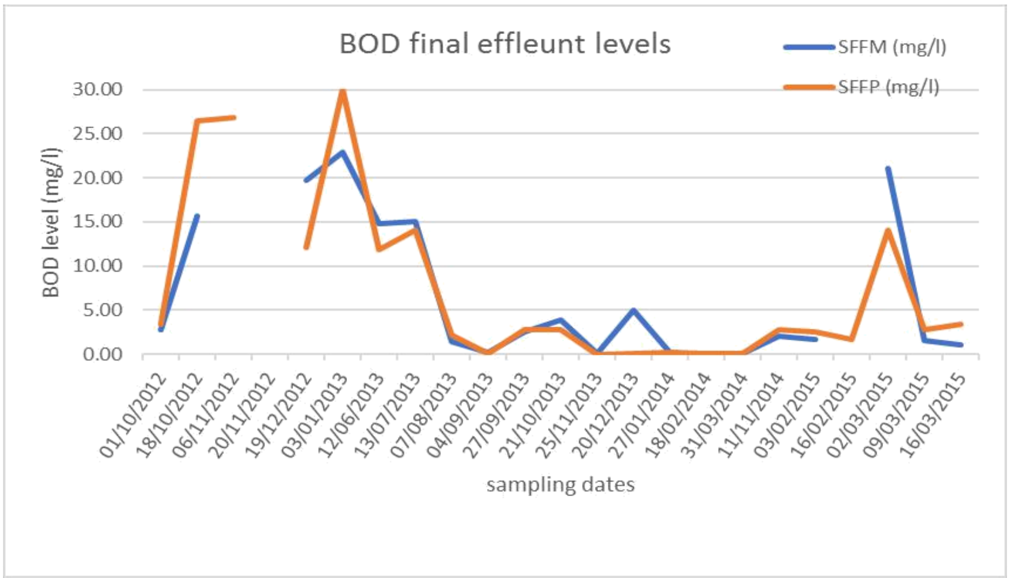


Fig. 4.13: *Time series curve showing BOD changes in the final effluents (2012-2015 study period).*

As seen in the final effluent time series for BOD (Fig. 4.13), The BOD level has been under the 20mg/l limit since the tree bark was replaced in the system. This system produces very stable and low BOD.

5. CONCLUSIONS AND RECOMMENDATIONS

After 55 months of operation, the onsite wastewater treatment system at Høyås is showing continuous increase in level of Phosphorus concentration in the final effluents. The final effluent from the Filtramar line (SFFM) now produces a mean effluent of total phosphorus (TP) of 1mg/l. Mean TP effluent from the Filtralite P line (SFFP) is still under the discharge limit of 1mg/l. Prediction is made for TP to exceed the 1mg/l limit by October 2017. The increasing of Total Phosphorus trends indicates that the filter media is approaching saturation. The orthophosphate (Ortho-P) concentration follows nearly same trend as TP concentration indicating increase in the final effluent ortho-P level over the period. For Biochemical oxygen demand (BOD), the final effluent from the system was under the discharge limit of 20mg/l as at the last time of measurement. The system produces low and stable BOD.

The system still removes Total Nitrogen (TN) to a considerable level in the final effluent. The mean of Total Nitrogen removal efficiency of the system is over 50%. The system also produces very good nitrification resulting in huge reduction in final effluent concentrations of Ammonium ions (NH_4^+). The system removes as much as 92%-94% of the NH_4^+.

The system produces effluents with stable conductivity level indicating stable levels of calcium and magnesium ions in the system. Also, the pH level (7-8) in the effluents indicates no risk of calcium bound phosphorus leaching out of the wastewater.

To improve the overall performance of the treatment system, it is recommended that:

- The nozzles spraying wastewater in the Phosphorus filter units should be replaced with nozzles having better spraying angles to achieve better distribution of wastewater over the filters.
- Samples should be collected and analysed for Total Phosphorus effluent concentration in October 2017 to monitor the Total Phosphorus concentration level to check whether the mean effluent Total Phosphorus concentration in both sand-filters for Filtramar and Filtralite P meets the 1mg/l discharge limit for phosphorus set by the Ås municipality.

REFERENCES

Adam, K., Krogstad, T., Suliman, F. R. & Jenssen, P. D. (2005). Phosphorous sorption by Filtralite P—small scale box experiment. *Journal of Environmental Science and Health*, 40 (6-7): 1239-1250.

Ádám, K., Krogstad, T., Vråle, L., Søvik, A. K. & Jenssen, P. D. (2007a). Phosphorus retention in the filter materials shellsand and Filtralite P®—Batch and column experiment with synthetic P solution and secondary wastewater. *Ecological Engineering*, 29 (2): 200-208.

ÁdÁm, K., Sovik, A., Krogstad, T. & Heistad, A. (2007b). Phosphorous removal by the filter materials light-weight aggregates and shellsand-a review of processes and experimental set-ups for improved design of filter systems for wastewater treatment. *Vatten*, 63 (3): 245.

Akratos, C. S. & Tsihrintzis, V. A. (2007). Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. *Ecological engineering*, 29 (2): 173-191.

Al Nabelsi, S. & Ganesh, R. (2013). *On-site wastewater treatment system in Høyås farm, Ås Norway*: Norwegian University of Life Sciences, Ås.

Anastasiadis, E. T., Eskridge, K., & Panoras, A. (2002). The Effect of Environmental Conditions on the Ability of a Constructed Wetland to Disinfect Municipal Wastewaters. *Environmental Management*, *29*(4), 510–515

Bennett, E. M., Carpenter, S. R. & Caraco, N. F. (2001). Human Impact on Erodable Phosphorus and Eutrophication: A Global Perspective: Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *BioScience*, 51 (3): 227-234.

Boumediene, B., & Abdelkader, E. (2015). Physico-chemical characterization of effluent from the effluent treatment plant using activated sludge from Saida city (Algeria) and evaluation of the pollution degree. Journal of Chemical and Pharmaceutical Research, 7(9), 749–763

Brady, N. & Weil, R. (1990). The nature and properties of soils. Macmillan New York: ISBN 0-02-946159-6.

Brothers, C. E. (2014). Efficiency of orthophosphate (SRP) uptake by five biochars and five biochar-soil.

BUSCH, A. W. 1958. Bod Progression in Soluble Substrates. Sewage and Industrial Wastes, 30, 1336-1349.

Cucarella, V. & Renman, G. (2009). Phosphorus sorption capacity of filter materials used for on-site wastewater treatment determined in batch experiments–a comparative study. *Journal of environmental quality*, 38 (2): 381-392.

Drizo, A., Comeau, Y., Forget, C. & Chapuis, R. P. (2002). Phosphorus saturation potential: a parameter for estimating the longevity of constructed wetland systems. *Environmental science & technology*, 36 (21): 4642-4648.

Du Toit, W. (2006). *Use of Total Organic Carbon Analyses on a Wastewater Treatment Plant*: Citeseer.

Flaten, T. P. (1991). A nation-wide survey of the chemical composition of drinking water in Norway. *Science of the total environment*, 102: 35-73.

Ellingsen, M. (2012). Sustainability of a Decentralized Wastewater Treatment System in Kathmandu Valley, Nepal - Technical and Social Challenges. NMBU.

HACH LANGE. (n.d.-a). Lck 338.

HACH LANGE. (n.d.-b). Lck 349, 4, 4–7.

HACH LANGE. (1998). Lck 304, 1998–2001.

HACH LANGE. (2016). LCK 339 Arbeitsvorschrift 0.23 – 13.50 mg/L NO3-N / 1 – 60 mg/L NO3, (3), 13–16.

Harrison, J. A. (1998). The Nitrogen Cycle

Heistad, A., Paruch, A. M., Vråle, L., Adam, K. & Jenssen, P. D. (2006a). A high–performance compact filter system treating domestic wastewater. *Ecological Engineering*, 28 (4): 374-379.

Heistad, A., Paruch, A. M., Vråle, L., Adam, K. & Jenssen, P. D. (2006b). *A high–performance compact filter system treating domestic wastewater*. Ecological Engineering, vol. 28. 374-379 pp.

Herrmann, I. (2014). *Filter beds for on-site wastewater treatment: Towards more reliable estimations of phosphorus retention*: Luleå tekniska universitet.

Hinesly, T. D. & Jones, R. L. (1990). Phosphorus in waters from sewage sludge amended lysimeters. *Environmental Pollution*, 65 (4): 293-309.

Isaacs, S. H. & Henze, M. (1995). Controlled carbon source addition to an alternating nitrification -denitrification wastewater treatment process including biological P removal. *Water Research*, 29 (1): 77-89.

Jenssen, P. & Siegrist, R. (1990). Technology assessment of wastewater treatment by soil infiltration systems. *Water science and technology*, 22 (3-4): 83-92.

Jenssen, P. & Siegrist, R. (1991). Integrated loading rate determination for wastewater infiltration system sizing: Oak Ridge National Lab., TN (United States).

Jenssen, P., Maehlum, T. & Krogstad, T. (1993). Potential use of constructed wetlands for wastewater treatment in northern environments. *Water Science and Technology*, 28 (10): 149-157.

Jenssen, P., Jonasson, S. & Heistad, A. (2006). *Naturbasert rensing av avløppsvann, en kunskapssammenstilling med hovedvekt på norske erfaringer*: Nr.

Jenssen, P. D., Mæhlum, T., Krogstad, T. & Vråle, L. (2005). High performance constructed wetlands for cold climates. *Journal of Environmental Science and Health*, 40 (6-7): 1343-1353.

Jenssen, P. D., Krogstad, T., Paruch, A. M., Mæhlum, T., Adam, K., Arias, C. A., Heistad, A., Jonsson, L., Hellström, D. & Brix, H. (2010). Filter bed systems treating domestic wastewater in the Nordic countries–performance and reuse of filter media. *Ecological engineering*, 36 (12): 1651-1659.

Jin, G., Kelley, T., Freeman, M. & Callahan, M. (2002). Removal of N, P, BOD5, and coliform in pilot-scale constructed wetland systems. *International journal of phytoremediation*, 4 (2): 127-141.

Jing, S.-R. & Lin, Y.-F. (2004). Seasonal effect on ammonia nitrogen removal by constructed wetlands treating polluted river water in southern Taiwan. *Environmental Pollution*, 127 (2): 291-301.

Johansson, B. & Johansson, B. (2002). *Småskalig avloppsrening–En exempelsamling*: Formas, Stockholm.

Johansson, B. & Johansson, B. (2002). Småskalig avloppsrening–En exempelsamling: Formas, Stockholm

Kadlec, R. & Knight, R. (1996). Treatment wetlands. CRC. *Baca Raton, FL*.

Khan, F. A. & Ansari, A. A. (2005). Eutrophication: an ecological vision. *The botanical review*, 71 (4): 449-482.

Köhler, J. (2006). Detergent phosphates: an EU policy assessment.

Kundu, S., Coumar, M. V., Rajendiran, S. & Rao, A. S. (2015). Phosphates from detergents and eutrophication of surface water ecosystem in India. *Current Science (00113891)*, 108 (7).

Lesikar, B. J., Garza, O. A., Persyn, R. A., Kenimer, A. L., & Anderson, M. T. (2006). Food-service establishment wastewater characterization. Water environment research, 78(8), 805-809.

Litke, D. W. (1999). *Review of phosphorus control measures in the United States and their effects on water quality*: US Department of the Interior, US Geological Survey.

Mæhlum, T. (1998). *Cold-climate constructed wetlands: aerobic pre-treatment and horizontal subsurface flow systems for domestic sewage and landfill leachate purification*: Norges Landbrukshoegskole.

Mæhlum, T. & Stålnacke, P. (1999). Removal efficiency of three cold-climate constructed wetlands treating domestic wastewater: effects of temperature, seasons, loading rates and input concentrations. *Water Science and Technology*, 40 (3): 273-281.

Maehlum, T. (1995). Treatment of landfill leachate in on-site lagoons and constructed wetlands. *Water Science and Technology*, 32 (3): 129-135.

McCray, J. E., Kirkland, S. L., Siegrist, R. L. & Thyne, G. D. (2005). Model parameters for simulating fate and transport of on-site wastewater nutrients. *Ground water*, 43 (4): 628-639.

Mironga, F. D. (2014). *Small Scale Wastewater Treatment System at Høyås Farm in Ås, Norway*: Norwegian University of Life Scinces, Ås.

Moshiri, G. A. (1993). *Constructed wetlands for water quality improvement*: CRC Press.

NKF and NORVAR (2001). 'Våtmarksfiltre: Utførelse, behandlingsanlegg, avløp: VA/miljø-blad'. Tech. Rep. 49, NKF and NORVAR

Norwegian Water. (2014). Available at: https://www.norskvann.no/images/torilh/The_water_services_in_Norway_endelig.pdf

Oakley, S. M., Gold, A. J. & Oczkowski, A. J. (2010). Nitrogen control through decentralized wastewater treatment: Process performance and alternative management strategies. *Ecological Engineering*, 36 (11): 1520-1531.

Paruch, A., Mæhlum, T., Obarska-Pempkowiak, H., Gajewska, M., Wojciechowska, E. & Ostojski, A. (2011). Rural domestic wastewater treatment in Norway and Poland: experiences, cooperation and concepts on the improvement of constructed wetland technology. *Water Science and Technology,* 63 (4): 776-781.

Ramalho, R. (2012). *Introduction to wastewater treatment processes*: Elsevier.

Rennesund, R., Jenssen, P. D. & Krogstad, T. (2003). *Light expanded clay aggregates for phosphorous removal*: Google Patents.

Rickert, B., Samwel, M., Shinee, E., Kožíšek, F. & Schmoll, O. (2016). STATUS OF SMALL-SCALE WATER SUPPLIES IN THE WHO EUROPEAN REGION Results of a survey conducted under the Protocol on Water and Health.

States Environmental Protection Agency, U. (1999). U.S. Environmental Protection Agency NPDES Permit Writers' Manual. Available at: http://www.sswm.info/sites/default/files/reference_attachments/U.S EPA 1999 NPDES Permit Writers' Manual.pdf

Thullen, J. S., Sartoris, J. J. & Nelson, S. M. (2005). Managing vegetation in surface-flow wastewater-treatment wetlands for optimal treatment performance. *Ecological Engineering*, 25 (5): 583-593.

UMB K. 2012. Annual climatological summary [Online]. Available at: http://klima.umb.no/NOAAYR.TXT

UNDP. (2016). Human Development Report 2016. United Nations Development Programme. Available at: http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf

Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., Schlesinger, W. H. & Tilman, D. G. (1997). Human alteration of the global nitrogen cycle: sources and consequences. *Ecological applications*, 7 (3): 737-750.

Vohla, C., Kõiv, M., Bavor, H. J., Chazarenc, F. & Mander, Ü. (2011). Filter materials for phosphorus removal from wastewater in treatment wetlands—A review. *Ecological Engineering*, 37 (1): 70-89.

Von Sperling, M. & de Lemos Chernicharo, C. A. (2005). *Biological wastewater treatment in warm climate regions*, vol. 1: IWA publishing.

Vymazal, J., Brix, H., Cooper, P., Green, M. & Haberl, R. (1998). *Constructed wetlands for wastewater treatment in Europe*: Backhuys Leiden.

Vymazal, J. (2008). *Constructed wetlands for wastewater treatment: A review*. Proceedings of Taal2007: The 12th World Lake Conference. 980 pp.

Westholm, L. J. (2006). Substrates for phosphorus removal—Potential benefits for on-site wastewater treatment? *Water Research*, 40 (1): 23-36.

Wittgren, H. B. & Maehlum, T. (1997). Wastewater treatment wetlands in cold climates. *Water Science and Technology*, 35 (5): 45-53.

www.therichest.com. (2016). Top 10 Countries With the Best Tap Water. Available at: http://www.therichest.com/expensive-lifestyle/location/top-10-countries-with-the-best-tap-water/

Zdragas, A., Zalidis, G., Takavakoglou, V., Katsavouni, S., Anastasiadis, E., Eskridge, K. & Panoras, A. (2002). The effect of environmental conditions on the ability of a constructed wetland to disinfect municipal wastewaters. *Environmental management*, 29 (4): 510-515.

ANNEXES

ANNEXES 01

SEPTIC TANK(ST) EFFLUENT CONCENTRATION AND LEVELS								
	PARAMETERS							
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING DATES	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012	6.86	4.36				158.00	1222.00	6.87
18/10/2012	11	11.00				101.00	1705.00	7.28
06/11/2012	12	9.34				249.00	2863.00	7.39
20/11/2012	13.6	10.30				411.00	1745.00	8.45
19/12/2012	14.9	12.90				507.00	1152.00	7.46
03/01/2013	14.8	12.50				620.00	1969.00	7.04
12/06/2013	19.30	14.60	101.70	96.90	0.89	265.00	1336.00	7.80
13/07/2013	13.70	13.40	98.70	95.60	1.30	225.00	1125.00	7.90
07/08/2013	15.30	14.20	131.20	127.90	1.34	214.00	1260.00	7.70
04/09/2013	17.62	14.14	101.20	98.10	0.78	256.00	1649.00	8.20
27/09/2013	13.66	10.50	125.00	122.30	0.94	287.00	1507.00	7.70
21/10/2013	18.40	11.50	120.10	119.20	0.82	248.00	1430.00	8.70
25/11/2013	13.20	12.70	115.30	110.20	0.84	208.00	1650.00	8.10
20/12/2013	17.70	17.50	119.20	115.80	1.10	237.00	1497.00	8.40
27/01/2014	17.30	17.10	108.30	103.10	0.72	270.00	1538.00	8.30
18/02/2014	17.30	14.80	114.30	108.80	1.40	287.00	1612.00	8.40
31/03/2014	18.70	17.40	103.00	99.90	0.76	299.00	1565.00	7.60
11/11/2014	8.80	7.30	115.60	143.00	0.30	180.00	1263.00	7.25
03/02/2015								
16/02/2015	16.00	15.00	309.00	195.00	0.40	214.00	1442.00	7.39
02/03/2015	21.40	19.50	187.60	196.50	0.40	259.00	1551.00	7.12
09/03/2015	21.00	20.20				237.00	1531.00	7.26
16/03/2015						299.00	1417.00	7.26
15/02/2017	3.80	3.52	86.7	37.4	0.34		1337.00	7.27
19/04/2017	12.96	13.46	81.50	3.84	0.64		1665.00	7.10
mean	14.75	12.92	126.15	110.85	0.81	274.14	1542.96	7.66
median	14.9	13.4	114.8	109.5	0.8	252.5	1519	7.53
max	21.4	20.2	309	196.5	1.4	620	2863	8.7
min	3.8	3.52	81.5	3.84	0.3	101	1125	6.87
st.Dev	4.33	4.23	54.20	47.32	0.35	112.38	345.82	0.53

ANNEXES 02

BIOFILTER (BF) EFFLUENT CONCENTRATION AND LEVELS								
	PARAMETERS							
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING DATES	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012		0.60					936.00	7.29
18/10/2012		2.94					1484.00	7.80
06/11/2012		7.67				10.70	2193.00	7.55
20/11/2012		5.70				39.50	1457.00	8.27
19/12/2012		6.66				53.50	2051.00	8.11
03/01/2013		9.43				80.30	1741.00	7.85
12/06/2013	16.40	13.60	68.40	26.20	36.10	32.60	1226.00	7.50
13/07/2013	11.04	9.13	47.90	26.40	20.20	36.80	1210.00	7.70
07/08/2013	13.45	10.25	69.60	46.90	21.47	17.20	1161.00	7.50
04/09/2013	15.52	13.15	54.60	15.70	41.50	2.80	1217.00	7.50
27/09/2013	7.82	5.84	72.30	51.20	19.40	4.20	1150.00	7.50
21/10/2013	10.00	8.21	79.40	63.50	14.90	3.90	1100.00	8.00
25/11/2013	6.22	6.28	75.90	57.30	16.81	4.50	1190.00	8.20
20/12/2013	7.80	6.90	81.30	66.90	12.10	0.00	1284.00	8.00
27/01/2014	8.20	7.75	83.70	71.60	10.90	3.40	1125.00	8.10
18/02/2014	7.90	8.10	87.90	75.80	10.60	7.00	1145.00	8.30
31/03/2014	10.10	9.80	79.20	67.70	9.20	7.80	1274.00	7.40
11/11/2014	4.70	4.20	81.60	23.00	37.10	5.60	927.00	6.94
03/02/2015	8.20	7.90	80.20	131.40	69.90	9.90	1082.00	7.39
16/02/2015	7.30	7.60	186.00	73.60	102.00	15.50	1113.00	7.20
02/03/2015	16.40	16.70	138.00	161.50	0.50	31.00	1365.00	7.71
09/03/2015	23.80	23.70				24.00	1385.00	7.73
16/03/2015						36.60	1323.00	7.64
15/02/2017	3.20	3.47	73.30	0.48	14.64		1141.00	7.53
19/04/2017	8.14	8.47	70.00	4.08	16.52		1348.00	7.63
mean	10.34	8.50	84.08	56.66	26.70	20.32	1305.12	7.69
median	8.20	7.83	79.20	57.30	16.81	10.70	1217.00	7.64
max	23.80	23.70	186.00	161.50	102.00	80.30	2193.00	8.30
min	3.20	0.60	47.90	0.48	0.50	0.00	927.00	6.94
st.Dev	5.05	4.74	32.15	42.15	25.34	20.56	301.21	0.35

ANNEXES 03

PHOSPHORUS FILTER FILTRAMAR(PFFM) EFFLUENT CONCENTRATION AND LEVELS								
	PARAMETERS							
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING DATES	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012	0.39	0.11				8.10	2002.00	
18/10/2012	0.35	0.04				5.90	1320.00	7.83
06/11/2012	0.30	0.04				19.40	1859.00	7.65
20/11/2012	0.29	0.15				19.90	1449.00	8.61
19/12/2012	1.70	1.36				30.90	1475.00	8.47
03/01/2013	1.20	1.05				21.10	1458.00	7.78
12/06/2013	2.16	1.93	47.50	5.90	44.40	18.20	1290.00	8.50
13/07/2013	1.91	1.82	29.70	5.20	26.70	18.70	1097.00	8.20
07/08/2013	2.05	2.08	42.10	27.20	32.10	2.80	1040.00	8.10
04/09/2013	2.32	1.99	44.90	18.40	63.30	0.80	1240.00	8.50
27/09/2013	1.77	1.79	58.10	30.30	27.40	2.20	1040.00	8.70
21/10/2013	1.21	1.18	50.80	28.30	18.80	2.50	1020.00	8.80
25/11/2013	0.82	0.91	53.40	32.00	22.10	0.80	1126.00	8.60
20/12/2013	1.23	1.09	73.20	57.40	17.30	2.20	1054.00	8.70
27/01/2014	1.57	1.46	74.30	53.70	19.30	0.80	1148.00	8.60
18/02/2014	1.68	1.59	70.30	51.10	18.80	1.10	1014.00	8.00
31/03/2014	1.81	1.76	63.20	49.20	17.10	0.30	1147.00	8.10
11/11/2014	1.00	1.50	106.60	0.00	55.20	5.30	1022.00	7.97
03/02/2015	8.60	8.30	37.00	61.70	60.00	2.50	1106.00	7.48
16/02/2015								
02/03/2015	6.10	6.40	121.20	45.80	53.60	7.20	1273.00	7.72
09/03/2015	10.00	10.00				2.20	1230.00	7.71
16/03/2015						2.80	1180.00	7.56
15/02/2017	3.65	3.83	68.50	1.14	56.00		1031.00	7.81
19/04/2017	6.98	7.27	59.00	2.20	25.70		1252.00	7.61
mean	2.57	2.51	62.49	29.35	34.86	7.99	1244.71	8.13
median	1.70	1.59	58.55	29.30	27.05	2.80	1164.00	8.10
max	10.00	10.00	121.20	61.70	63.30	30.90	2002.00	8.80
min	0.29	0.04	29.70	0.00	17.10	0.30	1014.00	7.48
st.Dev	2.70	2.76	24.04	21.95	17.32	8.93	255.15	0.43

ANNEXES 04

PHOSPHORUS FILTER FILTRALITE-P(PFFP) EFFLUENT CONCENTRATION AND LEVELS								
	PARAMETERS							
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING DATES	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012	0.53	0.01					8890.00	12.56
18/10/2012	0.03	0.01					5540.00	12.27
06/11/2012	0.08	0.25				4.80	1577.00	10.46
20/11/2012	0.30	0.12				50.60	1339.00	10.08
19/12/2012	0.50	0.30				4.80	1913.00	10.03
03/01/2013	0.48	0.24				4.80	1361.00	10.08
12/06/2013	1.43	1.37	55.70	12.10	40.10	15.40	1324.00	9.50
13/07/2013	1.12	0.93	38.20	16.30	24.80	17.40	1302.00	9.40
07/08/2013	1.07	1.12	51.20	39.20	20.40	6.70	1240.00	8.90
04/09/2013	1.62	1.48	39.10	20.10	43.80	1.60	1380.00	9.10
27/09/2013	0.68	0.53	68.30	45.80	20.30	2.80	1215.00	8.90
21/10/2013	1.12	1.17	66.70	46.10	16.10	2.50	1188.00	9.00
25/11/2013	0.59	0.46	60.80	41.60	19.80	0.30	1250.00	8.90
20/12/2013	1.48	1.39	77.40	63.70	14.80	2.80	1394.00	9.00
27/01/2014	1.21	1.14	78.10	63.90	17.50	4.99	1205.00	8.70
18/02/2014	1.39	1.42	75.10	59.80	17.30	1.60	1150.00	8.80
31/03/2014	1.38	1.33	74.30	60.10	12.20	0.60	1282.00	8.70
11/11/2014	1.40	2.10	96.00	5.70	50.40	2.80	1078.00	7.85
03/02/2015	2.00	2.00	32.10	35.50	56.80	4.80	1020.00	8.63
16/02/2015	1.20	1.60	166.50	43.80	103.30	2.20	1121.00	8.14
02/03/2015	5.10	5.10	124.20	134.00	7.70	9.60	1349.00	8.17
09/03/2015	8.00	8.80				6.70	1302.00	8.19
16/03/2015						1.40	1239.00	8.26
15/02/2017	2.66	2.94	58.40	0.78	36.30		1079.00	7.25
19/04/2017	4.48	4.72	56.00	4.66	27.06		1031.00	8.01
mean	1.66	1.69	71.65	40.77	31.10	7.10	1750.76	9.16
median	1.21	1.25	66.70	41.60	20.40	4.80	1282.00	8.90
max	8.00	8.80	166.50	134.00	103.30	50.60	8890.00	12.56
min	0.03	0.01	32.10	0.78	7.70	0.30	1020.00	7.25
st.Dev	1.82	2.00	33.01	32.17	23.32	10.91	1723.91	1.24

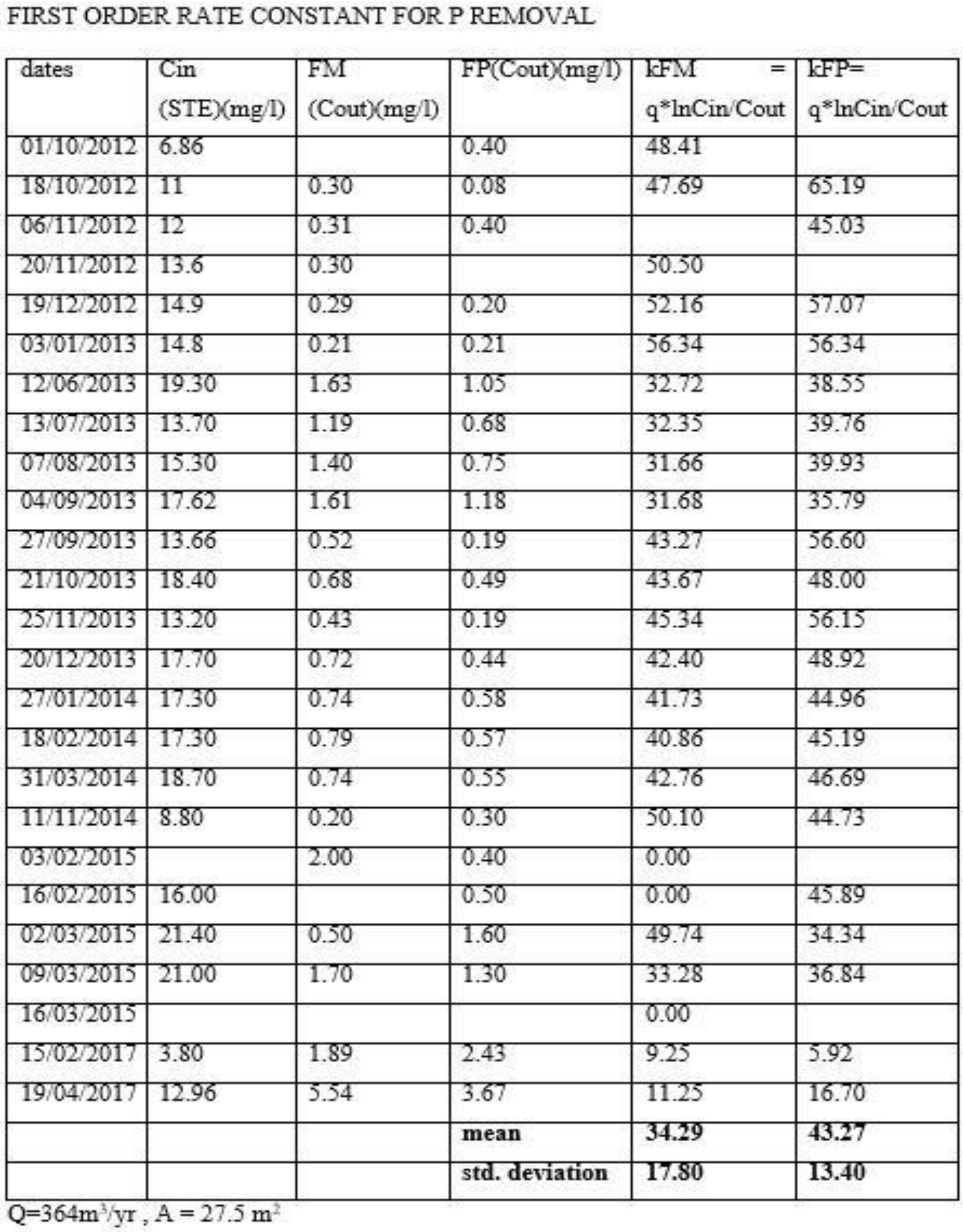
ANNEXES 05

SAND FILTER FILTRAMAR(SFFM) EFFLUENT CONCENTRATION AND LEVELS								
	PARAMETERS							
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING D	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012		0.08				2.80	702.00	6.71
18/10/2012	0.30	0.07				15.70	1064.00	7.24
06/11/2012	0.31							
20/11/2012	0.30	0.08				166.00	1272.00	8.80
19/12/2012	0.29	0.13				19.70	1131.00	7.55
03/01/2013	0.21	0.13				23.90	1339.00	7.48
12/06/2013	1.63	1.23	38.80	2.30	45.60	14.80	1097.00	8.40
13/07/2013	1.19	0.91	26.30	9.10	28.20	15.10	902.00	7.90
07/08/2013	1.40	0.93	35.30	12.20	36.00	1.40	860.00	8.30
04/09/2013	1.61	1.48	32.90	26.70	47.20	0.20	980.00	7.70
27/09/2013	0.52	0.54	55.10	20.30	33.70	2.50	1010.00	7.40
21/10/2013	0.68	0.57	36.10	17.30	22.50	3.90	1002.00	8.90
25/11/2013	0.43	0.41	34.70	11.10	23.90	0.10	814.00	8.40
20/12/2013	0.72	0.69	58.10	35.90	23.10	4.99	930.00	8.20
27/01/2014	0.74	0.75	60.30	40.10	22.00	0.20	1060.00	8.50
18/02/2014	0.79	0.77	48.70	43.10	21.30	0.00	950.00	8.50
31/03/2014	0.74	0.71	54.90	38.90	19.30	0.10	1115.00	8.50
11/11/2014	0.20	0.20	73.85	0.10	35.20	2.00	834.00	7.66
03/02/2015	2.00	1.90	48.60	38.30	95.60	1.70	1005.00	7.09
16/02/2015								
02/03/2015	0.50	0.40	53.80	0.00	37.60	21.00	492.00	6.87
09/03/2015	1.70	1.70				1.60	978.00	6.98
16/03/2015						1.10	1034.00	7.07
15/02/2017	1.89	1.89	59.50	0.28	53.50		1008.00	7.68
19/04/2017	5.54	5.92	66.00	2.01	32.10		1234.00	7.24
mean	1.08	0.98	48.93	18.61	36.05	14.23	991.87	7.79
median	0.73	0.70	51.25	14.75	32.90	2.50	1005.00	7.68
max	5.54	5.92	73.85	43.10	95.60	166.00	1339.00	8.90
min	0.20	0.07	26.30	0.00	19.30	0.00	492.00	6.71
st.Dev	1.16	1.25	13.56	16.30	18.88	35.68	183.09	0.66

ANNEXES 06

SAND FILTER FILTRALITE P (SFFP) CONCENTRATION								
PARAMETERS								
	TP	ORTHO-P	TN	NH4+	NO3-	BOD	Cond.	pH
SAMPLING D	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(µS/cm)	
01/10/2012	0.40	0.06				3.40	403.00	6.89
18/10/2012	0.10	0.08				26.40	668.00	8.84
06/11/2012	0.40	0.10				26.80	1530.00	8.61
20/11/2012								
19/12/2012	0.20	0.04				12.10	1433.00	8.80
03/01/2013	0.21	0.10				30.00	1527.00	8.32
12/06/2013	1.05	0.97	27.50	8.20	38.20	11.80	1249.00	8.70
13/07/2013	0.68	0.70	35.60	12.80	25.60	14.00	1244.00	8.90
07/08/2013	0.75	0.68	47.10	30.30	21.40	2.20	1090.00	8.50
04/09/2013	1.18	1.02	28.30	24.10	44.40	0.10	1190.00	8.30
27/09/2013	0.19	0.15	63.80	34.10	28.10	2.80	1090.00	8.60
21/10/2013	0.49	0.51	49.30	26.80	20.50	2.80	1065.00	8.30
25/11/2013	0.19	0.19	40.10	17.30	24.30	0.00	1028.00	8.60
20/12/2013	0.44	0.36	68.30	54.10	17.80	0.10	1063.00	8.10
27/01/2014	0.58	0.59	69.50	50.80	17.90	0.20	1053.00	8.70
18/02/2014	0.57	0.54	71.50	54.40	18.70	0.10	990.00	8.60
31/03/2014	0.55	0.52	68.30	52.80	15.10	0.10	1180.00	8.10
11/11/2014	0.30	0.30	93.90	0.00	43.50	2.80	990.00	7.53
03/02/2015	0.40	0.70	23.20	0.00	95.20	2.50	996.00	8.02
16/02/2015	0.50	0.50	129.50	0.90	118.30	1.70	1156.00	7.64
02/03/2015	1.60	1.60	85.00	87.60	8.60	14.00	1208.00	7.51
09/03/2015	1.30	1.30				2.80	1261.00	7.37
16/03/2015						3.40	1220.00	7.28
15/02/2017	2.43	2.57	49.70	1.50	48.10		1017.00	7.11
19/04/2017	3.67	3.86	60.00	2.09	55.50		1008.00	7.95
mean	0.79	0.76	59.45	26.93	37.72	7.28	1110.79	8.14
median	0.50	0.52	60.00	24.10	25.60	2.80	1090.00	8.30
max	3.67	3.86	129.50	87.60	118.30	30.00	1530.00	8.90
min	0.10	0.04	23.20	0.00	8.60	0.00	403.00	6.89
st.Dev	0.83	0.90	27.12	25.64	29.36	9.50	239.64	0.60

ANNEXES 07



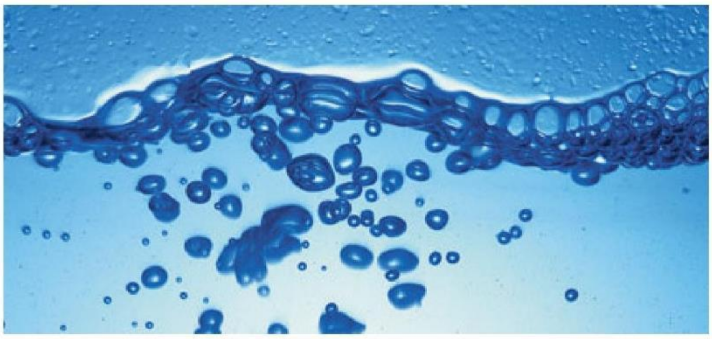
FIRST ORDER RATE CONSTANT FOR P REMOVAL

dates	Cin (STE)(mg/l)	FM (Cout)(mg/l)	FP(Cout)(mg/l)	kFM = q*lnCin/Cout	kFP= q*lnCin/Cout
01/10/2012	6.86		0.40	48.41	
18/10/2012	11	0.30	0.08	47.69	65.19
06/11/2012	12	0.31	0.40		45.03
20/11/2012	13.6	0.30		50.50	
19/12/2012	14.9	0.29	0.20	52.16	57.07
03/01/2013	14.8	0.21	0.21	56.34	56.34
12/06/2013	19.30	1.63	1.05	32.72	38.55
13/07/2013	13.70	1.19	0.68	32.35	39.76
07/08/2013	15.30	1.40	0.75	31.66	39.93
04/09/2013	17.62	1.61	1.18	31.68	35.79
27/09/2013	13.66	0.52	0.19	43.27	56.60
21/10/2013	18.40	0.68	0.49	43.67	48.00
25/11/2013	13.20	0.43	0.19	45.34	56.15
20/12/2013	17.70	0.72	0.44	42.40	48.92
27/01/2014	17.30	0.74	0.58	41.73	44.96
18/02/2014	17.30	0.79	0.57	40.86	45.19
31/03/2014	18.70	0.74	0.55	42.76	46.69
11/11/2014	8.80	0.20	0.30	50.10	44.73
03/02/2015		2.00	0.40	0.00	
16/02/2015	16.00		0.50	0.00	45.89
02/03/2015	21.40	0.50	1.60	49.74	34.34
09/03/2015	21.00	1.70	1.30	33.28	36.84
16/03/2015				0.00	
15/02/2017	3.80	1.89	2.43	9.25	5.92
19/04/2017	12.96	5.54	3.67	11.25	16.70
			mean	**34.29**	**43.27**
			std. deviation	**17.80**	**13.40**

Q=364m^3/yr , A = 27.5 m^2

filtralite

FILTRALITE® HC 2,5-5



Product description

PRODUCT

Filtralite® is high quality filter media, manufactured from a unique expanded clay material.

ADVANTAGES

Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.

EXPLANATIONS

N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round

Product specificaton

Commercial name	FILTRALITE® HC 2,5-5
Density	Bulk density, compressed: 840 kg/m³ Particle density: 1550 kg/m³
Type of material	Expanded clay
Appearance	Crushed particles, porous surface structure
Manufactured by	Weber Leca Rælingen, Norway
Version	8

Size and weight	Value	Deviation	Comments
Particle size range	2-5 mm	< 2 mm max. 5 % +Δ < 0,125 mm > 5 mm max. 5 %	EN 12905
Bulk density, dry, compressed	840 kg/m³	± 75 kg/m³	EN 1097-3, 10 strokes
Particle density, apparent	1550 kg/m³	± 150 kg/m³	EN 1097-6: Annex E

Other properties	Value	Comments
Voids	~52 %	EN 1097-3, approximat value
Acid solubility	< 5 %	EN 12902
Friability loss	< 5 %	EN 12902

CHEMICAL COMPOSITION, APPROXIMAT VALUES

SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	Na_2O
63%	17%	7%	4%	2%	2%

ANNEX 09

filtralite

FILTRALITE® P 0-4

Product description

PRODUCT

Filtralite® is high quality filter media, manufactured from a unique expanded clay material.

ADVANTAGES

Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.

EXPLANATIONS

N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round, P = Phosphorus binding.

Product specificaton

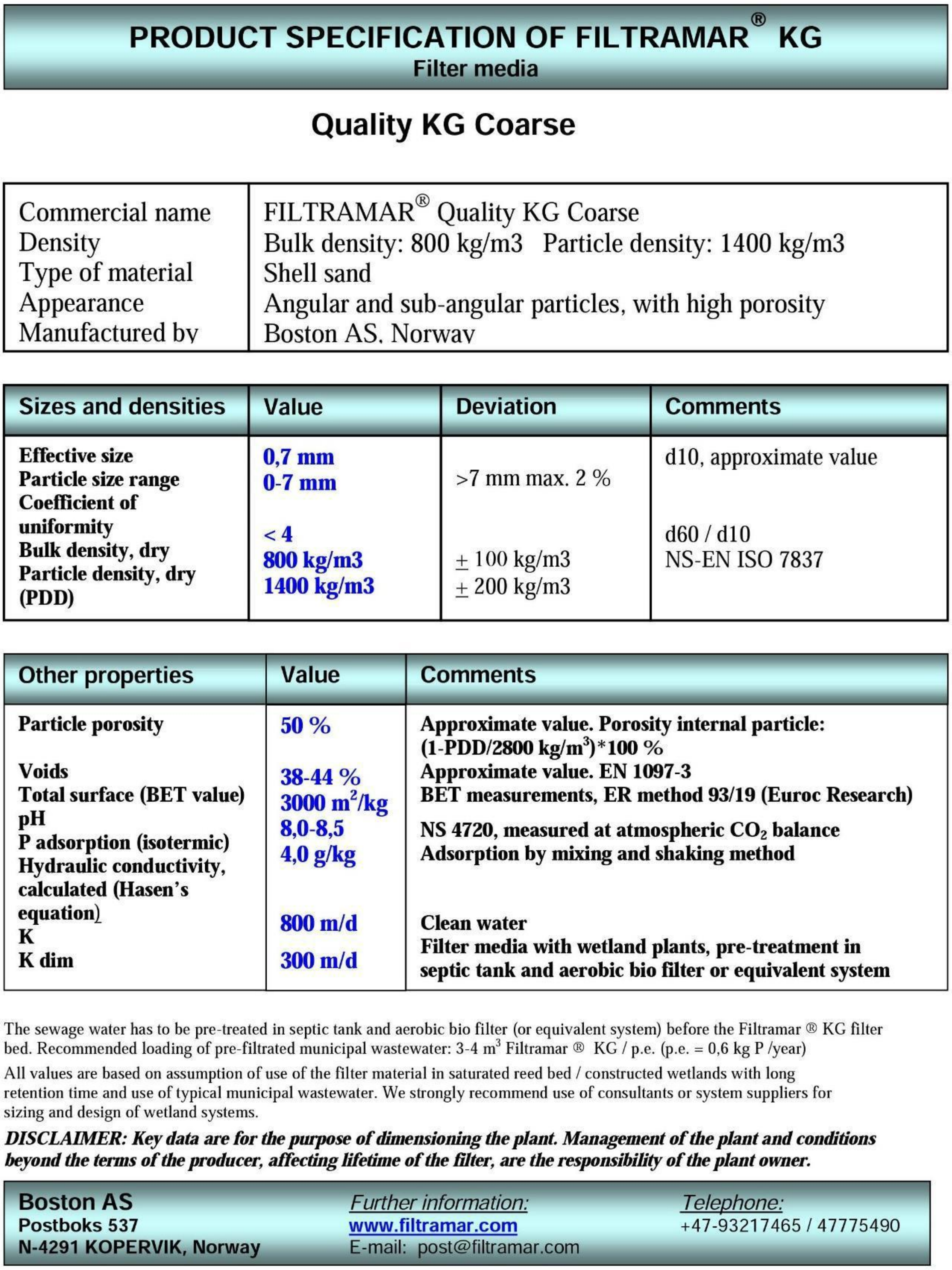
Commercial name	FILTRALITE® P 0-4
Density	Bulk density, loose: 500 kg/m³
Type of material	Expanded clay
Appearance	Porous surface with white particles
Manufactured by	Weber Leca Rælingen, Norway
Version	8

Size and weight	Value	Deviation	Comments
Particle size range	0-4 mm	> 4 mm max. 10 %	EN 12905
Bulk density, dry, loose	500 kg/m³	± 75 kg/m³	EN 1097-3

Other properties	Value	Comments
Voids	~60 %	EN 1097-3, approximat value
pH	~12	Weber Norm
Alkalinity	~35 mekv/l	NS 4754, approximat value
Hydraulic conductivity		Approximat value
K	100 m/d	9ºC, Clean water
K dim	25 m/d	9ºC, Filter media with wetland plants, pre-treatment in septic tank and aerobic biofilter or equivalent system

The sewage water has to be pre-treated in septic tank and aerobic biofilter (or equivalent system) before the Filtralite P filter bed. Recommended loading of prefiltrated municipal wastewater: 7-10 m³ Filtralite P / p.e, (p.e. = 0,6 kg P /year)
The material will leak some lime in the start-up period.
All values are based on assumption of use of the filtermaterial in saturated reed bed / constructed wetlands with long

ANNEX 10



PRODUCT SPECIFICATION OF FILTRAMAR® KG

Filter media

Quality KG Coarse

Commercial name	FILTRAMAR® Quality KG Coarse
Density	Bulk density: 800 kg/m3 Particle density: 1400 kg/m3
Type of material	Shell sand
Appearance	Angular and sub-angular particles, with high porosity
Manufactured by	Boston AS, Norway

Sizes and densities	Value	Deviation	Comments
Effective size	**0,7 mm**		d10, approximate value
Particle size range	**0-7 mm**	>7 mm max. 2 %	
Coefficient of uniformity	**< 4**		d60 / d10
Bulk density, dry	**800 kg/m3**	± 100 kg/m3	NS-EN ISO 7837
Particle density, dry (PDD)	**1400 kg/m3**	± 200 kg/m3	

Other properties	Value	Comments
Particle porosity	**50 %**	**Approximate value. Porosity internal particle: (1-PDD/2800 kg/m^3)*100 %**
Voids	**38-44 %**	**Approximate value. EN 1097-3**
Total surface (BET value)	**3000 m^2/kg**	**BET measurements, ER method 93/19 (Euroc Research)**
pH	**8,0-8,5**	**NS 4720, measured at atmospheric CO_2 balance**
P adsorption (isotermic)	**4,0 g/kg**	**Adsorption by mixing and shaking method**
Hydraulic conductivity, calculated (Hasen's equation)		
K	**800 m/d**	**Clean water**
K dim	**300 m/d**	**Filter media with wetland plants, pre-treatment in septic tank and aerobic bio filter or equivalent system**

The sewage water has to be pre-treated in septic tank and aerobic bio filter (or equivalent system) before the Filtramar ® KG filter bed. Recommended loading of pre-filtrated municipal wastewater: 3-4 m^3 Filtramar ® KG / p.e. (p.e. = 0,6 kg P /year)

All values are based on assumption of use of the filter material in saturated reed bed / constructed wetlands with long retention time and use of typical municipal wastewater. We strongly recommend use of consultants or system suppliers for sizing and design of wetland systems.

DISCLAIMER: Key data are for the purpose of dimensioning the plant. Management of the plant and conditions beyond the terms of the producer, affecting lifetime of the filter, are the responsibility of the plant owner.

Boston AS	*Further information:*	*Telephone:*
Postboks 537	www.filtramar.com	+47-93217465 / 47775490
N-4291 KOPERVIK, Norway	E-mail: post@filtramar.com	

ANNEX 11

Leca® Iso 10-20

Produktfordeler

Leca Iso 10-20 er sortert lettklinker til bruk i bl.a lette tilbakefyllinger kapillærbrytende, isolerende/frostsikrende og drenerende lag i gulv.

Lett tilbakefyllingsmateriale

Meget godt drenerende

Varmeisolerende

Produktbeskrivelse

Leca Lettklinker er et rent naturprodukt produsert av leire som er tørket og har gått gjennom en brenneprosess opp mot 1200°C. Kullene kommer ut i størrelse 0-32 millimeter og sorteres i forskjellige fraksjoner. Leca Lettklinker brukes både som her beskrevet i løs form og er basisen til Leca blokker, pipeelementer og Leca Byggeplank.

Produktspesifikasjon

YTELSESERKLÆRING/DoP

DoP-NO-Lecaiso10-20GEO

Tørr densitet: 220 kg/m³ +/- 15 %

Varmekonduktivitet: 0,11 W/mK

Flere egenskaper finnes i brosjyrer på hjemmesiden.

Leveringsform

Leca® ISO 10-20 kan blåses direkte på plass i konstruksjonen fra blåsebiler med inntil 90 m³ volum. Den kan også tippes på plass og flyttes maskinelt med doser/gravemaskin. Materialet leveres også i storsekker på 1m³ og småsekker på 50 liter.

Bruksområde

Leca Iso 10-20 er sortert i størrelsen 8-20 mm og er et coatet materiale som brukes som kapillærbrytende, isolerende og drenerende lag i gulv og tilbakefyllinger. Benyttes også som frost- og telesikring i kalde konstruksjoner.

Lagring

Leca® Lettklinker produkter tåler utendørs lagring, men vil kunne trekke til seg noe fuktighet. Ekstra fuktighet vil gi Leca® produktet noe høyere egenvekt, og kan ved kuldegrader medføre isdannelse. For enklest mulig håndtering av produktet, anbefales lagring under tak.

Utførelse

Se under brosjyrer eller ta kontakt med oss for nærmere beskrivelser av utførelse

Leca® Iso 10-20

Miljøanvisninger

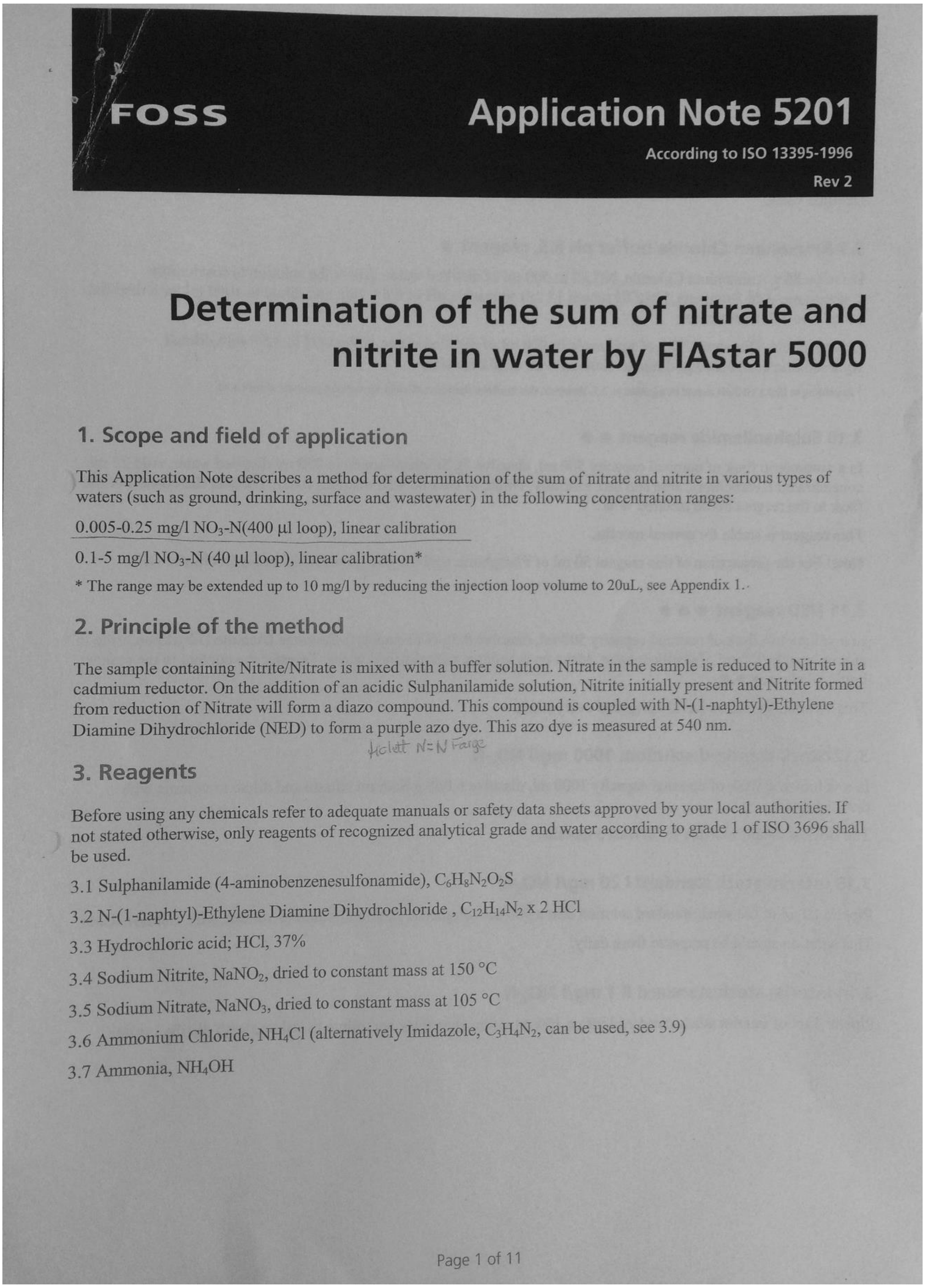
Leca Lettklinker er et rent naturprodukt som ikke belaster naturen med avfallsstoffer og kan gjenbrukes tilnærmet uendelig. Ved blanding med andre materialer kan disse sorteres bort og lecaen fortsatt gjenbrukes. I disse prosessene vil man oppleve en del knusing av de runde aggregatene.

Ansvar

Informasjonen som er gitt i dette datablad bygger på vår nåværende kunnskap og erfaring om produktet. All ovenstående informasjon må betraktes som retningsgivende. Det er brukerens ansvar å påse at produktet er egnet for tilsiktet anvendelse samt utføre egenkontroll. Brukeren står ansvarlig dersom produktet blir anvendt til andre formål enn anbefalt eller ved feil utførelse. Vi står gjerne til rådighet for veiledning i bruk av våre produkter.

Saint-Gobain Byggevarer as
Brobekkveien 84
Postboks 216 Alnabru
0614 Oslo
Tlf.: 22 88 77 00
Fax: 22 64 54 54
info@weber-norge.no
www.weber-norge.no

ANNEX 12



FOSS

Application Note 5201

According to ISO 13395-1996

Rev 2

Determination of the sum of nitrate and nitrite in water by FIAstar 5000

1. Scope and field of application

This Application Note describes a method for determination of the sum of nitrate and nitrite in various types of waters (such as ground, drinking, surface and wastewater) in the following concentration ranges:

0.005-0.25 mg/l NO_3-N(400 µl loop), linear calibration

0.1-5 mg/l NO_3-N (40 µl loop), linear calibration*

* The range may be extended up to 10 mg/l by reducing the injection loop volume to 20uL, see Appendix 1.

2. Principle of the method

The sample containing Nitrite/Nitrate is mixed with a buffer solution. Nitrate in the sample is reduced to Nitrite in a cadmium reductor. On the addition of an acidic Sulphanilamide solution, Nitrite initially present and Nitrite formed from reduction of Nitrate will form a diazo compound. This compound is coupled with N-(1-naphtyl)-Ethylene Diamine Dihydrochloride (NED) to form a purple azo dye. This azo dye is measured at 540 nm.

Violett N=N Farge

3. Reagents

Before using any chemicals refer to adequate manuals or safety data sheets approved by your local authorities. If not stated otherwise, only reagents of recognized analytical grade and water according to grade 1 of ISO 3696 shall be used.

3.1 Sulphanilamide (4-aminobenzenesulfonamide), $C_6H_8N_2O_2S$

3.2 N-(1-naphtyl)-Ethylene Diamine Dihydrochloride , $C_{12}H_{14}N_2$ x 2 HCl

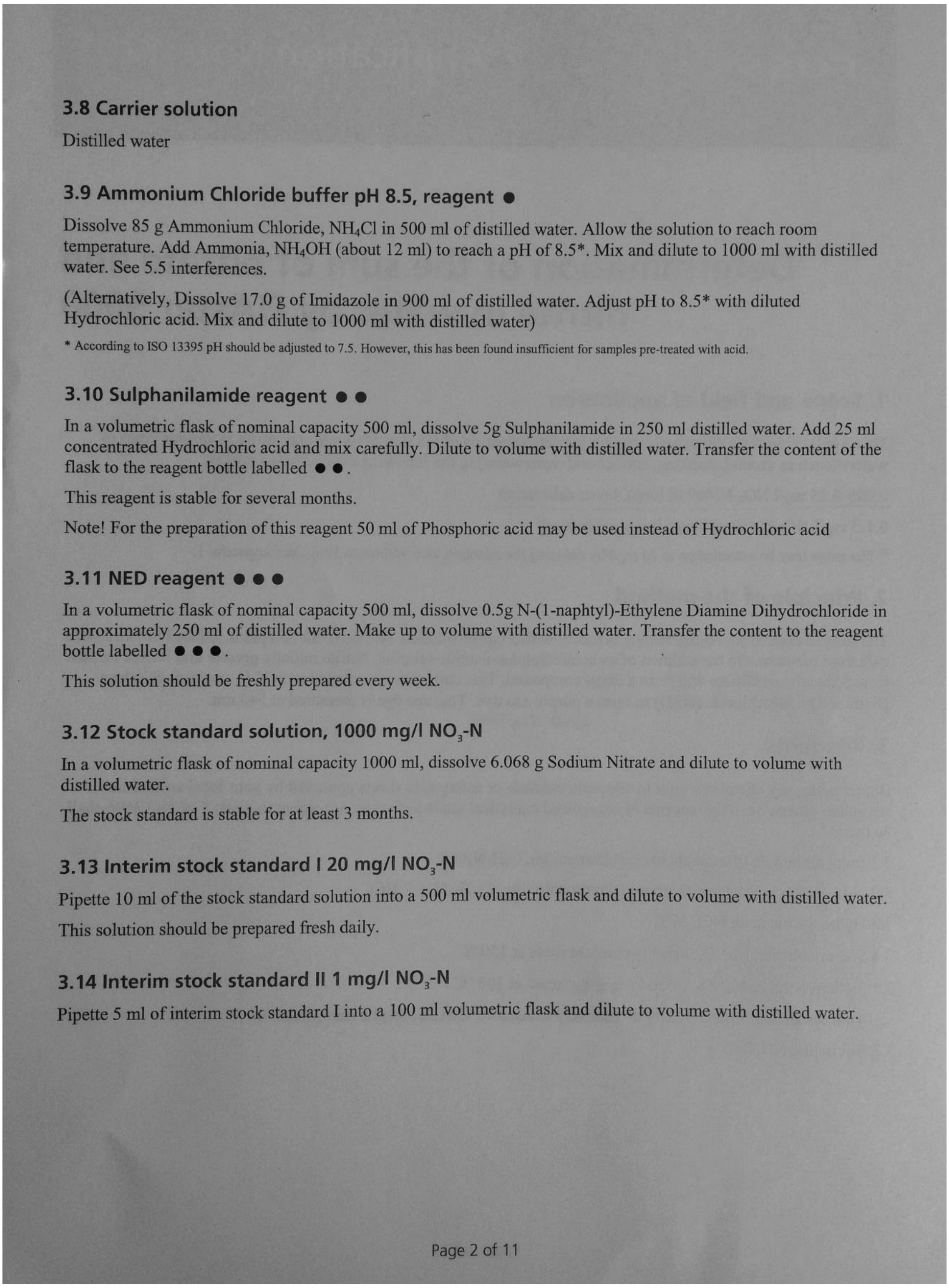
3.3 Hydrochloric acid; HCl, 37%

3.4 Sodium Nitrite, $NaNO_2$, dried to constant mass at 150 °C

3.5 Sodium Nitrate, $NaNO_3$, dried to constant mass at 105 °C

3.6 Ammonium Chloride, NH_4Cl (alternatively Imidazole, $C_3H_4N_2$, can be used, see 3.9)

3.7 Ammonia, NH_4OH



3.8 Carrier solution

Distilled water

3.9 Ammonium Chloride buffer pH 8.5, reagent ●

Dissolve 85 g Ammonium Chloride, NH_4Cl in 500 ml of distilled water. Allow the solution to reach room temperature. Add Ammonia, NH_4OH (about 12 ml) to reach a pH of 8.5*. Mix and dilute to 1000 ml with distilled water. See 5.5 interferences.

(Alternatively, Dissolve 17.0 g of Imidazole in 900 ml of distilled water. Adjust pH to 8.5* with diluted Hydrochloric acid. Mix and dilute to 1000 ml with distilled water)

* According to ISO 13395 pH should be adjusted to 7.5. However, this has been found insufficient for samples pre-treated with acid.

3.10 Sulphanilamide reagent ● ●

In a volumetric flask of nominal capacity 500 ml, dissolve 5g Sulphanilamide in 250 ml distilled water. Add 25 ml concentrated Hydrochloric acid and mix carefully. Dilute to volume with distilled water. Transfer the content of the flask to the reagent bottle labelled ● ●.

This reagent is stable for several months.

Note! For the preparation of this reagent 50 ml of Phosphoric acid may be used instead of Hydrochloric acid

3.11 NED reagent ● ● ●

In a volumetric flask of nominal capacity 500 ml, dissolve 0.5g N-(1-naphtyl)-Ethylene Diamine Dihydrochloride in approximately 250 ml of distilled water. Make up to volume with distilled water. Transfer the content to the reagent bottle labelled ● ● ●.

This solution should be freshly prepared every week.

3.12 Stock standard solution, 1000 mg/l NO_3-N

In a volumetric flask of nominal capacity 1000 ml, dissolve 6.068 g Sodium Nitrate and dilute to volume with distilled water.

The stock standard is stable for at least 3 months.

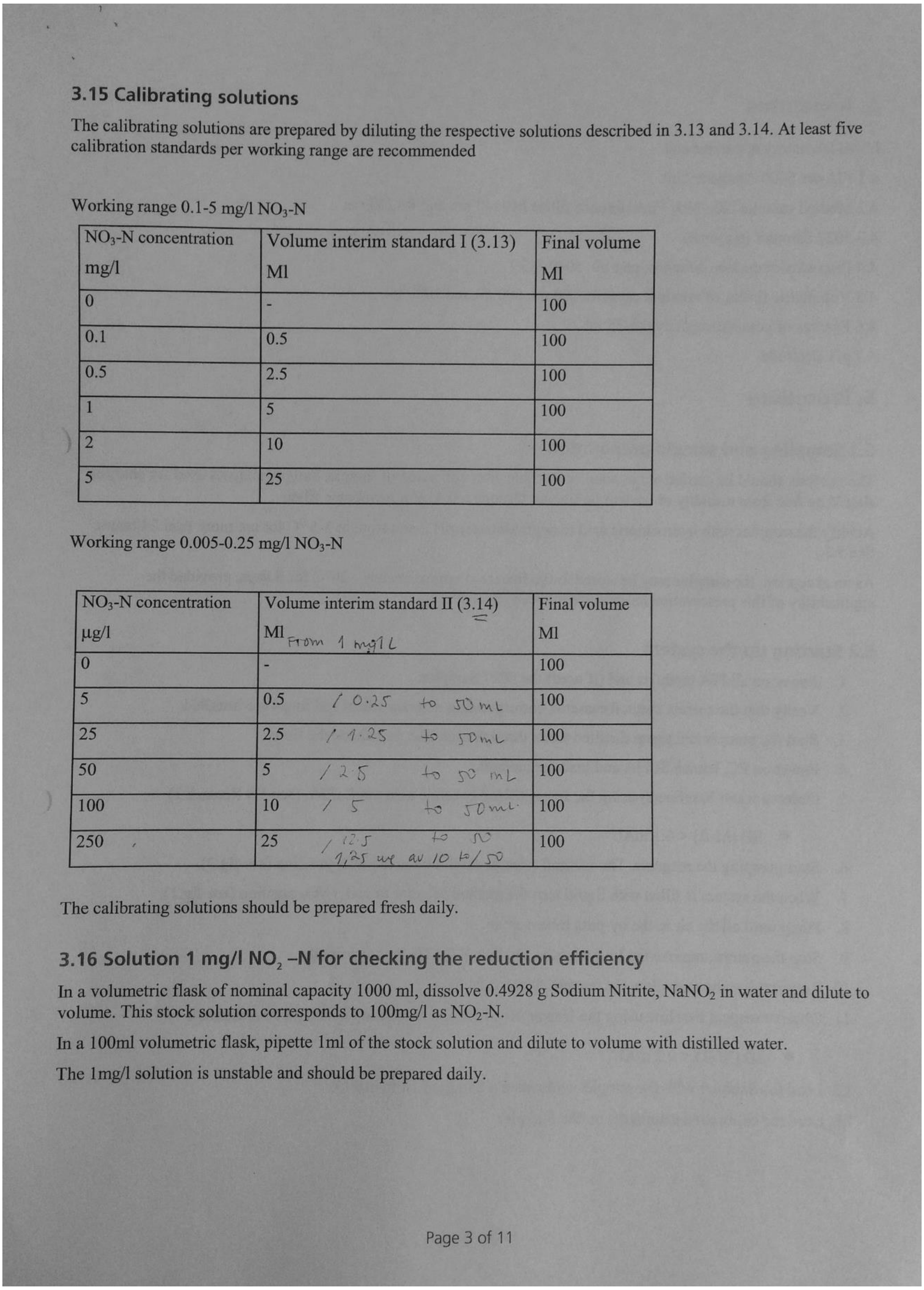
3.13 Interim stock standard I 20 mg/l NO_3-N

Pipette 10 ml of the stock standard solution into a 500 ml volumetric flask and dilute to volume with distilled water.

This solution should be prepared fresh daily.

3.14 Interim stock standard II 1 mg/l NO_3-N

Pipette 5 ml of interim stock standard I into a 100 ml volumetric flask and dilute to volume with distilled water.



3.15 Calibrating solutions

The calibrating solutions are prepared by diluting the respective solutions described in 3.13 and 3.14. At least five calibration standards per working range are recommended

Working range 0.1-5 mg/l NO_3-N

NO_3-N concentration mg/l	Volume interim standard I (3.13) Ml	Final volume Ml
0	-	100
0.1	0.5	100
0.5	2.5	100
1	5	100
2	10	100
5	25	100

Working range 0.005-0.25 mg/l NO_3-N

NO_3-N concentration µg/l	Volume interim standard II (3.14) Ml From 1 mg/L	Final volume Ml
0	-	100
5	0.5 / 0.25 to 50 mL	100
25	2.5 / 1.25 to 50 mL	100
50	5 / 2.5 to 50 mL	100
100	10 / 5 to 50 mL.	100
250	25 / 12.5 to 50 1,25 we av 10 to/50	100

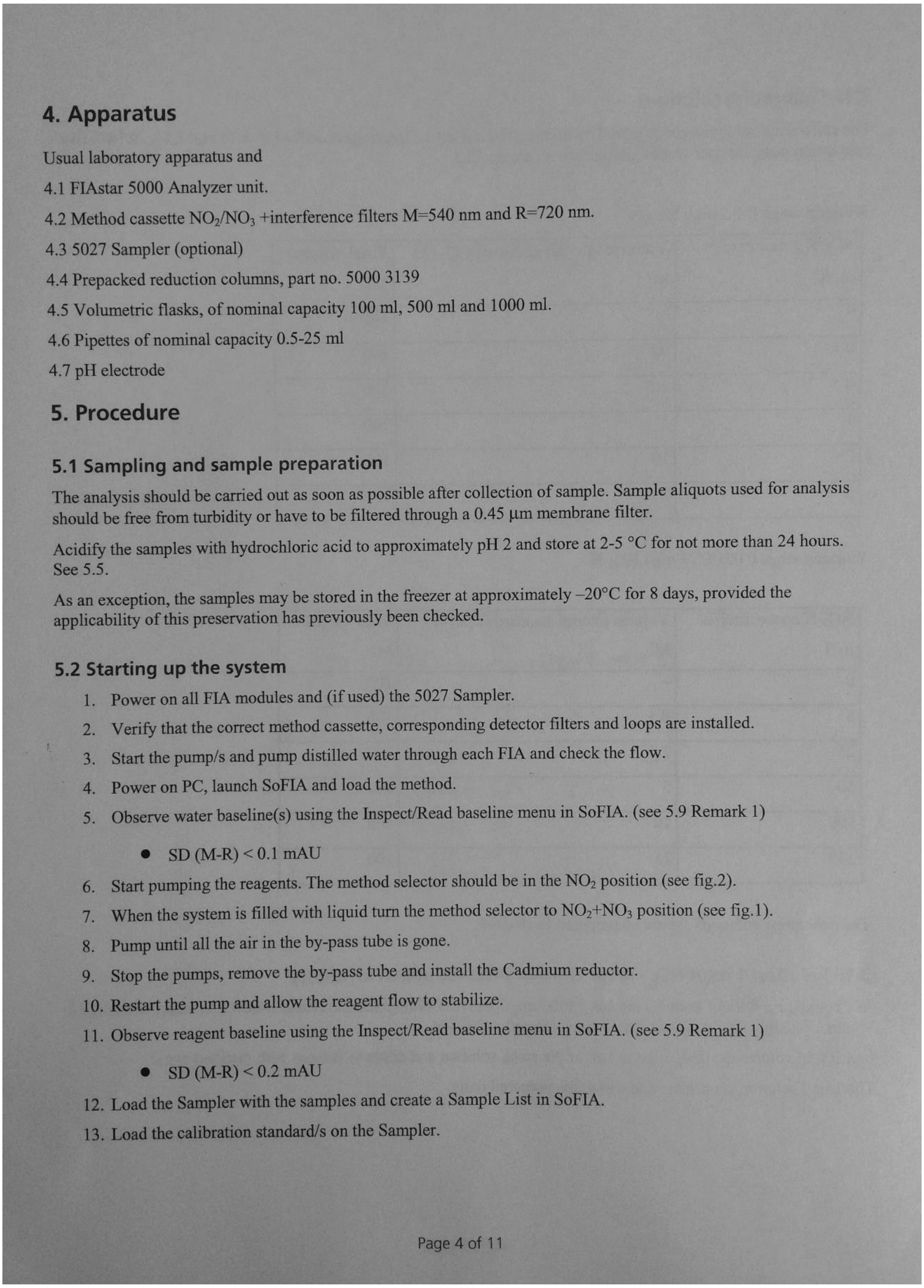
The calibrating solutions should be prepared fresh daily.

3.16 Solution 1 mg/l NO_2 –N for checking the reduction efficiency

In a volumetric flask of nominal capacity 1000 ml, dissolve 0.4928 g Sodium Nitrite, $NaNO_2$ in water and dilute to volume. This stock solution corresponds to 100mg/l as NO_2-N.

In a 100ml volumetric flask, pipette 1ml of the stock solution and dilute to volume with distilled water.

The 1mg/l solution is unstable and should be prepared daily.



4. Apparatus

Usual laboratory apparatus and

4.1 FIAstar 5000 Analyzer unit.

4.2 Method cassette NO_2/NO_3 +interference filters M=540 nm and R=720 nm.

4.3 5027 Sampler (optional)

4.4 Prepacked reduction columns, part no. 5000 3139

4.5 Volumetric flasks, of nominal capacity 100 ml, 500 ml and 1000 ml.

4.6 Pipettes of nominal capacity 0.5-25 ml

4.7 pH electrode

5. Procedure

5.1 Sampling and sample preparation

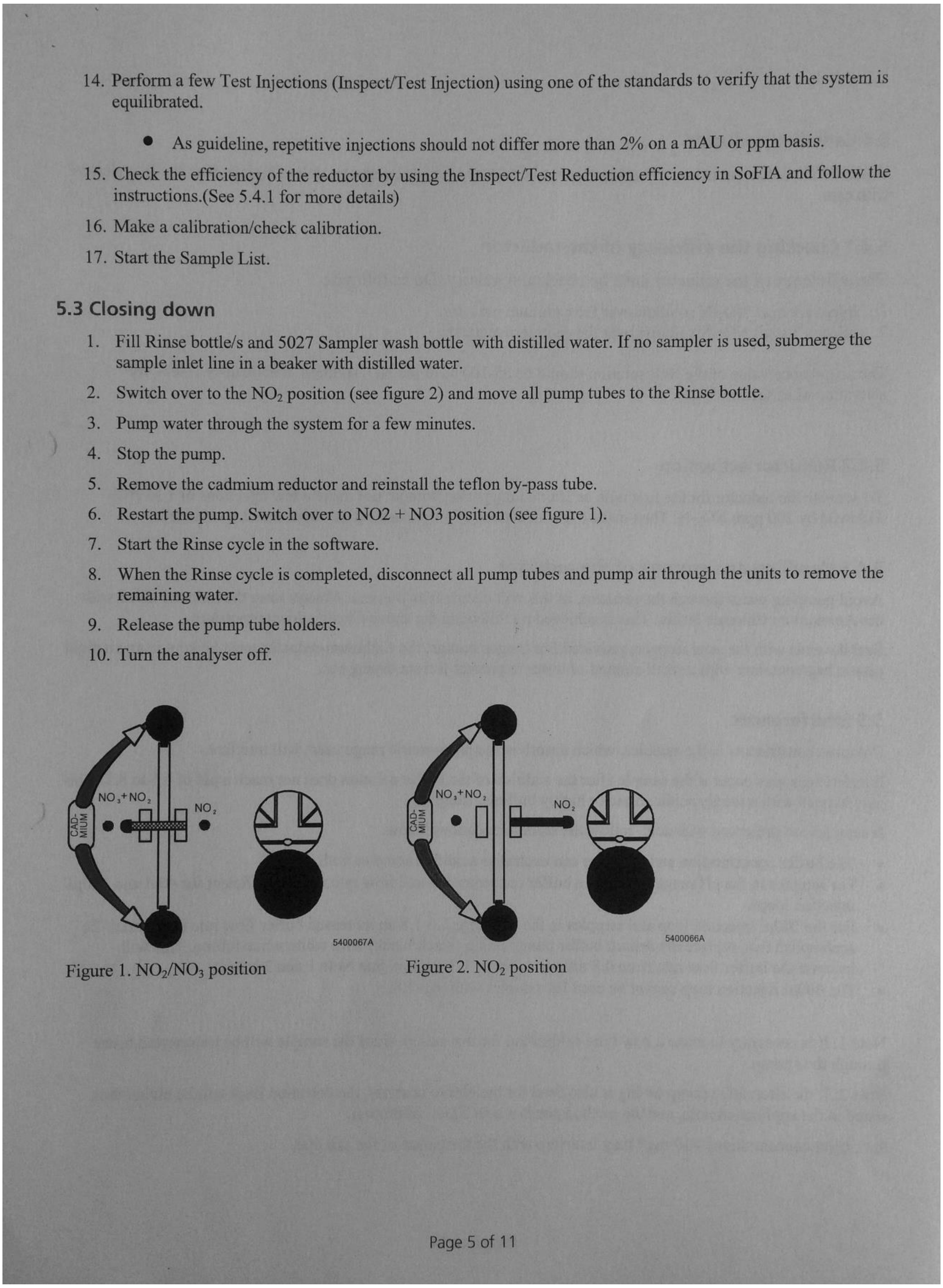
The analysis should be carried out as soon as possible after collection of sample. Sample aliquots used for analysis should be free from turbidity or have to be filtered through a 0.45 µm membrane filter.

Acidify the samples with hydrochloric acid to approximately pH 2 and store at 2-5 °C for not more than 24 hours. See 5.5.

As an exception, the samples may be stored in the freezer at approximately –20°C for 8 days, provided the applicability of this preservation has previously been checked.

5.2 Starting up the system

1. Power on all FIA modules and (if used) the 5027 Sampler.
2. Verify that the correct method cassette, corresponding detector filters and loops are installed.
3. Start the pump/s and pump distilled water through each FIA and check the flow.
4. Power on PC, launch SoFIA and load the method.
5. Observe water baseline(s) using the Inspect/Read baseline menu in SoFIA. (see 5.9 Remark 1)
    - SD (M-R) < 0.1 mAU
6. Start pumping the reagents. The method selector should be in the NO_2 position (see fig.2).
7. When the system is filled with liquid turn the method selector to NO_2+NO_3 position (see fig.1).
8. Pump until all the air in the by-pass tube is gone.
9. Stop the pumps, remove the by-pass tube and install the Cadmium reductor.
10. Restart the pump and allow the reagent flow to stabilize.
11. Observe reagent baseline using the Inspect/Read baseline menu in SoFIA. (see 5.9 Remark 1)
    - SD (M-R) < 0.2 mAU
12. Load the Sampler with the samples and create a Sample List in SoFIA.
13. Load the calibration standard/s on the Sampler.



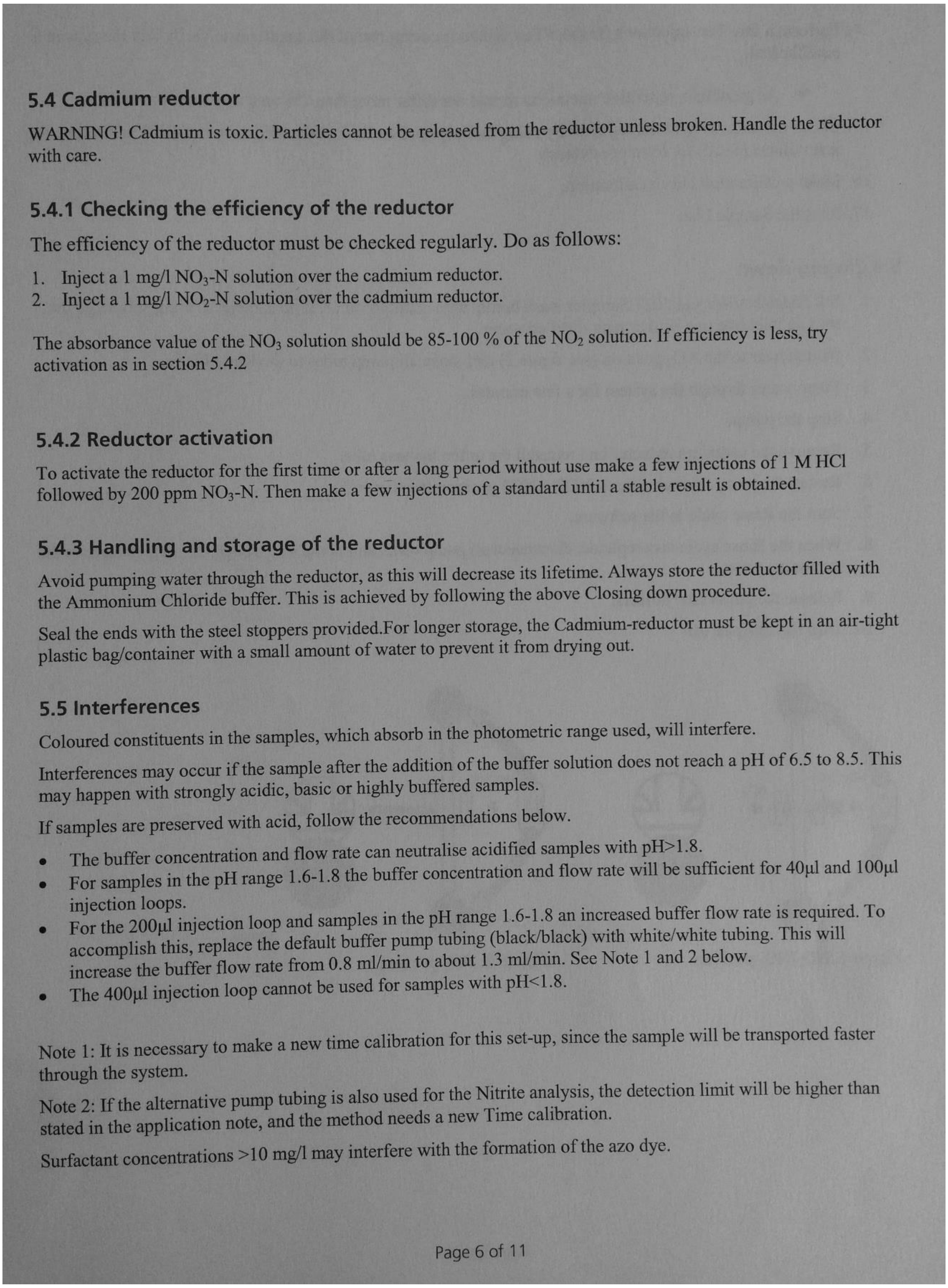
14. Perform a few Test Injections (Inspect/Test Injection) using one of the standards to verify that the system is equilibrated.
    - As guideline, repetitive injections should not differ more than 2% on a mAU or ppm basis.
15. Check the efficiency of the reductor by using the Inspect/Test Reduction efficiency in SoFIA and follow the instructions.(See 5.4.1 for more details)
16. Make a calibration/check calibration.
17. Start the Sample List.

5.3 Closing down

1. Fill Rinse bottle/s and 5027 Sampler wash bottle with distilled water. If no sampler is used, submerge the sample inlet line in a beaker with distilled water.
2. Switch over to the NO_2 position (see figure 2) and move all pump tubes to the Rinse bottle.
3. Pump water through the system for a few minutes.
4. Stop the pump.
5. Remove the cadmium reductor and reinstall the teflon by-pass tube.
6. Restart the pump. Switch over to NO2 + NO3 position (see figure 1).
7. Start the Rinse cycle in the software.
8. When the Rinse cycle is completed, disconnect all pump tubes and pump air through the units to remove the remaining water.
9. Release the pump tube holders.
10. Turn the analyser off.

Figure 1. NO_2/NO_3 position

Figure 2. NO_2 position



5.4 Cadmium reductor

WARNING! Cadmium is toxic. Particles cannot be released from the reductor unless broken. Handle the reductor with care.

5.4.1 Checking the efficiency of the reductor

The efficiency of the reductor must be checked regularly. Do as follows:

1. Inject a 1 mg/l NO_3-N solution over the cadmium reductor.
2. Inject a 1 mg/l NO_2-N solution over the cadmium reductor.

The absorbance value of the NO_3 solution should be 85-100 % of the NO_2 solution. If efficiency is less, try activation as in section 5.4.2

5.4.2 Reductor activation

To activate the reductor for the first time or after a long period without use make a few injections of 1 M HCl followed by 200 ppm NO_3-N. Then make a few injections of a standard until a stable result is obtained.

5.4.3 Handling and storage of the reductor

Avoid pumping water through the reductor, as this will decrease its lifetime. Always store the reductor filled with the Ammonium Chloride buffer. This is achieved by following the above Closing down procedure.

Seal the ends with the steel stoppers provided.For longer storage, the Cadmium-reductor must be kept in an air-tight plastic bag/container with a small amount of water to prevent it from drying out.

5.5 Interferences

Coloured constituents in the samples, which absorb in the photometric range used, will interfere.

Interferences may occur if the sample after the addition of the buffer solution does not reach a pH of 6.5 to 8.5. This may happen with strongly acidic, basic or highly buffered samples.

If samples are preserved with acid, follow the recommendations below.

- The buffer concentration and flow rate can neutralise acidified samples with pH>1.8.
- For samples in the pH range 1.6-1.8 the buffer concentration and flow rate will be sufficient for 40µl and 100µl injection loops.
- For the 200µl injection loop and samples in the pH range 1.6-1.8 an increased buffer flow rate is required. To accomplish this, replace the default buffer pump tubing (black/black) with white/white tubing. This will increase the buffer flow rate from 0.8 ml/min to about 1.3 ml/min. See Note 1 and 2 below.
- The 400µl injection loop cannot be used for samples with pH<1.8.

Note 1: It is necessary to make a new time calibration for this set-up, since the sample will be transported faster through the system.

Note 2: If the alternative pump tubing is also used for the Nitrite analysis, the detection limit will be higher than stated in the application note, and the method needs a new Time calibration.

Surfactant concentrations >10 mg/l may interfere with the formation of the azo dye.

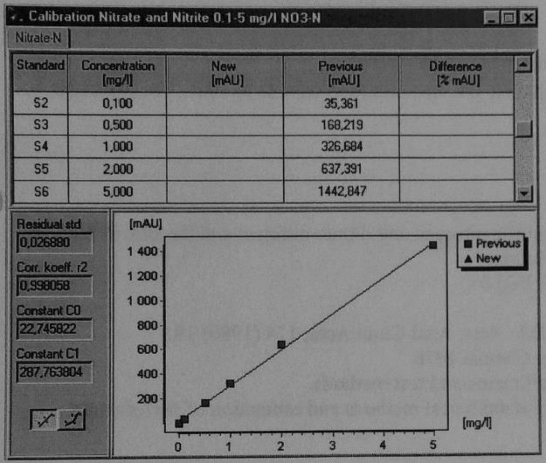
5.6 Analysis of the sum of nitrite/nitrate in seawater

Seawater can be analysed with this method if the carrier and standards are adapted to the salinity of the samples. There will be changes in sensitivity.

5.7 Results

Typical calibration data

Range 0.1-5 mg/l



Calibration Nitrate and Nitrite 0.1-5 mg/l NO3-N

Nitrate-N

Standard	Concentration [mg/l]	New [mAU]	Previous [mAU]	Difference [% mAU]
S2	0,100		35,361	
S3	0,500		168,219	
S4	1,000		326,684	
S5	2,000		637,391	
S6	5,000		1442,847	

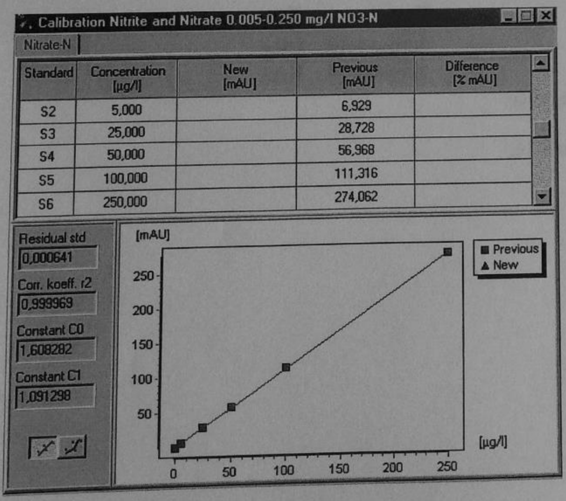
Residual std: 0,026880

Corr. koeff. r2: 0,998058

Constant C0: 22,745822

Constant C1: 287,763804

Range 0.005-0.25 mg/l



Calibration Nitrite and Nitrate 0.005-0.250 mg/l NO3-N

Nitrate-N

Standard	Concentration [µg/l]	New [mAU]	Previous [mAU]	Difference [% mAU]
S2	5,000		6,929	
S3	25,000		28,728	
S4	50,000		56,968	
S5	100,000		111,316	
S6	250,000		274,062	

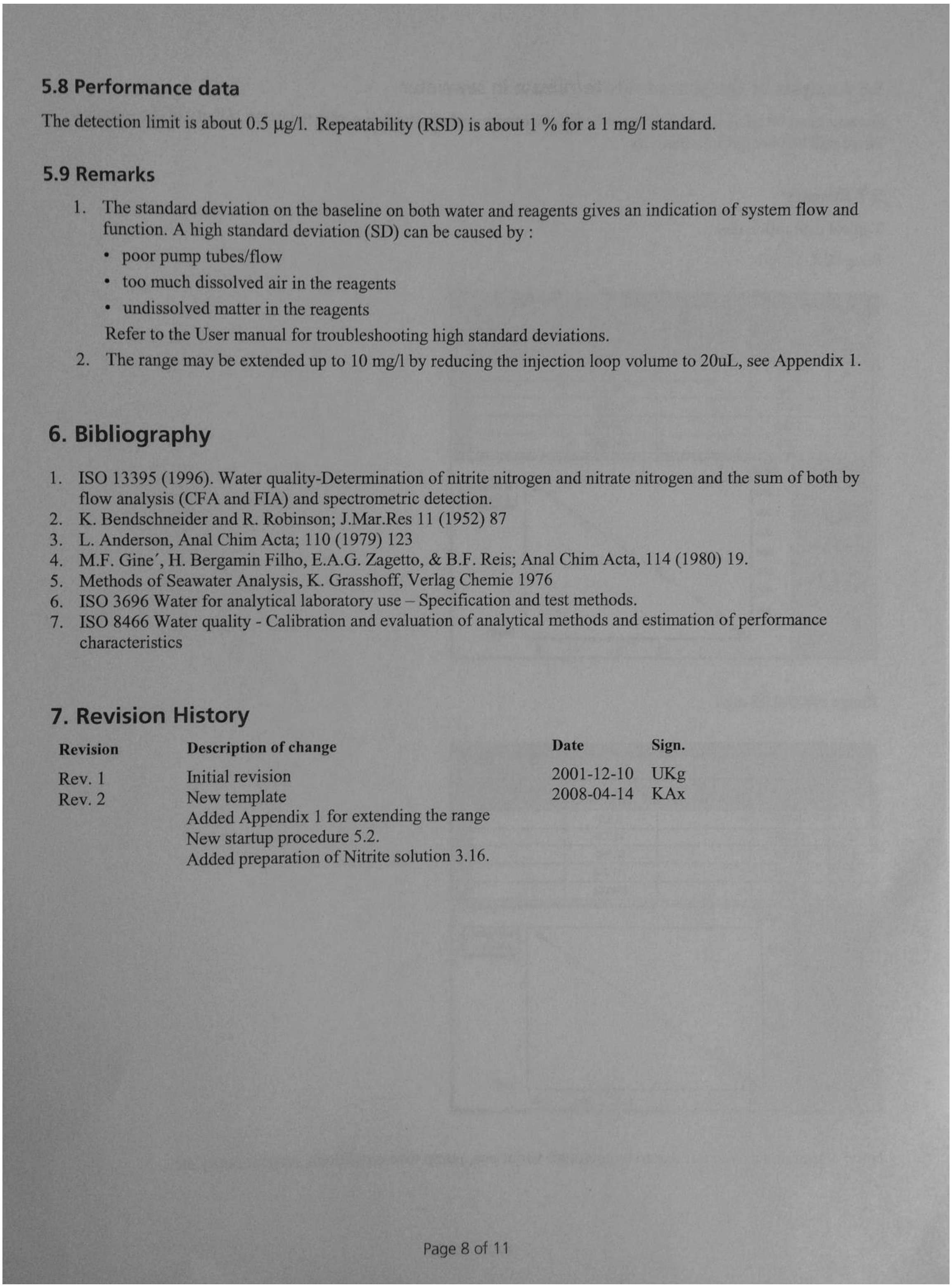
Residual std: 0,000641

Corr. koeff. r2: 0,999969

Constant C0: 1,608282

Constant C1: 1,091298

Note! Variations may occur due to temperature variations, pump tube conditions, reagent purity etc.



5.8 Performance data

The detection limit is about 0.5 µg/l. Repeatability (RSD) is about 1 % for a 1 mg/l standard.

5.9 Remarks

1. The standard deviation on the baseline on both water and reagents gives an indication of system flow and function. A high standard deviation (SD) can be caused by :
    - poor pump tubes/flow
    - too much dissolved air in the reagents
    - undissolved matter in the reagents

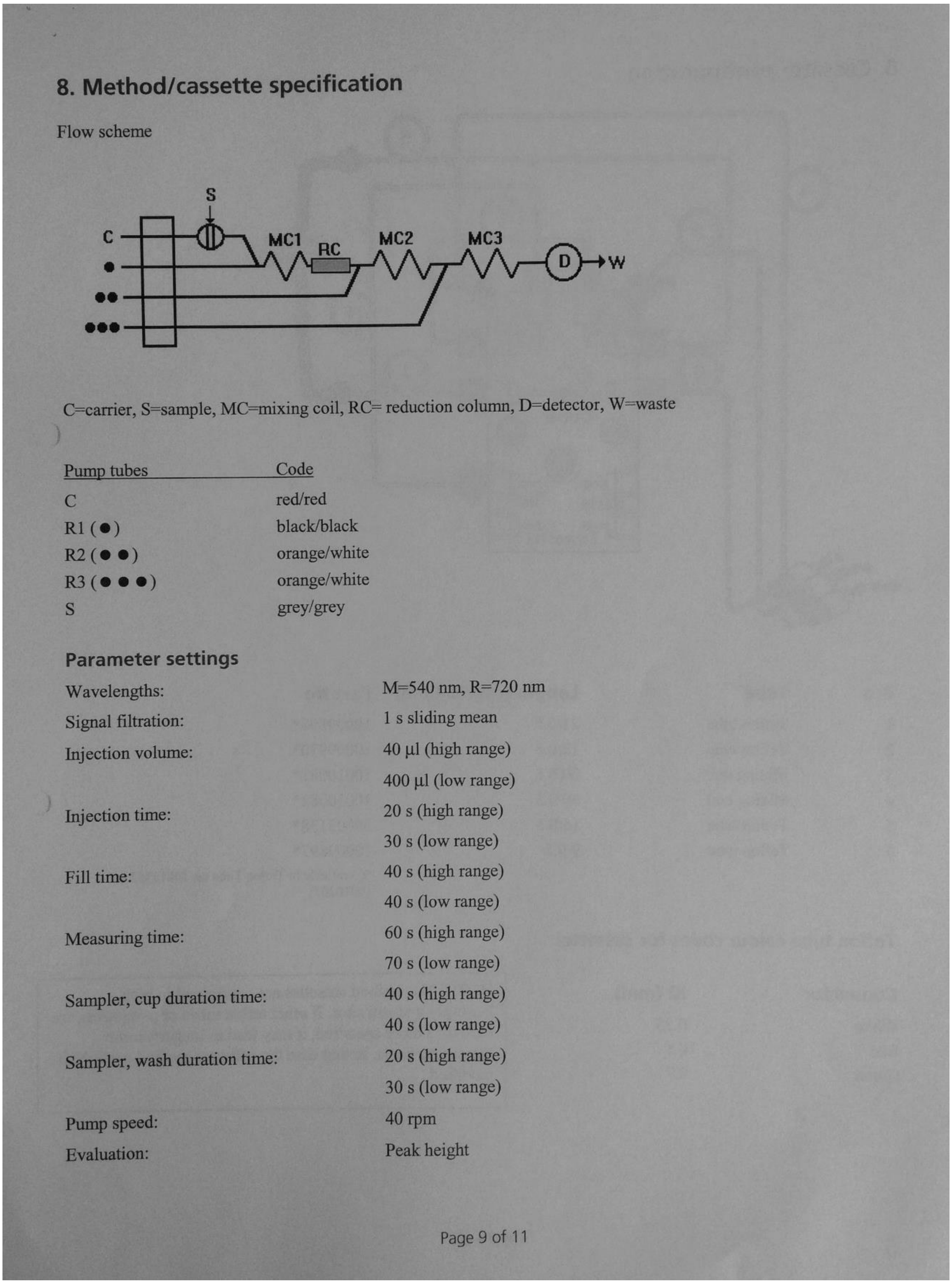
    Refer to the User manual for troubleshooting high standard deviations.
2. The range may be extended up to 10 mg/l by reducing the injection loop volume to 20uL, see Appendix 1.

6. Bibliography

1. ISO 13395 (1996). Water quality-Determination of nitrite nitrogen and nitrate nitrogen and the sum of both by flow analysis (CFA and FIA) and spectrometric detection.
2. K. Bendschneider and R. Robinson; J.Mar.Res 11 (1952) 87
3. L. Anderson, Anal Chim Acta; 110 (1979) 123
4. M.F. Gine´, H. Bergamin Filho, E.A.G. Zagetto, & B.F. Reis; Anal Chim Acta, 114 (1980) 19.
5. Methods of Seawater Analysis, K. Grasshoff, Verlag Chemie 1976
6. ISO 3696 Water for analytical laboratory use – Specification and test methods.
7. ISO 8466 Water quality - Calibration and evaluation of analytical methods and estimation of performance characteristics

7. Revision History

Revision	Description of change	Date	Sign.
Rev. 1	Initial revision	2001-12-10	UKg
Rev. 2	New template Added Appendix 1 for extending the range New startup procedure 5.2. Added preparation of Nitrite solution 3.16.	2008-04-14	KAx



8. Method/cassette specification

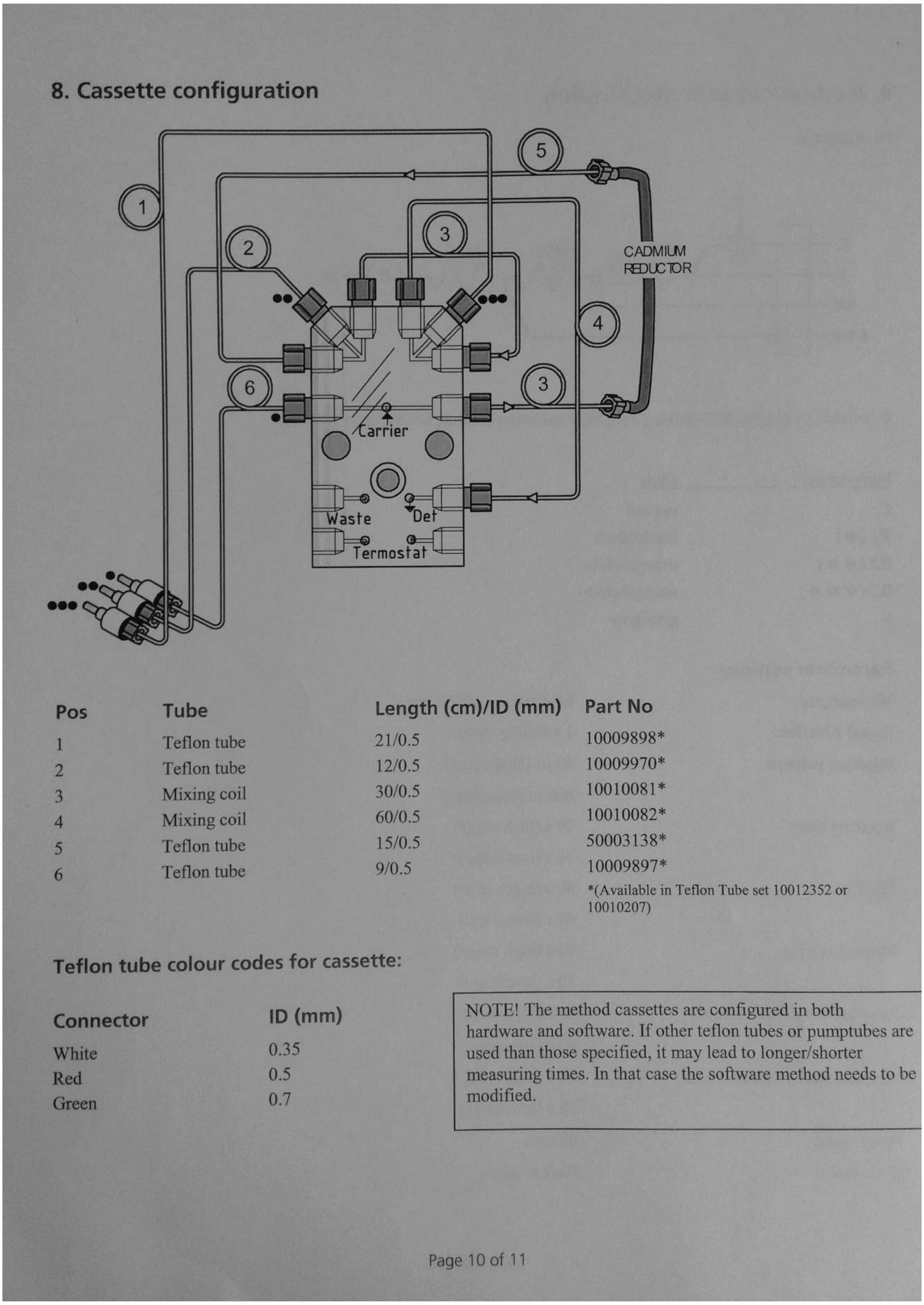
Flow scheme

C=carrier, S=sample, MC=mixing coil, RC= reduction column, D=detector, W=waste

Pump tubes	Code
C	red/red
R1 (●)	black/black
R2 (● ●)	orange/white
R3 (● ● ●)	orange/white
S	grey/grey

Parameter settings

Wavelengths:	M=540 nm, R=720 nm
Signal filtration:	1 s sliding mean
Injection volume:	40 µl (high range) 400 µl (low range)
Injection time:	20 s (high range) 30 s (low range)
Fill time:	40 s (high range) 40 s (low range)
Measuring time:	60 s (high range) 70 s (low range)
Sampler, cup duration time:	40 s (high range) 40 s (low range)
Sampler, wash duration time:	20 s (high range) 30 s (low range)
Pump speed:	40 rpm
Evaluation:	Peak height



8. Cassette configuration

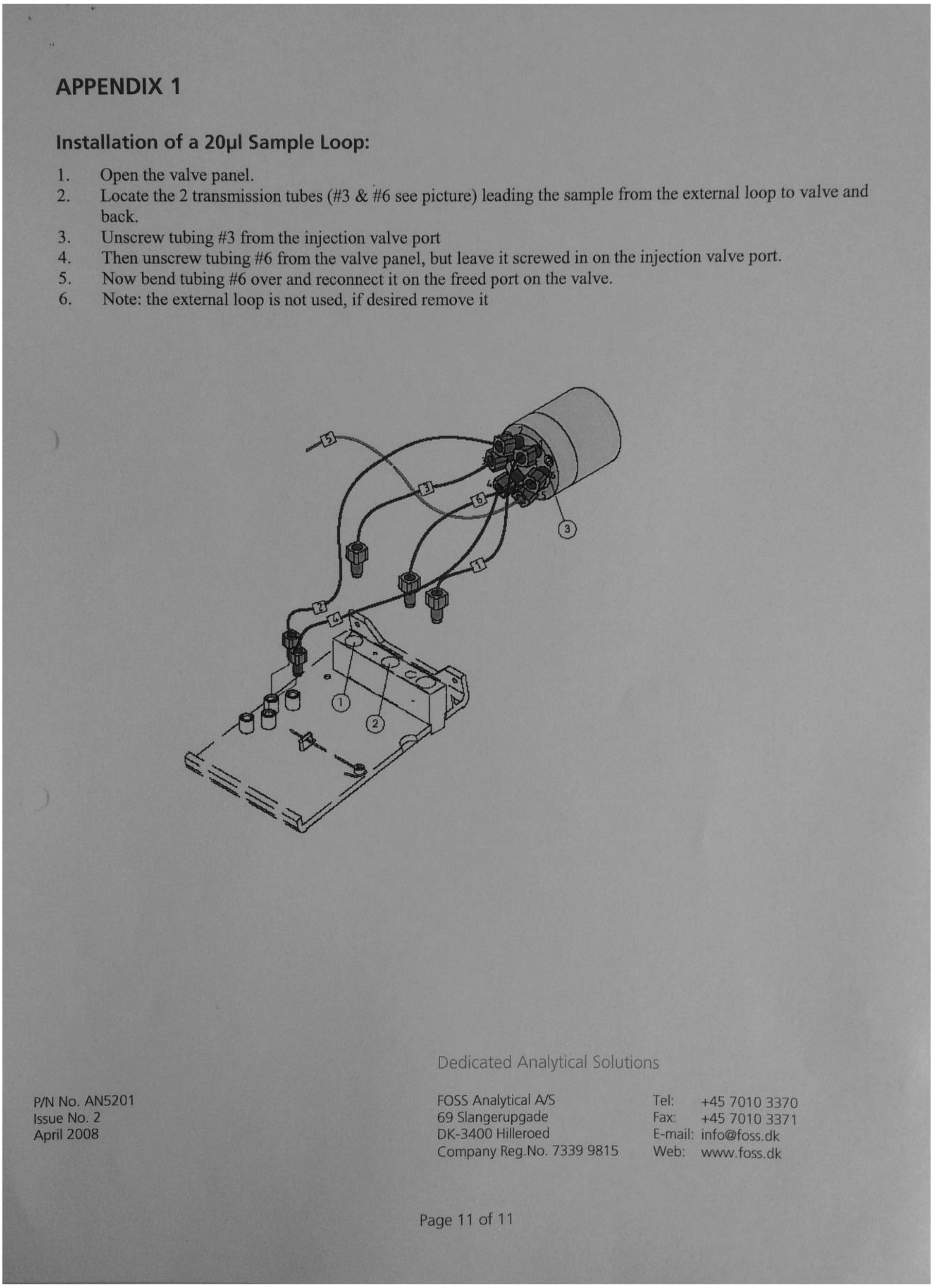
Pos	Tube	Length (cm)/ID (mm)	Part No
1	Teflon tube	21/0.5	10009898*
2	Teflon tube	12/0.5	10009970*
3	Mixing coil	30/0.5	10010081*
4	Mixing coil	60/0.5	10010082*
5	Teflon tube	15/0.5	50003138*
6	Teflon tube	9/0.5	10009897*

*(Available in Teflon Tube set 10012352 or 10010207)

Teflon tube colour codes for cassette:

Connector	ID (mm)
White	0.35
Red	0.5
Green	0.7

NOTE! The method cassettes are configured in both hardware and software. If other teflon tubes or pumptubes are used than those specified, it may lead to longer/shorter measuring times. In that case the software method needs to be modified.



APPENDIX 1

Installation of a 20µl Sample Loop:

1. Open the valve panel.
2. Locate the 2 transmission tubes (#3 & #6 see picture) leading the sample from the external loop to valve and back.
3. Unscrew tubing #3 from the injection valve port
4. Then unscrew tubing #6 from the valve panel, but leave it screwed in on the injection valve port.
5. Now bend tubing #6 over and reconnect it on the freed port on the valve.
6. Note: the external loop is not used, if desired remove it

Dedicated Analytical Solutions

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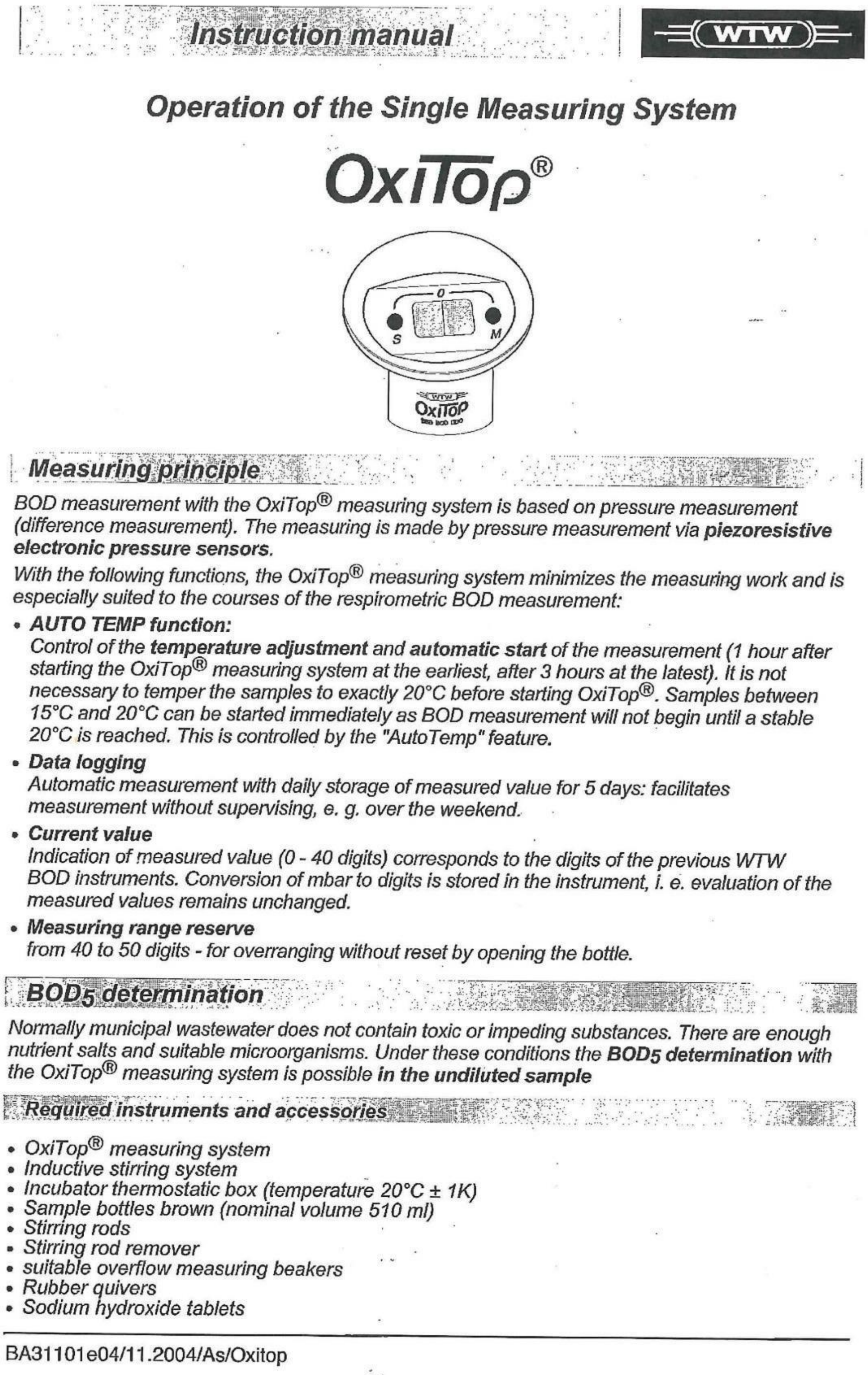
ANNEX 12



Instruction manual WTW

Operation of the Single Measuring System

OxiTop®

Measuring principle

BOD measurement with the OxiTop® measuring system is based on pressure measurement (difference measurement). The measuring is made by pressure measurement via ***piezoresistive electronic pressure sensors.***

With the following functions, the OxiTop® measuring system minimizes the measuring work and is especially suited to the courses of the respirometric BOD measurement:

- ***AUTO TEMP function:***
  Control of the ***temperature adjustment*** *and* ***automatic start*** *of the measurement (1 hour after starting the OxiTop® measuring system at the earliest, after 3 hours at the latest). It is not necessary to temper the samples to exactly 20°C before starting OxiTop®. Samples between 15°C and 20°C can be started immediately as BOD measurement will not begin until a stable 20°C is reached. This is controlled by the "AutoTemp" feature.*
- ***Data logging***
  Automatic measurement with daily storage of measured value for 5 days: facilitates measurement without supervising, e. g. over the weekend.
- ***Current value***
  Indication of measured value (0 - 40 digits) corresponds to the digits of the previous WTW BOD instruments. Conversion of mbar to digits is stored in the instrument, i. e. evaluation of the measured values remains unchanged.
- ***Measuring range reserve***
  from 40 to 50 digits - for overranging without reset by opening the bottle.

BOD$_5$ determination

Normally municipal wastewater does not contain toxic or impeding substances. There are enough nutrient salts and suitable microorganisms. Under these conditions the ***BOD$_5$ determination*** *with the OxiTop® measuring system is possible* ***in the undiluted sample***

Required instruments and accessories

- *OxiTop® measuring system*
- *Inductive stirring system*
- *Incubator thermostatic box (temperature 20°C ± 1K)*
- *Sample bottles brown (nominal volume 510 ml)*
- *Stirring rods*
- *Stirring rod remover*
- *suitable overflow measuring beakers*
- *Rubber quivers*
- *Sodium hydroxide tablets*

BA31101e04/11.2004/As/Oxitop

Selection of sample volume

Estimate the BOD5 value to be expected for the wastewater sample:
Expected BOD5 value • 80 % of the COD value
Look for corresponding measuring range in the following chart and gather correct values for sample volume and factor.

Sample volume (ml)	*Measuring range (mg/l)*	*Factor*
432	*0 - 40*	*1*
365	*0 - 80*	*2*
250	*0 - 200*	*5*
164	*0 - 400*	*10*
97	*0 - 800*	*20*
43.5	*0 - 2000*	*50*

Sample preparation

See following WTW application reports:

- WTW *Application report 895230: "BOD measurement in household wastewater"*
- WTW *Application report 895231: "BOD measurement in organically heavily contaminated wastewater"*
- WTW *Application report 895232: "BOD measurement with presence of impeding or toxic substances"*

Measurement

Information: *To measure the sample volume, usually overflow measuring beakers or measuring cylinders are used.*
Chose the volume according to the measured value expected. Too large measuring ranges will lead to inaccurate results. To estimate the measured value you can reckon with approx. 80% of the CBS value.

- ***Sample preparation and filling of the measuring bottles*** *compare following instruction: DIN 38409 part 52: "Measurement of the oxygen consumption" as well as WTW applications-reports see chapter "Sample preparation and measurement".*
- ***Rinse*** *measuring bottle with* ***sample****. Empty thoroughly.*
- ***Exactly measure*** *the required oxygen-saturated (thoroughly homogenized)* ***quantity of the sample*** *according to information.*
- *Put the* ***magnetic stirring rod*** *into the bottle.*
- *Insert a* ***rubber quiver*** *in the neck of the bottle.*
- *Put* ***2 sodium hydroxide tablets*** *into the rubber quiver with a tweezers. (Caution: The tablets must never come into the sample!)*
- *Screw OxiTop® directly on sample bottle (tightly close).*

● + ●
S M

Start measurement:
Press S and M simutaneously. (2 seconds) untill the display shows 00.

-- 2 sec ⇨ 00

Display: Stored values are deleted.

- *Keep the measuring bottle with the OxiTop put on* ***for 5 days at 20°C*** *(e.g. in an incubator).*

After the meas. temperature has been reached (after 1 hour at the earliest, after 3 hours at the latest; ***AutoTemp function****), the OxiTop automatically starts the measurement of the oxygen consumption .*

- *During the 5 days the sample is continuously stirred. The OxiTop* ***automatically stores one value every 24 hours*** *for 5 days. To have the current value shown press the M key.*

●
M

Display current measured value:
Press M until measured value is displayed (1 second).

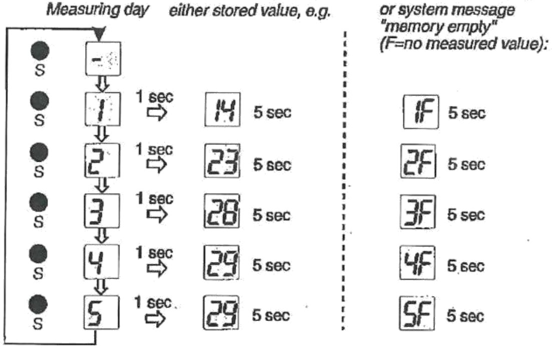
38 ***e.g.***

氢 NaOH + CO_2 → $NaHCO_3$ [illegible]

- ***Readout of the stored values** after the 5 days have passed.*

S

<u>Recall stored values:</u>
Press S until measured value is displayed (1 second).
Scroll to next day by repressing the S key while the measured value is displayed (5 sec). Fast scrolling by repeatedly pressing the S key.



- *Convert the displayed measured value (digits) into the BOD value with the following table (Digits x Factor = BOD5 in mg/l):*

Sample volume (ml)	*Measuring range (mg/l)*	***Factor***
432	*0 - 40*	***1***
365	*0 - 80*	***2***
250	*0 - 200*	***5***
164	*0 - 400*	***10***
97	*0 - 800*	***20***
43.5	*0 - 2000*	***50***

Disturbances

- ***Measured value remains below measuring range: the display shows zero or too low a value.***
  The measuring equipment is not water-tight.
  Check rubber quiver, screw top and bottle. Insufficient sample pretreatment or preservation.
  The temperature of the sample had not sufficiently been adjusted (< 15°C).
- ***Measuring range exceeded.***
  The measuring range chosen is too small. With very high values (> 2000 mg/l) we recommend to predilute the sample.
  Nitrification inhibitor (allylthiourea) is missing or lacking.

Errors due to procedure have not been mentioned.

System messages

1F	*Memory empty* *(1F= measured value of day 1 is missing)*	-- _	*Value remains below measuring range < 0 Digit*
LO	*Change batteries* *(approx. every 3 years)*	‾ --	*Value exceeds measuring range > 50 Digit*

Cleaning of sample bottles

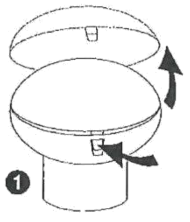
- ***Do not use disinfectants!** (Disinfectants will kill the required microorganisms!)*
- *Remove **gross contaminations** mechanically, e.g. with a **brush.***
- *Rinse the bottles with **clear water** or with **water of the next sample.**(After using detergents rinse thoroughly! Detergent residues may disturb the BOD5 determination!)*

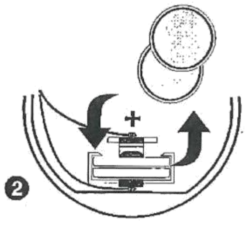
Maintenance

Cleaning of the OxiTop® Single Measuring System

- ***Do not use alcohol or acetone!***
- *Clean with a soft cloth and aqueous soap solution*

Battery replacement (approx. every 3 years)





❶ - *Push in spring catch.*
- *Open upper lid.*

❷ - *Remove batteries.*
- *Put in new batteries, pay attention to polarity! (e.g. WTW-Modell* ***Batt/Oxitop®****, Order No. 209 012).*
- *Place upper lid with tap on locking pin (lower lid). Attention! Do not squeeze cable connection.*
- *Close upper lid (make the hook click).*

Disposal note: *Please dispose of the lithium batteries at a battery collection point.*

Information

Never use sealing grease or other lubricants *for your OxiTop® instruments. Some of these products contain solvents which cause severe damages on the plastic housings. The tightness of the BOD bottles is completely sufficient without grease. Rough contaminations and particles on the contact surfaces of the rubber quiver annd the OxiTop® must always be wiped off. WTW grants no guarantee for damages caused by sealing grease.*

Labelling:
To label the bottles clearly, WTW offers a marking set (6 marking rings with numbers, which can be put on the neck of the bottle):
Model ***MARK-6*** *(6 pcs)* *Order No. 209 013*

Check of the measuring system:
On request WTW offer special test instruments for test control.

Further literature: *WTW BOD handbook* *DIN 38409T51* *DIN 38409T52*

Technical data

Measuring principle	*Respirometric (manometric)*	***Power consumption***	*Max. 25 mA (during measurement)*
Display	*2-digit 7-segment LED, 10 mm*	***Protection class*** ***Protection system***	*3 IEC 1010* *IP 54 IEC 529*
Measured parameter	*Digits*	***EMC Emissions*** ***Immunity***	*EN 50081-1, FCC Class A* *EN 50082-2, NAMUR recommend.*
Measuring range	*0 ... 40 digits (+10 digits for overranging)*	***Climate class*** ***Ambient temperature***	*2, VDI/VDE 3540* *Storage: -25°C ... +65°C* *Operation: +20°C ± 1K*
Admissible measuring temperature	*20°C ± 1 K*	***Test mark***	*CE*
Admissible sample temp.	*15-20°C (when being filled)*	***Dimensions***	*H: 69 mm, • 70 mm*
Power supply	*Lithium batteries (260 mAh), 2 x type CR 2430 (3V)*	***Weight***	*Approx. 85 g*

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