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An investigation of fluorescent organic matter in water during springtime at Borgunda water treatment plant

Master's thesis in Infrastructure and Environmental Engineering

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MASTER'S THESIS ACEX30

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Cover:
Photo of Lake Vättern, taken at the raw water intake to the Borgunda drinking water treatment plant.
Department of Architecture and Civil Engineering
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ABSTRACT

An analysis of fluorescent organic matter was performed at Borgunda drinking water treatment plant. The plant draws water from the lake Vättern and provides about 100 000 consumers with drinking water. Previous spring seasons, the plant experienced problems with their sand filters being clogged and occasionally complaints have been made about an unpleasant taste and odour from the water. It is likely that these problems are caused by organic matter such as algae bloom. The objective of the thesis was to investigate how the composition of the water changed over time, how it changed over sand filters and if the sand filters gave different results.

The aim of the thesis was to investigate the composition of dissolved organic matter (DOM) at the intake of the raw water, before and after sand filtration at Borgunda treatment plant, using fluorescence spectroscopy. In addition to this, three hypotheses were formulated such as; the fluorophore signal will increase with warmer temperature, with eastern wind direction and the presence of algae can be linked to operational problems in the sand filter.

To investigate, a sampling campaign was performed at seven occasions during the spring season at the raw water, incoming water to the plant, outflow of each sand filter, after UV radiation and of the outgoing water. The samples were analysed in the laboratory by using fluorescence, absorbance, and dissolved organic matter measurements. The PARAFAC model was applied and showed that chlorophyll was found in the raw water, incoming and outgoing water. Two components above wavelengths of 550 nm were found that likely correspond to more than one algae species. During a visible pollution event on the surface in one of the sand filters, samples were also analysed in microscope and found diatoms and green algae. The removal performance of the sand filters was analysed, and results indicate that there are biofilms in the sand filters that during the sample period sometimes produce material that increases the fluorescence signal. Sand filer 2 most frequently had worse removal or was producing stronger signals when compared to the other sand filters. Sand filter 3 overall had the best removal performance over the sampling period.

No clear connection could be found between the increasing temperature and increased signal in fluorescence components. The eastern wind direction could however be linked to increased signals and is a possible explanation for increased organic material, causing problems in sand filters. Future studies are recommended to investigate the impact of snowmelt and increased flow in runoff streams, that bring nutrient and enables phytoplankton growth in, on surface waters used as drinking water sources.

Key words:

Organic matter
Drinking water
Vättern
Fluorescence
Algae
Phytoplankton

En analys av fluorescerande organiskt material i vatten på Borgunda vattenverk under våren.

Examensarbete inom masterprogrammet Infrastruktur och miljöteknik

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SAMMANFATTNING

En analys av fluorescerande organiskt material genomfördes på Borgunda vattenverk. Vattenverket försörjer ca 100 000 konsumenter med dricksvatten från Vättern. Tidigare vårar har verket upplevt problem med sandfilter som blir igensatta och ibland även fått in klagomål på smak och lukt av vattnet. Troligtvis beror dessa problem av organiskt material som uppkommer genom till exempel algblomning. Målet med denna uppsats var att utreda hur vattnets sammansättning ändras över tid, hur det ändras över sandfiltren och om sandfiltrens resultat skiljer sig åt.

Syftet var därför att undersöka vattnets sammansättning med avseende på löst organiskt material (DOM) vid intaget av råvattnet, före och efter sandfiltrering i vattenverket, med hjälp av fluorescensspektroskopi. Som tillägg formulerades tre hypoteser som; fluorescenssignalerna blir starkare med varmare temperatur, med östlig vindriktning och eventuella alger kan länkas till driftsproblem i sandfiltren.

För att utreda detta, gjordes provtagningar vid sju tillfällen under våren av råvattnet, det inkommande vattnet till vattenverket, utflödet vid varje enskilt sandfilter, efter varje UV aggregat och av det utgående vattnet. Proverna analyserades därefter i laboratorium genom mätningar av fluorescens, absorbans, och löst organiskt kol. PARAFAC modellering användes och visade på förekomsten av klorofyll i råvattnen, inkommande och utgående vattnen. Två komponenter över våglängden 550 nm hittades och korresponderar troligen till fler än en art av alger. Under ett synligt utbrott av någon förorening vid ytan av ett sandfilter togs ett prov som kunde analyseras i mikroskop. Från mikroskopbilderna kunde kiselalger och en grön alg identifieras. Sandfiltren analyserades också utefter hur mycket organiskt material som avlägsnades över filtren och resultatet indikerade att det fanns biofilmer i sandfiltren som under provtagningsperioden ibland producerade material som ökade fluorescenssignalen. Sandfilter 2 visade oftast på sämre borttagning eller rentav producerande starkare signaler jämfört med de andra sandfiltren. Sandfilter 3 hade generellt den bästa borttagningen under provtagningsperioden.

Ingen tydlig koppling kunde dras mellan ökande temperaturer och ökad styrka i fluorescenssignaler. Den östliga vindriktningen kunde dock länkas till starkare fluorescenssignaler och därmed ses som en möjlig förklaring till förhöjda halter av organiskt material som orsakar problem i sandfiltren. Framtida studier rekommenderas att utreda påverkan av snösmältning och ökat flöde i tillflöden, som för med sig näring och möjliggör tillväxt i växtplankton, i ytvatten som används som dricksvatten.

Nyckelord:

Organiskt material
Dricksvatten
Vättern
Fluorescens
Alger
Växtalger

Contents

Preface

This master thesis was carried out at the Department of Architecture and Civil Engineering at Chalmers University during spring term 2023. I would like to express my gratitude to Kathleen Murphy who has been my supervisor and examiner at Chalmers and provided valued guidance and support throughout the entire process. I would also like to thank Ali Esmaeeli and Aina Mc Evoy who generously provided their knowledge and laboratory skills to enable this project.

Lastly, a very special thanks to Josefine Stångberg, Henrik Larsson and Carl Doverholm at Borgunda water treatment plant, without whom this project would never have started in the first place. Thank you for the opportunity and for sharing your wisdom, time, and commitment. You were very much appreciated for assisting me in all that was needed to bring this project to life.

Gothenburg, June 2023

Eira Karlsson

Notations

DBP	Disinfectant By-Product
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EEMs	Excitation and Emission Matrices
NOM	Natural Organic Matter
SUVA	Specific Ultraviolet Absorbance
TOC	Total Organic Carbon
UV	Ultraviolet
UV-vis	Ultraviolet-Visual Spectroscopy
PARAFAC	Parallel Factor Analysis

1 Introduction

Fresh water is a scarce resource and is expected to become even more so with climate change (Bernauer & Böhmelt, 2020). Other factors such as unsustainable water management, population growth, increased water demand by industry, agriculture and energy forebodes access to fresh water to be one of the biggest challenges in the future (UN DESA, 2022). To "Ensure access to water and sanitation for all" by 2030 as stated by the UN DESA (2022) is the 6th of the United Nations sustainable development goals since it is a necessity for human health and well-being. This, in combination with the scarcity of fresh water, emphasizes that the ground water and surface water resources available today must be managed wisely.

The lake Vättern is the second largest lake in Sweden and is used for many different purposes (Öhrling et al., 2020). One important purpose is providing drinking water to almost 300 000 consumers (Björnsdotter et al., 2022). Today, eleven different municipalities get their water from lake Vättern, and even more municipalities are expected to connect. One treatment plant that uses the raw water from the lake is Borgunda drinking water treatment plant, run by the municipal association Skaraborgsvatten located in Skaraborg. It provides drinking water to the three municipalities Skövde, Falköping and Skara. The Borgunda drinking water treatment plant has in recent spring seasons occasionally experienced problems with unpleasant taste after treatment of the water. Late spring the plant also has encountered problems with their rapid sand filters becoming covered in foam which increases the need for backwashing.

It is likely that these problems are related to dissolved organic matter (DOM) that exists naturally in surface waters and which contributes to the taste, odour, and colour of the water (Kothawala et al., 2017). DOM can also be connected to other problems in the drinking water production such as disinfection by-products (DBPs) and regrowth of bacteria in water mains. If the DOM composition is known, the problems Borgunda is experiencing with taste and their sand filters can be predicted. Eventually this could lead to optimising the treatment processes.

Many treatment plants, including Borgunda's plant, lack the capability to closely monitor changes in the DOM composition since the methods to do this require significant expertise and hence are not widely available (Li et al., 2020). A rapid method of measuring DOM is based on the property of DOM that absorbs light (Wünsch et al., 2015) which means that absorption (UV-vis) and fluorescence spectroscopy can be utilised.

1.1 Aim and objectives

The aim of the thesis is to investigate the composition of dissolved organic matter (DOM) at the intake of the raw water, before and after sand filtration at Borgunda treatment plant, using fluorescence spectroscopy.

The research questions are therefore:

- How does the water composition fingerprint change over time?
- How stable is the raw water source?
- How does it change over the sand filtration?

- Do different sand filters give different results?

In addition to this, three hypotheses are formulated as:

- The fluorophore signals will increase throughout the sampling period due to warmer temperatures.
- The fluorophore signals will increase when there is eastern wind, causing the direction of the water to flow directly to the intake.
- There are algae in the raw water that can be linked to operational problems in the sand filters.

1.2 Limitations

This study is limited to analysing quantity and quality of dissolved organic matter (DOM) in the water samples. Other microbial and physiochemical water quality indicators will not be considered, such as number of bacteria, viruses, pesticides or disinfection by-products. The main methods that will be used for analysing the water samples are absorbance and fluorescence spectroscopy. Furthermore, the geographical area of sampling is limited to the water from lake Vättern at the intake to Borgunda treatment plant and to sampling at several locations in the treatment train at Borgunda plant.

2 Background and theory

Sweden is a country with nearly 100 000 lakes, many of which has been formed during several glacial periods (Andréasson et al., 2015). Lake Vättern, which is the second largest lake of Sweden, was however formed under different circumstances (Öhrling et al., 2020). The lake was created as a result of a rift valley and has great depths up to 120 meters, but with a mean depth of just 40 meters (Willén, 2001). The outflow is relatively small which plays a part in why the turnover time is very long, 58 years. With an area of approximately 1 900 km^2 it serves almost 300 000 inhabitants in different municipalities with water, and even more municipalities are expected to connect (Björnsdotter et al., 2022). Generally, the water quality is very good since the lake has nutrient- poor conditions and cool water. Yet, there have been reports of unpleasant taste and odour in drinking water mainly during summer, that are likely caused by algae bloom. For example, the diatom *Aulacoseira* is common in spring and has been found in lake Vättern. There are however few studies that have covered the topic of freshwater algae in Swedish lakes during spring season, and the extent of the algae problem is quite unknown. With climate change, higher water temperatures can aggravate the water quality by promoting growth of algae and bacteria, which increases the treatment requirements (Eklund et al., 2018). Although these problems are not widespread in lake Vättern today, they might lead to an increasing demand on drinking water from Vättern, that needs to replace other drinking water sources that become more polluted.

Figure 1. Photo of Lake Vättern, taken at the raw water intake to the Borgunda drinking water treatment plant.

2.1 Borgunda water treatment plant

The Borgunda water treatment plant draws water from Vättern and supplies approximately 100 000 consumers with drinking water. Because the treatment plant is located on the west side of the lake, which is very shallow, the intake had to be installed above the mean depth of the lake. This location obstructs the general aspiration to have a water intake below the mean depth and thermocline to achieve consistent water quality and temperature, which enables precise and optimised treatment processes. The location of Borgunda plant in relation to Vättern can be seen in Figure 2 and a photo of Vättern near the intake can be seen in Figure 1.

Figure 2. The Lake Vättern and the location of Borgunda treatment plant (Google maps 3rd of March 2022, scale 1: 20 km).

A schematic figure of the whole treatment process can be seen in Figure 3.
The first treatment step occurs at the pumping station at the raw water source, when the water has passed through a coarse grid. Here, chloramine is added to prevent microbial growth in the 30 kilometres long water main that connects the raw water source to the treatment plant. The disinfection product is formed by adding sodium hypochlorite and ammonium sulfate. Although chloramine is formed, it does not count as a microbial barrier, only the usage of free chlorine does according to the Swedish Food Agency (2023). The added dose of chloramine depends on the season, between 0,35 mg/l wintertime and 0,45 mg/l late summer. The incoming water to the plant is then treated by adding carbon dioxide before it passes through rapid sand filters containing media with a grain size of 0,8-1,6 mm. The plant has six sand filters, but only five are in use due to renovation of sand filter 1. Sand filter 2 and 4 have gone through renovation during the last two years. Subsequently, the water undergoes UV radiation, and the units are attached to each outflow of the sand filters respectively. After the UV, lime is added to increase pH. The lime is added in the

mixing chute where sodium hypochlorite and ammonium sulfate are mixed to create final disinfection. The water is then distributed to the different municipalities, and Borgunda is strategically located in between them geographically. Currently there are plans on implementing another microbial barrier in form of Ultrafiltration, which will likely be constructed and operating within the next 10 years.

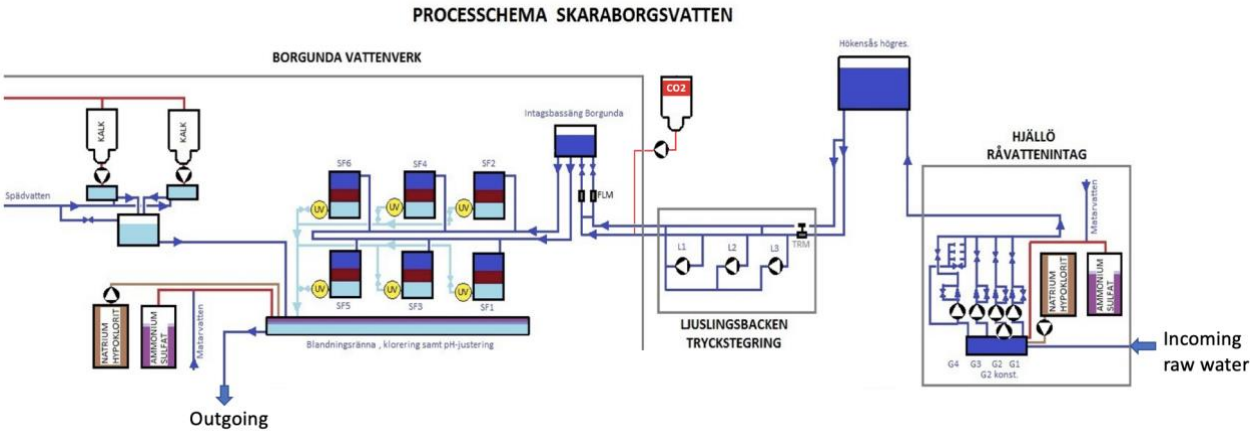

Figure 3. The treatment steps at Borgunda plant. The disinfection treatment step at the raw water intake is also displayed.

The treatment plant was designed and constructed during the 1950's. The plant was finished and put into use 1959 and it has delivered water with good quality ever since. However, in recent spring seasons there have been occasional complaints from consumers about the water tasting "earthy" and like "forest lake". Around late spring or early summer, the plant sometimes encounters problems with the rapid sand filters, where a sort of foam starts appearing that can persist for hours or days. When this happens, it significantly increases the need for backwashing which must then be performed much more frequently than usual. The backwashing is normally performed once a week or when the filter resistance becomes too high. During the period when the special problems occur, the need for backwashing can increase to as frequent as once per day. The plant personal believes that the wind direction is affecting the water quality. Since the water intake is located towards east, an eastern wind will carry possible pollutants with it and bring it straight to the inlet.

2.2 Dissolved Organic Matter

In raw water used for drinking water purposes, the amount of natural organic matter (NOM) present has a great effect on treatment processes (Zheng et al., 2016). There is a wide terminology used to refer to different parts of organic matter, as NOM can vary in different sizes. NOM can range from solid to dissolved matter, which is referred to as particulate and dissolved organic matter respectively (Docter et al., 2015). Dissolved organic matter (DOM) composes of organic compounds that originates from either microbial degradation, abiotic percolation of solid organic matter or as a result of metabolic processes in aquatic plants, i.e., algae (McDowell, 2022). DOM can also be described by its main constituents namely dissolved organic carbon (DOC), dissolved organic nitrogen and dissolved organic phosphorus.

Because NOM contains carbon, it can promote growth or support the regrowth of microorganisms in pipes and water networks (Zheng et al., 2016). This is a concern for the Borgunda treatment plant since the water travels 30 km from the source to the plant. The water distribution network also contains long distances, creating the risk of microbial regrowth. To prevent microbial growth in the pipes, chloramine is added at the pumping station at the raw water source and to the outgoing, treated water.

NOM content in water can impact the treatment processes, such as disinfection by chlorination which is used to inactivate bacteria and viruses (Blom and Furuberg, 2013). The effect of chlorination is dependent on the concentration and type of chlorine used and the contact time with the water. The combination of time and concentration is referred to as the CT-value, and is expressed in mg*min/L. Borgunda uses monochloramine to disinfect, which is a weaker form of disinfectant. Thus, it needs longer contact time than free chlorine to ensure proper disinfection. In addition to this, pH, amount of organic material and temperature also affects the CT-value and thereby the disinfection efficiency. However, chlorinating raw water generates the risk of creating disinfection by-products (DBPs) if the chloramine reacts with NOM. The trihalomethanes that can be generated cause adverse health effect such as different types of cancer or miscarriage (Yang et al., 2022). But when the content of DOM is very low, as it generally is in Vättern, there is little risk of creating DBPs. The usage of chloramine offers a long-lasting disinfection effect which is important in long pipes with long residence times, which is why it is also added at the outflow from the plant. Although it has a longer lasting effect than free chlorine, it still degrades over time and the reaction process is enhanced by increased DOM concentrations. This leaves less chloramine residual and makes the system less resilient to microbial pollution, which is important to consider in cases with long distances in water distribution systems.

Furthermore, the concentration of DOM has great effect on the treatment processes filtration, adsorption, and membrane fouling (Li et al., 2020). In water treatment plants that uses coagulation, DOM also has a great effect on the coagulation process. Precipitation chemicals are often overdosed because the raw water composition and DOM fractions are unknown. Jar tests are often used as a routine check-up to adjust dose, but this creates a time lag. Overdosing also leads to increasing costs and unnecessary chemical consumption.

The DOM content is known to be related to the taste and odour of water. During decay, water living organisms can release taste and odour compounds (Adams et al., 2022). Factors affecting decay therefore also influences taste and odour of the water. Algal blooms can significantly increase pH of surface waters, which in turn can destroy pH-sensitive organisms. Decay of algae can also cause anaerobic odours such as organic sulphides. Research has shown that pH itself can affect the taste of the water, as can be seen in Figure 4. A higher pH is likely to cause an earthy, musty, grassy odour. In contrast, a lower pH can produce a metallic, medicinal, sweet taste. In drinking water, the outgoing water is desired to have a pH between 7.5 and 9.0. Borgunda usually has outgoing water with a pH around 8 and sometimes a little higher during late spring (up to 8.8 as highest). This could suggest that pH also influences the problems with taste. It is however desired to provide outgoing water with a high pH, to keep the distribution system from corroding.

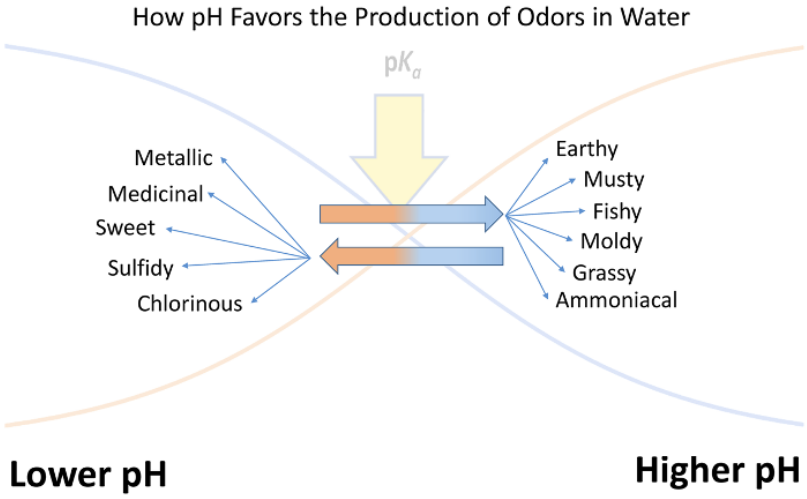

Figure 4. Shows how pH can influence the odour and taste in water (Adams et al., 2022). CC BY 4.0

DOM has been studied over the last 100 years, though the focus has been mostly on DOM in form of protein, carbohydrates, and the functional properties that i.e., absorbing of light (McDowell, 2022). Despite the long history of research, there is no method that has yet been able to provide information on the full molecular structure of the total DOM-pool. McDowell (2022) points out the main challenges and recommendations for future research in the field of DOM. One challenge is to establish long-term documentation on changes in concentration and another to develop the use optical sensors to analyse DOM content in water.

2.2.1 Algae and phytoplankton

The term algae refer to an organism functioning through photosynthesis that is not defined as a "higher plant" (Raven, 2014). Common algae are cyanobacteria and eukaryotes. Most algae are unicellular but can despite this vary greatly in size. It is estimated that there are between 30 000 to over a million number of algal species, depending on how a species is defined. According to Raven (2014) a commonly accepted definition, however, limits the number to about 72 500. Most algae live in water ecosystems, though some can thrive on ground, in soil or even desert crusts. To

survive and multiply, all algae need light, water, and nutrition (SMHI, 2020). In water bodies and oceans, microscopic algae are the basis for the food chain which many ecosystems are based on. The photosynthesis performed by algae, produces approximately half of all the oxygen on our planet. Many factors affect the occurrence of phytoplankton in different seasons. In late winter or early spring, lakes overturn because of temperature difference which brings up nutrients from the bottom of the lake to the surface (Cotte et al., 2023). This process makes nutrients accessible for algal bloom in the surface layers. With climate change, this turnover is expected to occur earlier in the year, prolonging the algae growing season. In Nordic countries, the snow melting increases the flow of the water inflows in the catchment area which brings other nutrient sources. Other than access to nutrients, algal bloom is dependent on factors like temperature, hours of sunlight and flow speed (Cotte et al., 2023). The sun can have a great effect on the photosynthesis of algae, which grows more rapidly in spring when more energy is available.

Phytoplankton are microscopic plankton, and the most common ones are diatoms, golden brown algae, green algae, blue green algae and dinoflagellates (Vasconcelos, 2020). All phytoplankton contain pigments like chlorophyll, which is the key to transforming light into chemical energy. Different types of chlorophyll can expand the accessible light wavelength range and make use of more light energy to photosynthesis. The pigments give different fingerprints depending on which wavelengths are absorbed from the light. These fingerprints can be tracked using absorption and fluorescence, leading to information about phytoplankton biomass in aquatic systems. All phytoplankton and cyanobacteria contain chlorophyll *a* which have an emission peak at wavelength 680 nm (Vasconcelos, 2020). Only green algae phytoplankton and freshwater cyanobacteria contain chlorophyll *b*. Cyanobacteria and red algae also contain phycocyanin and phycoerythrin which have emission peaks at around 640 nm and 580 nm respectively (Nair et al., 2018). Only spectral data cannot distinguish between species of phytoplankton, but can still provide information about clusters (Vasconcelos, 2020).

Cyanobacteria, often referred to as blue-green algae because of its colour, is a common group of algae that can function using nitrogen, which other phytoplankton cannot (Raven, 2014). Cyanobacteria is the very reason that the planet was oxygenated in the first place and created the conditions for evolution to form more advanced life. Other types of common algae are green, brown, red algae and diatoms that are related to red algae. According to Cvjetinovic (2023) diatoms make up to a quarter of all organic material on the planet and produce up to 20 % of all oxygen. Diatoms are vital algae playing part in food web and energy transport in marine ecosystems as well as freshwater lakes, especially during spring in temperate lakes (B-Béres et al., 2022). Diatoms have an exoskeleton made of silica, which constitutes a very durable case. These shells cause them to look very beautiful when examining them in a microscope, something once stated by Charles Darwin himself in *Origin of Species* (1859). But they also have many functions, protecting, filtrating, and controlling absorption of light amongst other vital mechanisms (B-Béres et al., 2022).

2.3 Methods of measuring DOM

There is no single, established method to measure DOM, but several techniques have been developed with different aims. A commonly used, rapid method is based on the property of DOM that absorbs light (Wünsch et al., 2015). This property means that optical methods like absorption, UV and fluorescence spectroscopy can be utilised. Traditionally, specific absorbance (SUVA) has been used to analyse DOM, but the method has some disadvantages. Firstly, it requires a UV spectrophotometer which is not always reliable since it can vary a lot in sensitivity (Philibert et al., 2022). The UV spectrophotometer also poorly predicts oxidation and adsorption because it cannot detect the low-molecular weight fractions of DOM. In addition to this, SUVA requires a TOC analyser which is not very common at treatment plants. This is partly due to practical difficulties while being rather expensive when comparing to other monitoring parameters. The detection limits for TOC are also quite high. Fluorescence spectroscopy has in previous research been shown to offer high sensitivity while being affordable (Philibert et al., 2022). It can also distinguish between different fractions of DOM, assessing the quantity of pollutants while giving more information about water quality (Moona et al., 2018).

2.3.1 Fluorescence spectroscopy

Fluorescence is a tool capable of characterising DOM in water environments, which has been utilised the last few decades (Carstea et al., 2020). As early as in the 1970s, fluorescence was used to track pollution and oil spills in oceans. During the last 15 years, research has shifted to freshwater and in situ measurements in water systems. As previously stated in 2.3, Fluorescence spectroscopy is a comparably inexpensive method with high sensitivity. It uses two-directional wavelength scanning that measures a small part of the total dissolved carbon pool in water samples (Philibert et al., 2022). Another advantage compared to other methods, is that it can also analyse changes in DOM concentration.

When a molecular substance in a sample is subjected to light of a certain wavelength, the parts of the material that absorbs the energy are called fluorophores (Hauch & Ratner, 2013). Some of the energy absorbed will transform to heat in the excited state and the rest will be emitted again in form of a longer wavelength, that contains less energy. As can be seen in Figure 5, the incoming energy is absorbed. In this process the electron is brought to a higher, excited stage, before returning to its ground state and emitting another wavelength. The energy difference between absorption and emission wavelengths is called Stokes shift and can be seen in Figure 6. The Emission spectrum or Stokes shift can be used to analyse content in water, since it is specific for different molecular substances.

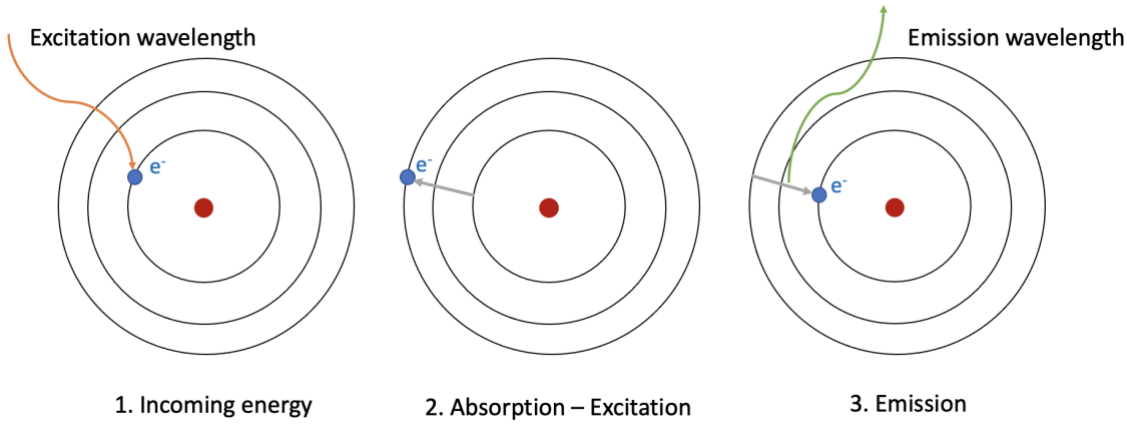

Figure 5. The excitation of an electron and emission of wavelength on a molecular level.

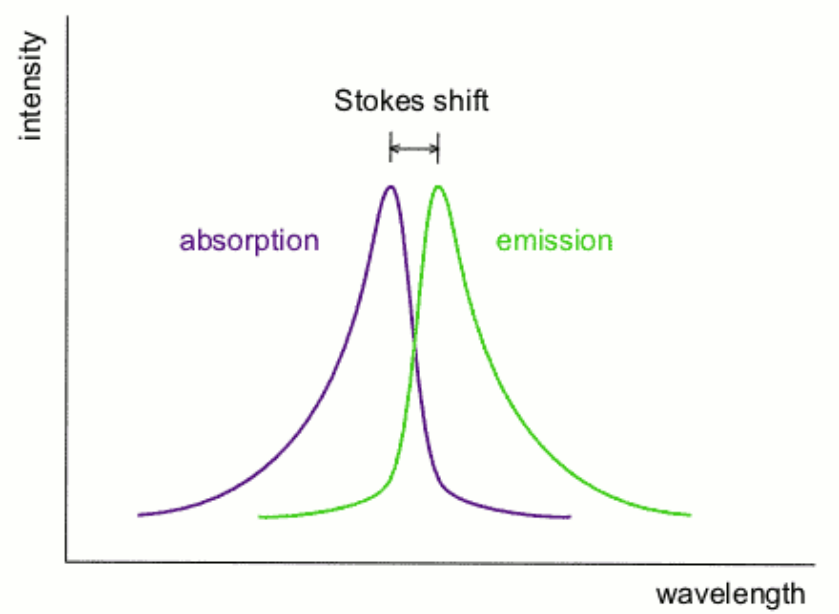

Figure 6. A spectrum of absorption and emission wavelengths, including Stokes shift. Stokes shift, Mykhal, 2004, Commons Wikipedia (https://commons.wikimedia.org/wiki/File:Stokes_shift.pn). CC BY-SA 3.0

The excitation wavelengths can be plotted against the scanned emission wavelengths. From this behaviour, excitation, and emission matrices (EEMs) can be formed. The EEMs contain information for each sample, excitation and emission that has occurred in the material. Such multivariate datasets can be very complex and large, which in turn can be difficult to handle and interpret (Coble et al., 2014). This can result in that important information or differences between samples will remain undetected. For this reason, it is better to reduce the dimensionality of the dataset and distinguish the relevant information from the uncalled-for information. Subsequently, fluorescence spectroscopy is often coupled with a model called parallel factor analysis (PARAFAC) to easier visualise and interpret the complex data sets.

PARAFAC is commonly used to distinguish and quantify components in multi-way datasets, which is data in arrays of at least three-order (Murphy et al., 2013). It can decompose the EEMs and identify unique, underlaying, chemical components, assuming that the fluorescence signal itself is the result of combined chemical components. This method can identify humic-terrestrial-, protein-like-, and microbial-

humic groups that correlate with DOC. The Fluorescent fractions correlating with peaks in the wavelength can be seen in Table 1 below.

Table 1. Fluorescent fractions in PARAFAC and possible or acknowledged sources (Philbert et al, 2022).

Name	Wavelength peak	Possible sources
Hi	360/455	Humics: ubiquitous
Hii	395/521	Conjugated humics: ubiquitous
Hiii	330/404	Microbially-linked humics: ubiquitous
Hiv	300/430	Terrestrial humics: ubiquitous
Pi	290/365	Amino acids-tryptophan

In a perfect scenario, fluorescence follows Beers law. Although, in real cases lot of disturbances must be considered, such as light-scatter, concentration-dependent nonlinearity because of inner filter effects or components with similar spectral properties. Therefore, it is important to follow the steps of PARAFAC analysis described in Murphy et al. (2013) which include pre-processing and exploring the data set before validating the model and interpreting the results.

3 Method

The main parts of the thesis were a literature study for the background information, the sampling and laboratory work as well as data analysis.

3.1 Information about the treatment plant

There have been several meetings with the staff at Borgunda treatment plant when information about the plant was provided through personal communications. Due to increasing demands on safety, some information is confidential and will not be described in detail in this report. However, this did not have a great effect on the main objective of the study since it focuses mainly on the raw water and first steps of treatment.

3.2 Literature study

A literature study was conducted to connect this study as a link in chain of previous research in the field. It specified the importance of the subject and provided fundamental knowledge in the background chapter for the reader. Scientific sources were selected to provide a theoretical framework and to give insight on the occurrence and problem of DOM, existing methods to measure and characterise it. Furthermore, it provided information about the study area of Lake Vättern and the use of it as a raw water source.

To conduct the literature review, several keywords were identified and used in the search: DOM, Drinking water, Dissolved organic matter, taste, Odour/Odor, Fluorescence spectroscopy, NOM, Fluorescence, Fluorophore, Disinfection by-products, algae, sand filters, backwash, clogging, algae, DOC, Turbidity

3.3 Sampling techniques

A sampling plan was initially made but had to be modified several times. The first sampling location was at the raw water source at the pumping station, before the chloramine was added. Because of the chloramine addition, another sampling point was at the incoming water to the plant, which was raw water with only added chloramine. Regarding the sand filters, filter 1 was currently under renovation and sampling was conducted after the sand filters in operation (filter 2-6). This corresponded to 13 sampling points in total, which can be seen in Figure 7 and 8.

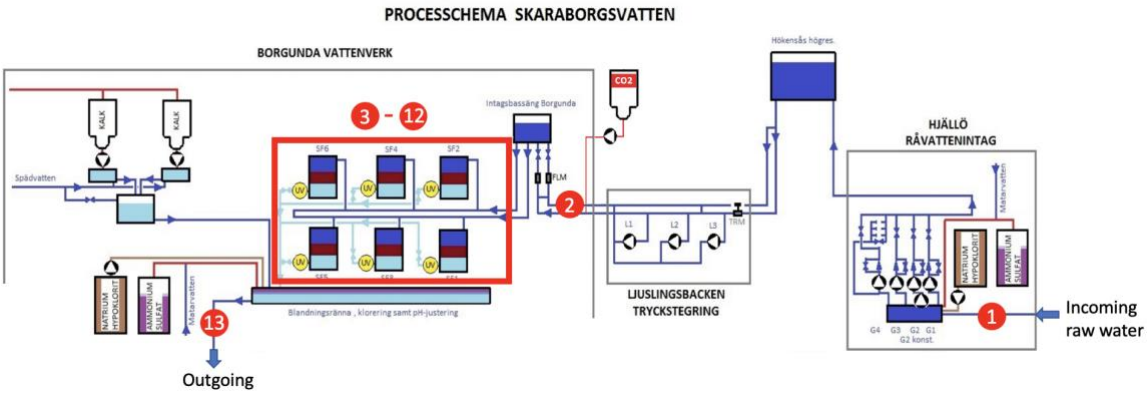

Figure 7. Samplings points are indicated in red in the process scheme. The red square is representing the close-up which can be seen in Figure 8 below.

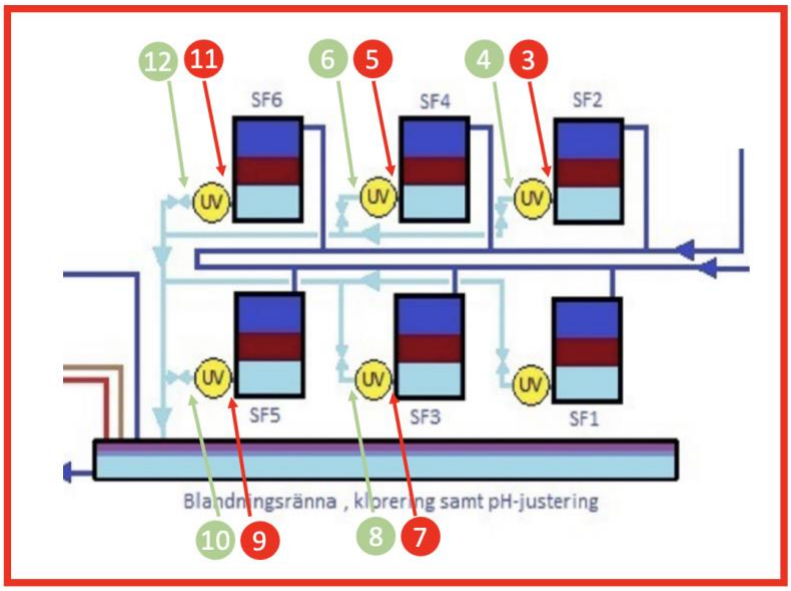

Figure 8. Close-up on the sand filters 1-6 with UV units and markings where the samples were taken. Red points indicate sampling points at the outflow of each sand filters and the green points indicate sampling points after the UV.

The sampling locations were the following (see number markings in Figure 7 and 8):

- At the raw water source (pumping station) [1]
- At the incoming water to the treatment plant [2]
- At the outflow of each sand filter (filter 2-6) [3, 5, 7, 9, 11]
- After each UV units installed after each separate sand filter [4, 6, 8, 10, 12]
- At the outgoing water from the plant [13]

The samples were taken once a week, at the raw water source and subsequently 20 hours later at the plant. This was the time it took for the water to travel to the treatment plant, which varies in season depending on the flow and water consumption. Samples were taken at the UV and outgoing water to gather as much information as possible and to validate results of the sand filters, to ensure no cross-contamination occurred in the laboratory.

The sampling containers initially used was 40 ml bottles of brown glass. To make sure that there would be enough sample to perform the required measurements, double samples were taken on the raw water, before and after sand filtration. After the first week it was established that larger sample containers varying between 100-250 ml bottles was preferable. The samples after UV were however still collected in 40 ml bottles since those were not subjected to additional tests, only fluorescence. Before the samples were taken, the vials were rinsed through three times with the relevant water. There were taps available both at the pumping station at the raw water source and after each treatment step in the plant. Before sampling, the taps were burned using a gas burner to minimise risk of any microbial contamination that could be attached to the tap. The exception for this is the outflow of sand filter six, which had an old tap with a packing made of flax and was therefore flammable. Before sampling, the water ran for about a minute to get representative samples from each tap.

On one occasion during sampling, there was some sort of pollution that had started to appear on the surface of sand filter 6. It looked as though there might be algal bloom or some sort of bacteria. For this event, a plastic bottle was used to take a grab measurement of water at the surface of the filter, gathering some of the floating materia.

The sampling was conducted at a total of seven weeks, at occasions which can be seen in the Table 2 below. Originally it was planned to perform the sampling over 8 weeks, but it was prevented due to illness, which is also the explanation of the longer timeslot between 12 and 24 of May. A sampling diary was kept, which included a record of wind and weather prevailing at the time of sampling. The data weather data was obtained through the Swedish Meteorological and Hydrological Institute (SMHI, 2023) and gathered from observation and modelling data made for the nearest location to the water intake, which was in Hjo. On each sampling occasion, it was also recorded whether the filter had been backwashed the latest 24 hours. This information was compiled in a table, for which a template can be seen in Table 2.

Table 2. A template with sampling dates used to compile weather data and backwashing data.

Sampling date	Weather annotation	Backwashed latest 24 hours
7-8/3		
13-14/3		
20-21/3		
27-28/3		
3-4/4		
11-12/4		
24-25/4		

3.3.1 Storage and transportation

After the sampling had been conducted, the raw water and treatment plant samples were stored in a refrigerator over one, respectively two nights and then transported by train to the laboratory at Chalmers, which took about 2 hours. For the first sample

campaign a cooling bag with icepacks was used to keep the samples cool during transportation to the laboratory. However, to perform the fluorescence analysis the samples should be room temperature, which became a problem for the cooled samples. Since the analysis were performed almost immediately upon arriving, the decision was made to transport the samples in a box without cooling, to allow for thawing. The transport of the raw water sample from source to the plant was 40 minutes at which the sample kept itself cool enough and was thereafter stored in the refrigerator at the plant. After the samples at the plant has been taken, they were transported ca 25 minutes together with the raw water sample to another refrigerator. The box in which the samples were transported in was sealed with a plastic bag to prevent contamination from the outside, and the lids were always attached to the bottles.

3.4 Laboratory measurements

The laboratory measurements were performed each week the sampling was conducted. Firstly, the fluorescence was measured, followed by absorbance measurements and filtration for DOC. The absorbance measurements performed with the UV-spectrophotometer was however not used during the first three lab occasions, but then absorbance data was only gathered from the Aqualog.

All samples were analysed using fluorescence spectroscopy. At the first sampling occasion, both unfiltered and filtered samples was measured for all the sand filters, raw water, incoming and outgoing water. For the following lab analyses, only unfiltered fluorescence was measured since it was assessed non-essential for the output and rather a risk of cross contamination.

The Aqualog instrument was used for measuring fluorescence. It measured excitation wavelengths in a spectrum from 200-600 nm. On each measuring session a lamp check was performed to ensure that the instrument lamp had sufficient intensity at the correct wavelength. In addition to this, a cuvette check was performed to confirm that the cuvette was clean before measuring. A blank was also created with the cuvette filled with Milli-Q, for each measuring session, to subtract from the resulting plots and remove influence of the cuvette and any background noise. The Aqualog automatically measures absorbance, but to make sure the data was reliable the absorbance was also measured with a UV-spectrophotometer with a spectrum of 200-800 nm. When using the UV-spectrophotometer another reference, sealed cuvette was used for base-correction for each measurement.

DOC measurements were performed on the raw water, incoming water to plant, sand filters and outflow. All the samples were filtrated using filter size 0.45 nm.
For the filtration, a syringe was rinsed two times with distilled water and one time with Milli-Q. The filter was rinsed through with approximately 10 ml of Milli-Q and then with 10-15 ml of sample. This procedure was repeated in between each sample. The TOC analyzer was used, and the 40 ml filtered samples were placed four at a time on a tray, with two Milli-Q-filled vials in between each set and three at the start. Before the test was performed, it was ensured that the connected Milli-Q water container was full, that the synthetic gas pressure was enough and that all sefltests and calibration were working properly.

For the extra sample taken at the surface of sand filter 6 during the visible pollution event, the sample was shaken up and measured with fluorescence, both unfiltered and filtered. A subsample was then created out of the original sample by adding 10 ml of Milli-Q, and again measuring unfiltered and filtered fluorescence. An additional subsample was then created by adding 10 more ml of Milli-Q and measured fluorescence as unfiltered. This was done to obtain several, slightly different samples so that the PARAFAC model could be applied. Unfortunately, this was unsuccessful and no useful result was derived from this. In addition to the fluorescence, the original sample were also analysed in a microscope to see the presence of possible chlorophyll and phytoplankton. The microscope was set to a scale of 20 micrometre.

3.4.1 Cleaning the cuvette and sample containers

The cleaning process changed a bit during the course of the experiment. During the first two lab sessions, the cuvette was cleaned before use and in-between each fluorescence measurement with Milli-Q and ethanol (70%). Starting with Milli-Q, and followed by ethanol, the cuvette was rinsed through five times over at both the inside and outside of the cuvette. After weighing the time and resource aspect of this method to only rinsing with the sample three times, the latter alternative was deemed better. Hence, the cuvette was only rinsed with Milli-Q once, and then the relevant sample was used to rinse the cuvette 3 times. After cuvette filled with sample, any excessive water on the outside was wiped off using a fine fibred cloth.

The syringe used for the filtration was rinsed with distilled water two times over and then with Milli-Q, between each sample filtration. A new filter was rinsed through with 15-20 ml of Milli-Q and then in between each sample filtration with 10 ml of Milli-Q and 10 ml of Milli-Q of the subsequent sample.

After sampling, the bottles were cleaned in a dishwasher, and then baked in the furnace for 6 hours at a temperature of 450 degrees. The lids were acid washed (with approximately 10% HCL) and left in acid bath for 2-7 days and then rinsed three times with Milli-Q.

3.5 Data analysis

The data was pre-processed in Matlab to remove Rayleigh and other scatter. When enough data series had been gathered, the PARAFAC model was applied. For the provided data from the PARAFAC model and in Matlab, tools in Microsoft Excel were used to analyse and display the data in graphs. Since a lot of data was available, a selection was made to further investigate the data that was especially distinctive. Firstly, the data was investigated to see if any correlations were found between the variables. Then the signal data from the sand filter outflows were recalculated to relative removal of each fluorophore component over each sand filter.

The analyse then focused on which sand filters had the best or worst removal of the fluorophore components. Thereafter the sand filters that were identified as especially interesting were investigated further in relation to fluorophore signals and over the time period. The fluorophore components are also referred to as fmax, see Table 4 in 4.4. When a fmax signal is high compared to other samples, it means that more of that substance is present. In other words, fmax can be interpreted similar to concentration,

yet no pure samples of each fmax exists and thus real calibration cannot be done to find the concentration in units. A lot of information can however be extracted from an increasing or decreasing signal.
The data for raw water, incoming and outgoing water was analysed in a separate PARAFAC model. This was done to enable identification of possible algae components, which are more likely to be found in the raw water and incoming water. The outgoing water was included to see to which extent possible algae was removed.

4 Results

Through the fluorescence of the water samples the PARAFAC model found peak signals in five fluorophore components. The PARAFAC model also identified chlorophyll in two components with specific wavelengths corresponding to algae species.

4.1 General results

The results of the sampling occasions and prevailing weather conditions (approximately over 6 hours before sampling) can be seen in Table 3 below. The table also includes which sand filters were backwashed the latest 24 hours.

Table 3. Sampling diary at the raw water source and at the plant.

Sampling date	Weather annotation	Backwashed latest 24 hours
7-8/3	Strong, *east* wind (8-15 m/s), air temperature -3°C	Filter 6, Filter 4
13-14/3	South wind, air temperature + 3°C	Filter 5, Filter 4
20-21/3	West wind, air temperature + 6°C	Filter 5
27-28/3	North-west wind, air temperature + 2°C	Filter 5
3-4/4	*East* wind, air temperature + 2°C	Filter 6, Filter 5
11-12/4	South-*east* wind, air temperature + 10°C	Filter 6, Filter 2
24-25/4	North-*east* wind, air temperature + 11°C	Filter 6, Filter 5

No complaints about taste or odour were made during the period that the sampling took place. Yet, there was on one occasion, the 21/3, when there were visible problems with sand filter 6.

4.2 Detected algae components

From the excitation and emission matrixes, chlorophyll can be seen in Figure 9 as the contours above 550 in the emission spectra. Two signals of algae were picked up by the fluorescence measurements. Either these are two algal species, or there are different parts of one algae specie that responds to different wavelengths. These are named as Component 4 and Component 5. Both signals appear at wavelength above 550 nm, which indicates chlorophyll and the representation of algae.

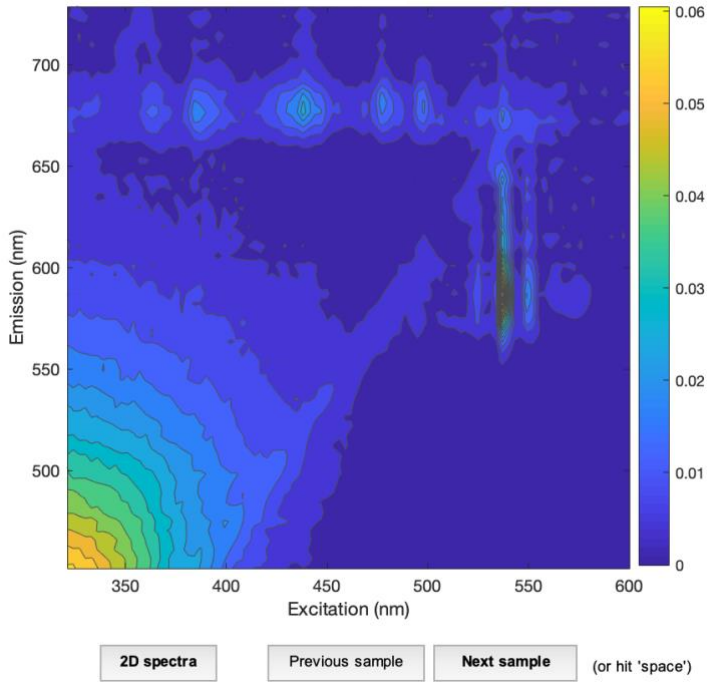

Figure 9. An excitation and emission matrix of the rawwater fluorescence at Borgunda.

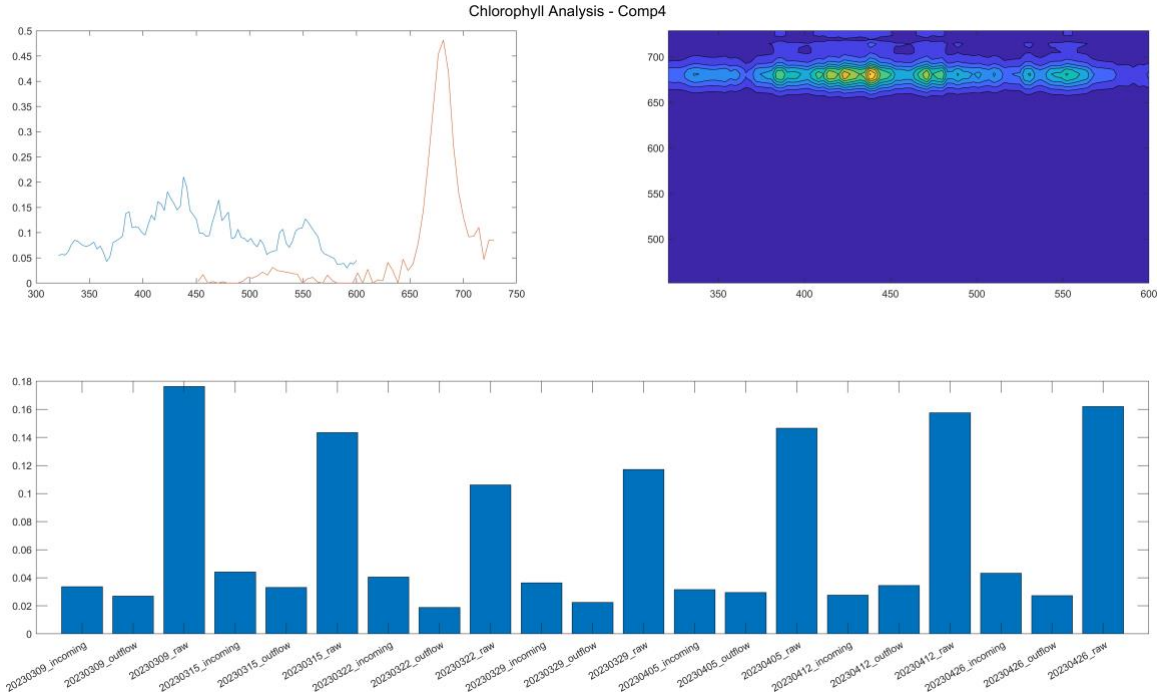

Figure 10. Chlorophyll analysis with identified Component 4.

In Figure 10, Component 4 is displayed and can be distinguished in the plot at the top, in the emission wavelength range around 680 nm.

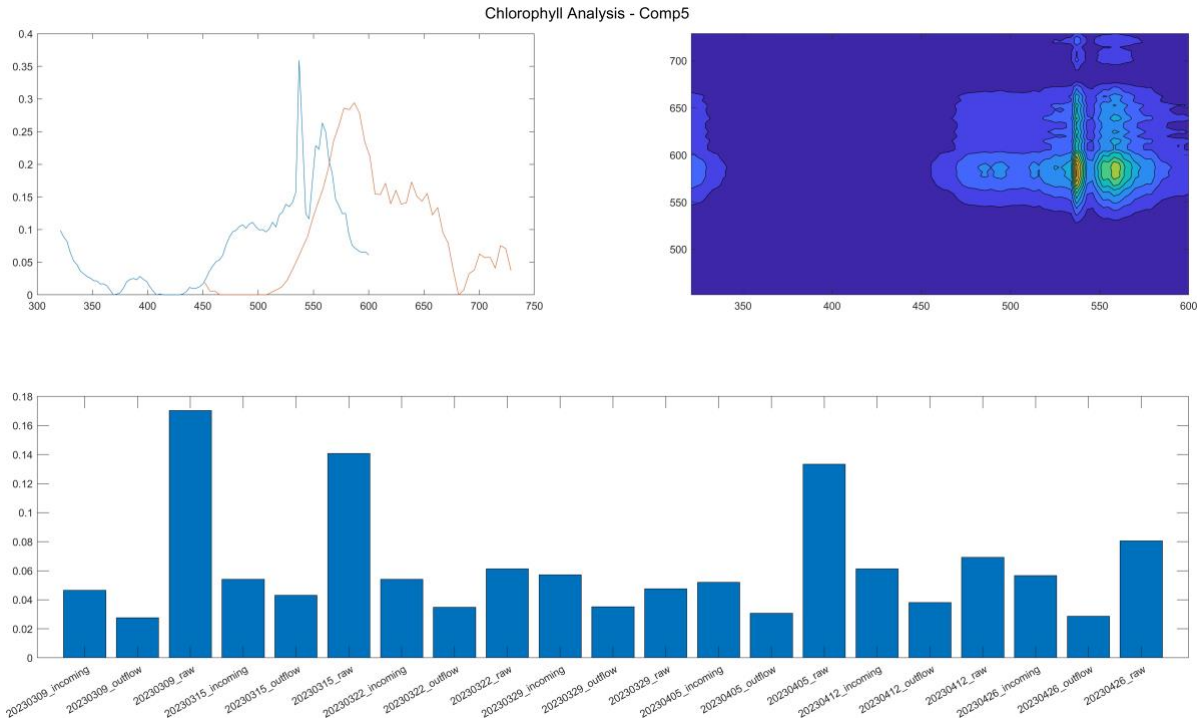

Figure 11. Chlorophyll analysis with identified Component 5.

In Figure 11, Component 5 is displayed and can be distinguished in the plot at the right side, in the emission wavelength range around 580 nm.

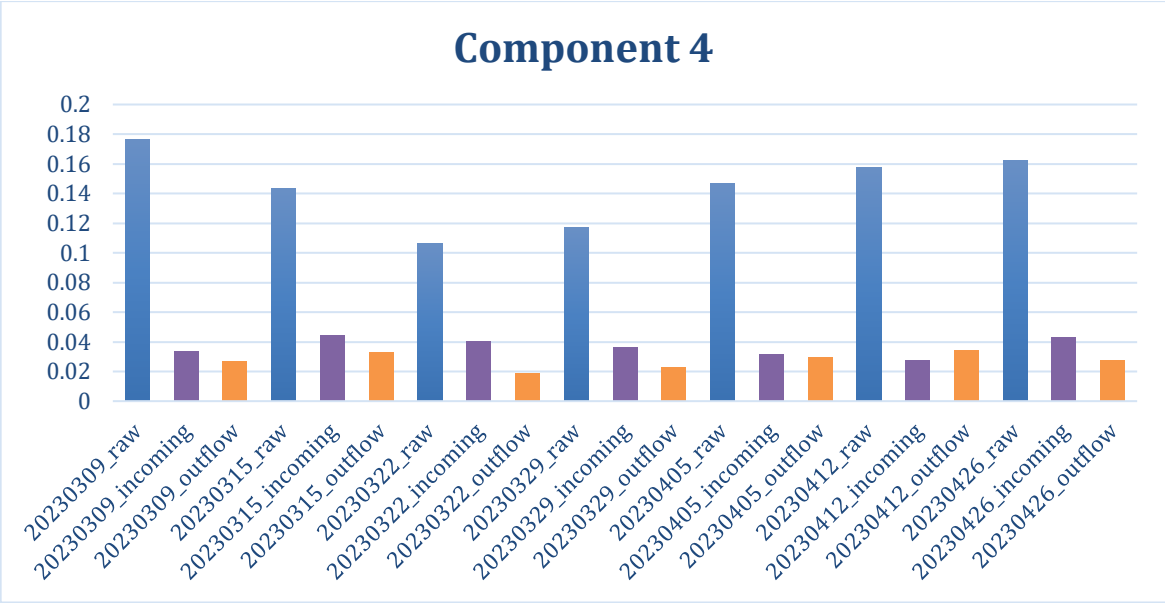

Figure 12. The signal of Component 4 during the sampling period.

The signal of Component 4 was the strongest one and varied in intensity over the sampling period, see Figure 12. The strongest signal, when there is most of this substance present, occurred at the beginning of the sampling period. It thereafter decreased until the 22/4, when it started to increase again through the last sampling campaigns.

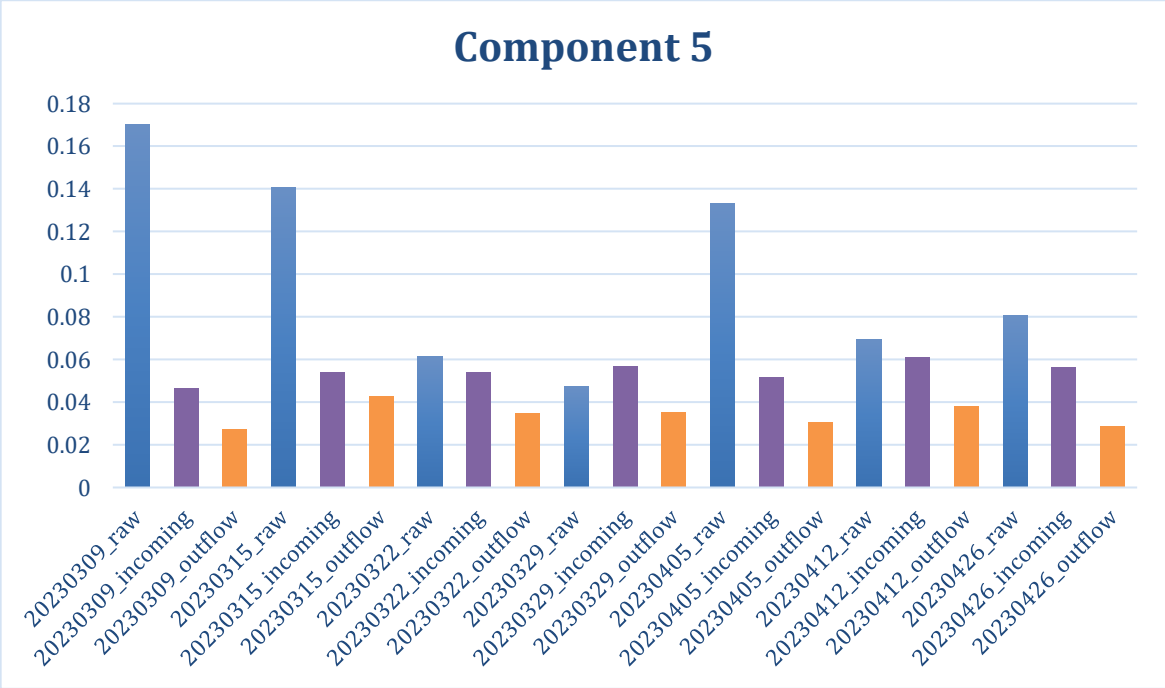

Figure 13. The signal of Component 5 during the sampling period.

Component 5 followed a similar pattern as Component 4, although there was one significant peak in the raw water at 5/4 which did stand out from the pattern, see Figure 13.

The signals in raw water and incoming water to the plant was recalculated to see how much was removed at the first treatment step. Figure 14 and 15 shows how much of Component 4 and 5 respectively was removed by only the addition of chloramine and allowing the contact time in the pipe network up to the plant. The results differ between Component 4 and 5. The removal follows the signal trends in Figure 12 and 13 and was most effective when the signals from Component 4 and 5 was the highest. The chloramine seems to remove Component 4 better than Component 5. During the 29/3, the removal is negative for Component 5, meaning that there is more substance of Component 5 in the incoming water than in the raw water.

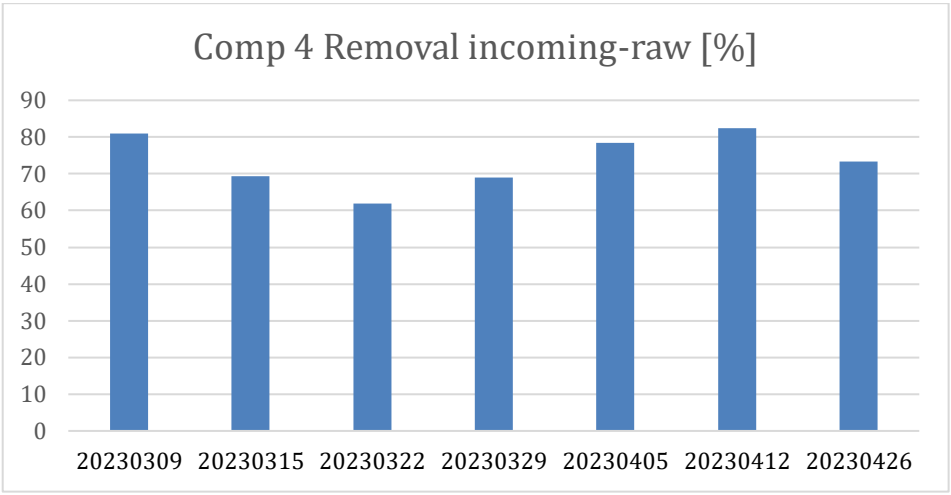

Figure 14. Removal of Component 4 from the raw water to the incoming water to the plant.

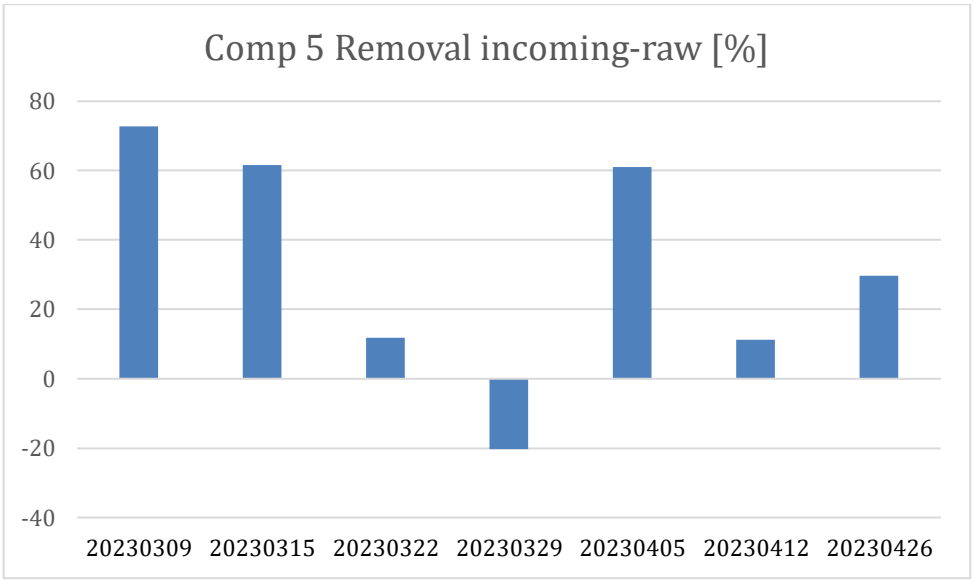

Figure 15. Removal of Component 5 from the raw water to the incoming water to the plant.

4.3 Visible algae

From the samples taken 21/3 at the surface of sand filter 6 with the visible pollution, at least two types of present algae could be identified by using a microscope. These were some type of green alga, and several diatoms and shells from previous living diatoms. Figure 16 show how sand filter 6 appeared, where the samples were taken from the coating at the surface. The microscopic images with comments can be seen in Figure 17, 18 and 19.

Figure 16. Showing the pollution coating on the surface of sand filter 6, in the plant.

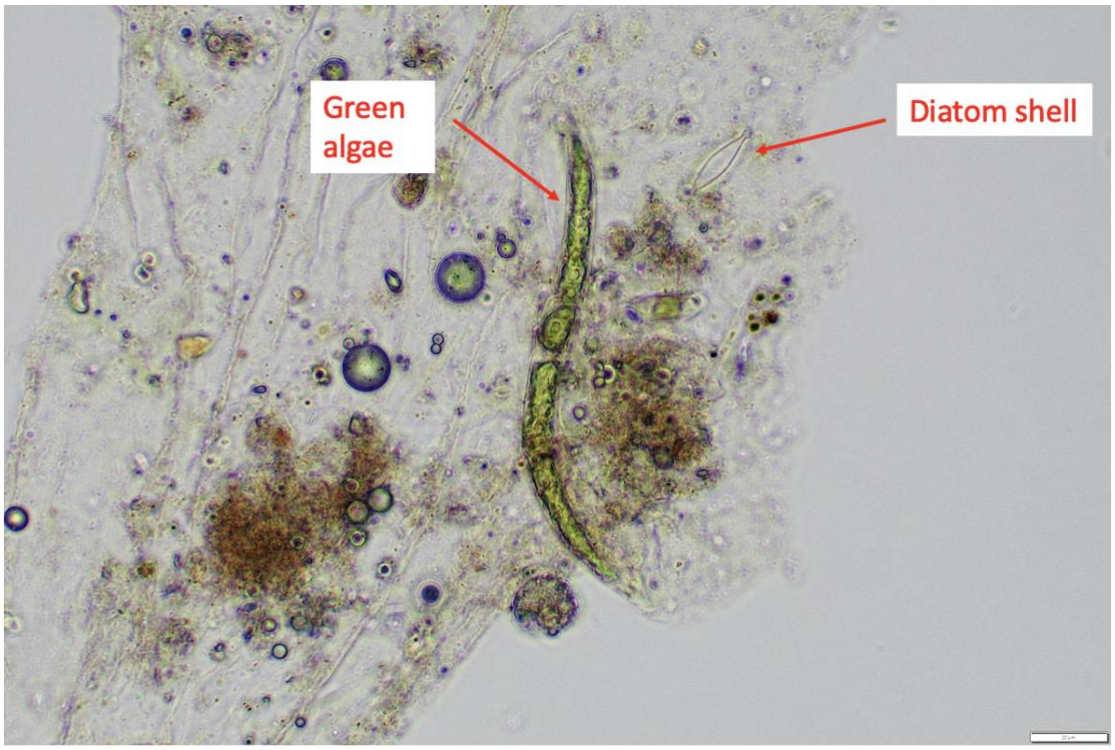

Figure 17. Showing one green alga and one diatom shell.

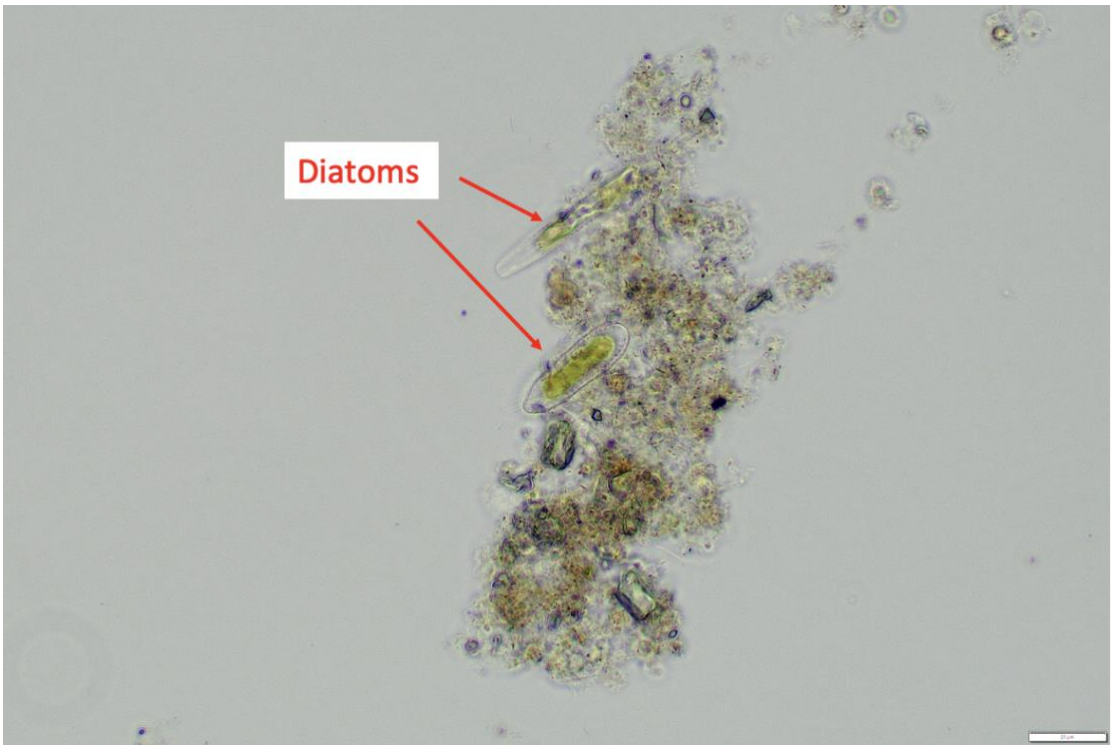

Figure 18. Two living diatoms are on display.

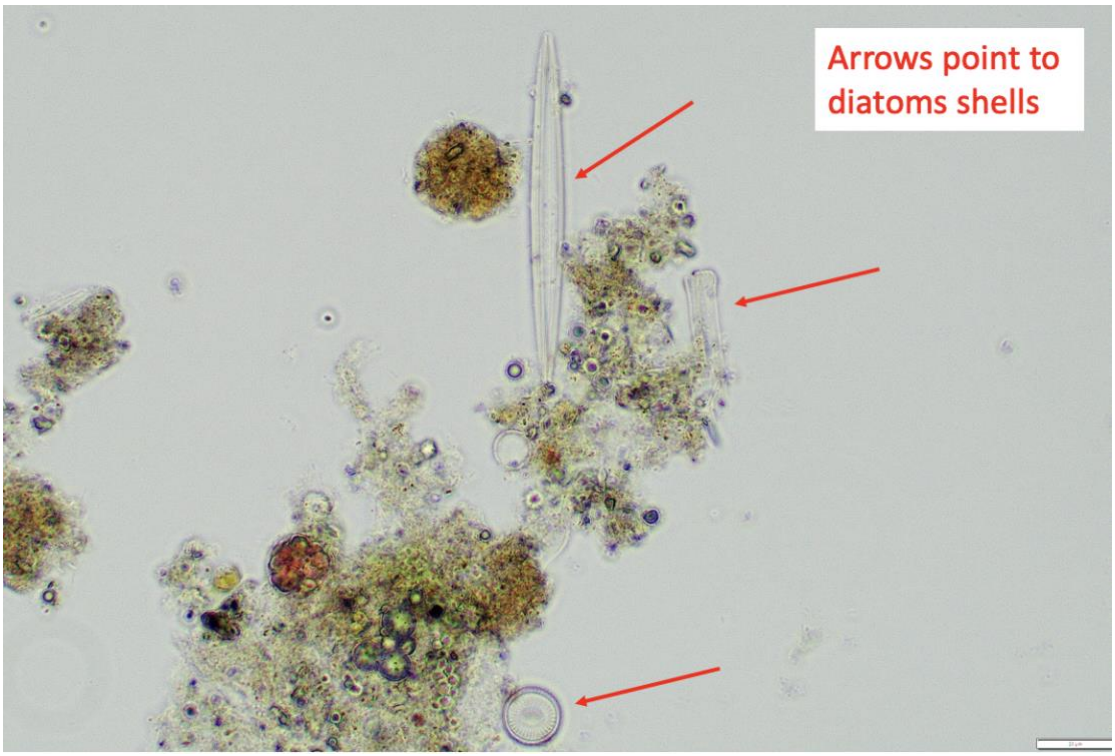

Figure 19. Several shells from diatoms are visible in different shapes.

4.4 Sand filter performance

The fluorescent signals in the outflow from sand filters found five peaks. Each peak was identified and named according to Philibert et al. (2022), see Table 4.

Table 4. Found fluorophores, their corresponding wavelengths, and possible sources.

Fluorophore	Name	Wavelength peak	Possible sources
Fmax 1	Hi	360/455	Humics: ubiquitous
Fmax 2	Hii	395/521	Conjugated humics: ubiquitous
Fmax 3	Hiii	330/404	Microbially-linked humics: ubiquitous
Fmax 4	Hiv	300/430	Terrestrial humics: ubiquitous
Fmax 5	Pi	290/365	Amino acids-tryptophan

At first look, the results of the sand filters seem rather inconsistent. For some dates, the outcome signals were rather uniform while other times there were clear peaks in some of the sand filters.

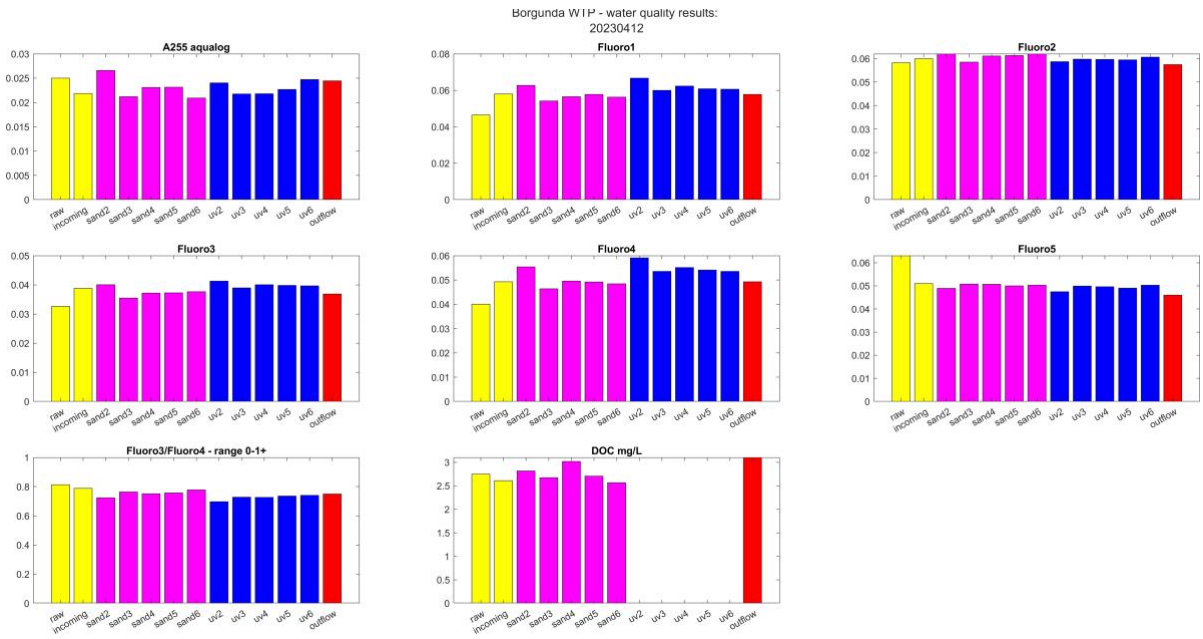

Figure 20. Absorbance and fluorescent signals gathered the 12/4.

Figure 20 shows a summary of the absorbance and fluorescent signals at one of the dates (12/4) that was analysed. This type of data was analysed for all the sampling occasions. In some cases, the signal at the outflow of the sand filters is higher than the signal in the incoming water. This means that the sand filters are producing material that are being picked up in the fluorophore signals. Sand filters are never sterile, instead, they contain bacteria or other organic matter that can grow. In this case, it is likely biofilms which release material that produce signals in fluorophores. In Figure 20 it can also be observed that the signals are higher in the incoming water than in the raw water for fluoro 1, 2, 3 and 4. Thus, these substances are increasing on the way to the plant in the pipe.

The relative removal of the fluorophores varied between the sand filters, indicating uneven performances, see Figure 21-25. The relative removal was sometimes negative, which is a sign that the filter during the sample period sometimes produced material in biofilms rather than removed.

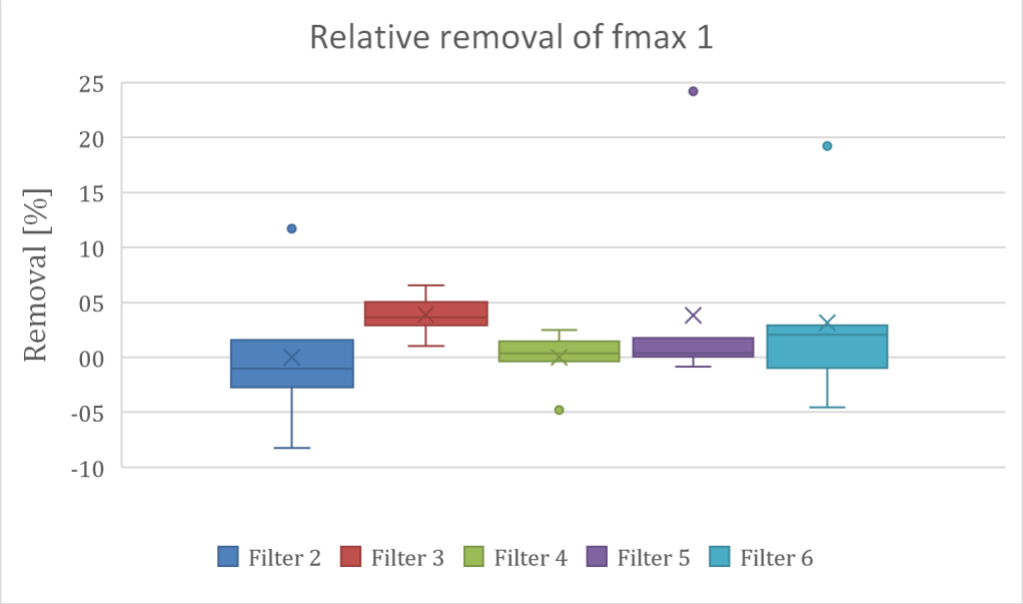

Figure 21. Relative removal of fmax 1 over respective sand filter over the whole sampling period.

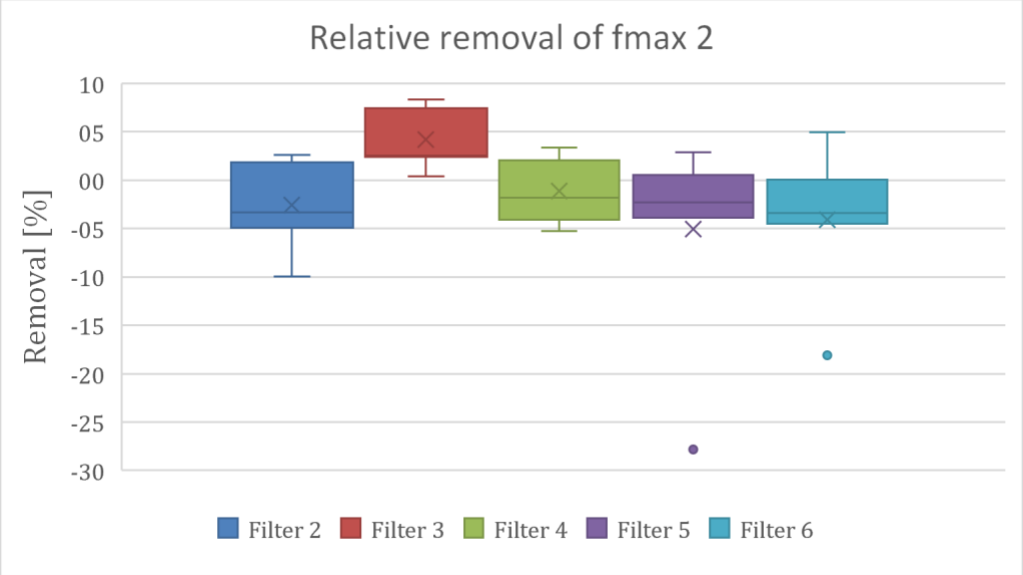

Figure 22. Relative removal of fmax 2 over respective sand filter over the whole sampling period.

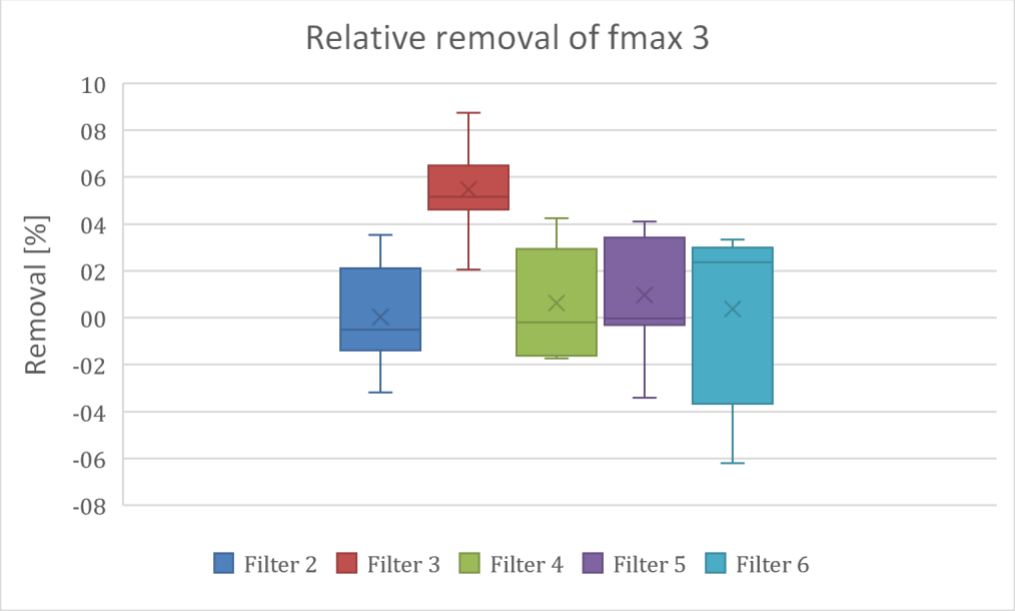

Figure 23. Relative removal of fmax 3 over respective sand filter over the whole sampling period.

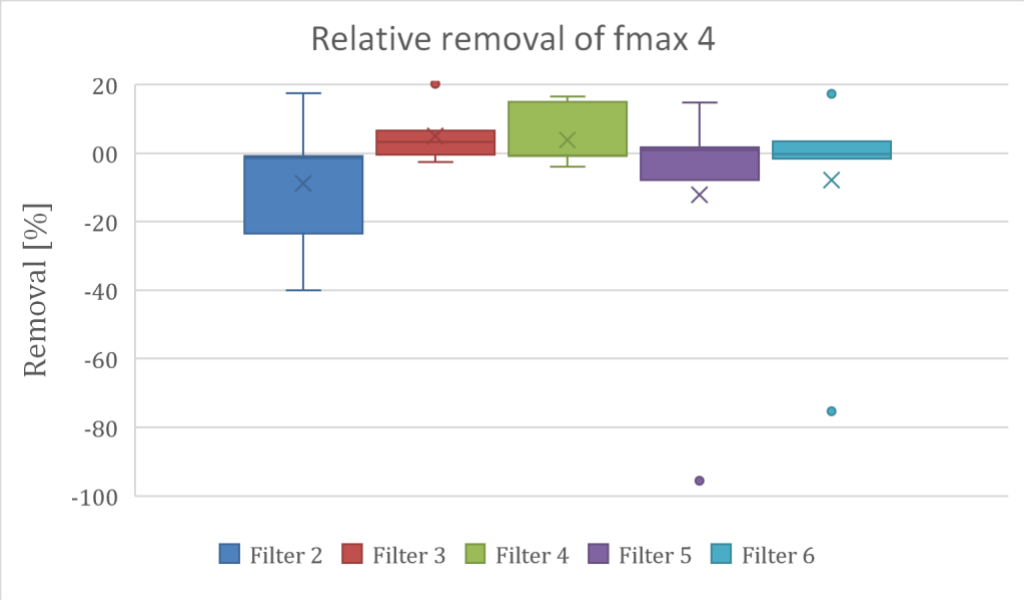

Figure 24. Relative removal of fmax 4 over respective sand filter over the whole sampling period.

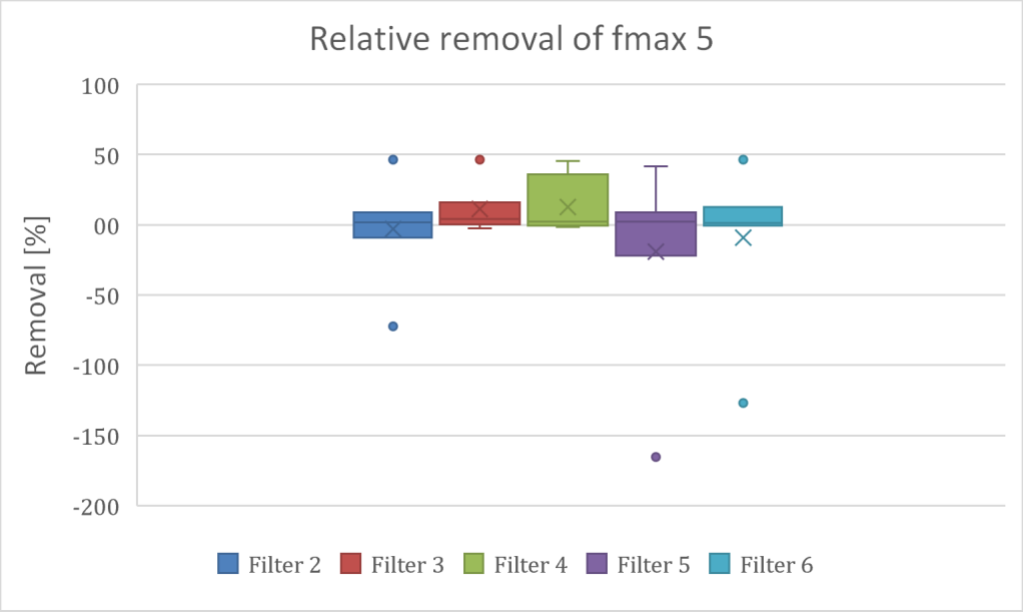

Figure 25. Relative removal of fmax 5 over respective sand filter over the whole sampling period.

The sand filters that, compared to the other sand filters, most frequently had a more negative removal (i.e., was producing) or lower removal, was sand filter 2. Filter 3 performed best removal of fmax 1, fmax 2 and fmax 3, compared to the other sand filters.

For sand filter 2 there seem to be two peaks in several of the fluorophore components, see Figure 26. The signal on the 12/4 is significantly high for absorbance, fmax 2, and among the highest fmax 1 and fmax 3. This either means that less DOM was removed that date or that there was more DOM coming into the plant due to externalities. The other peak is visible on 14/3 for fmax 4 and fmax 5.

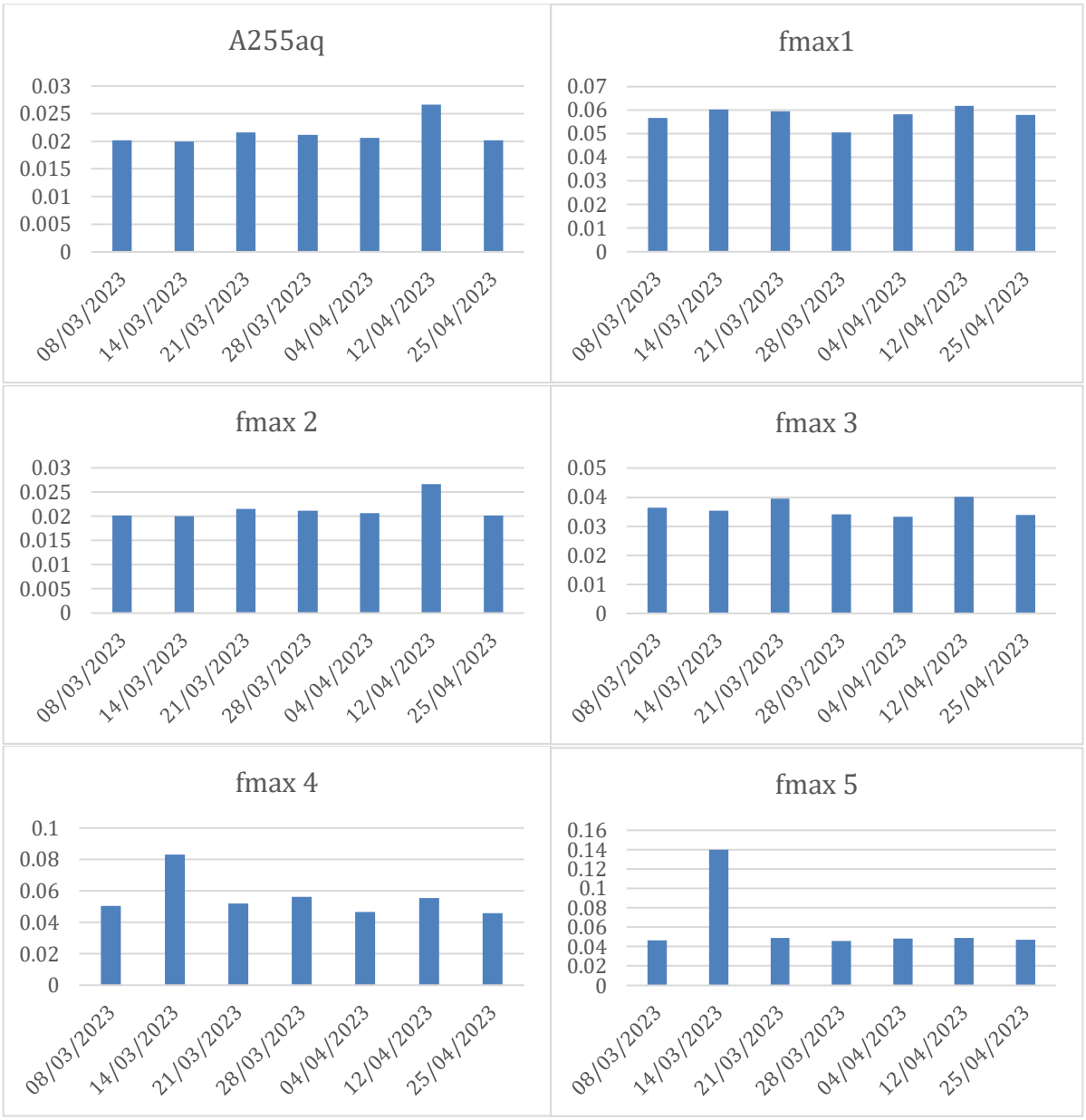

Figure 26. Displaying different fluorescence components in sand filter 2 over the sampling period, and A225aq which is the absorbance.

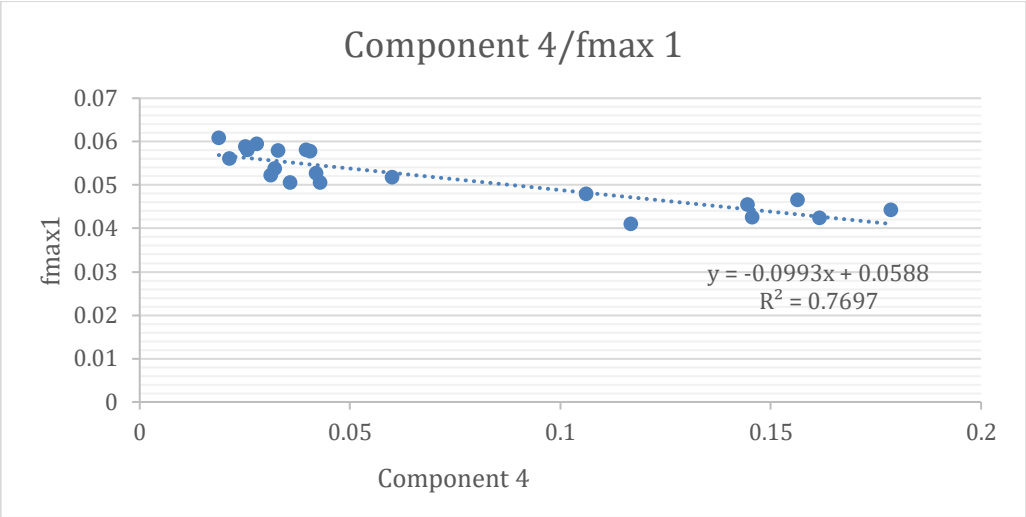

Figure 27. A scatter plot that shows the correlation between fmax 1 and Component 4.

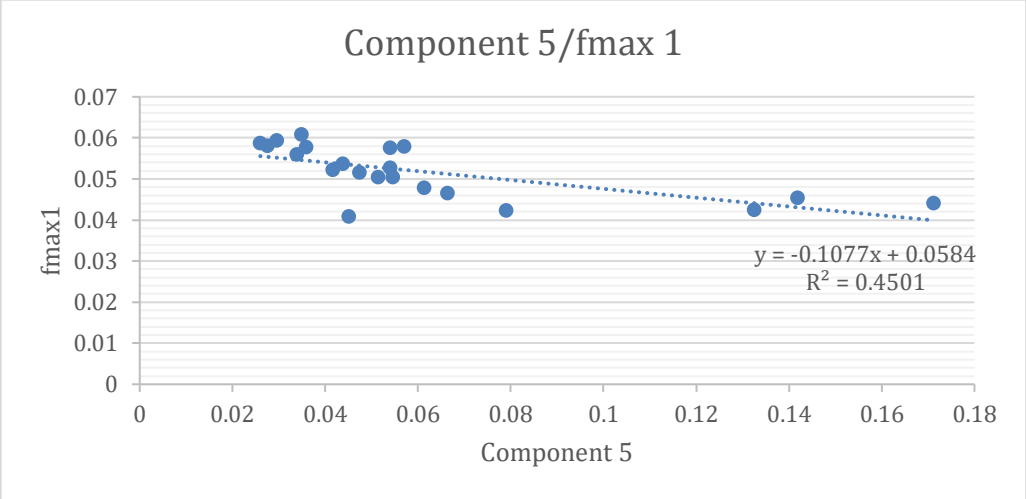

Figure 28. A scatter plot that shows the correlation between fmax 1 and Component 5.

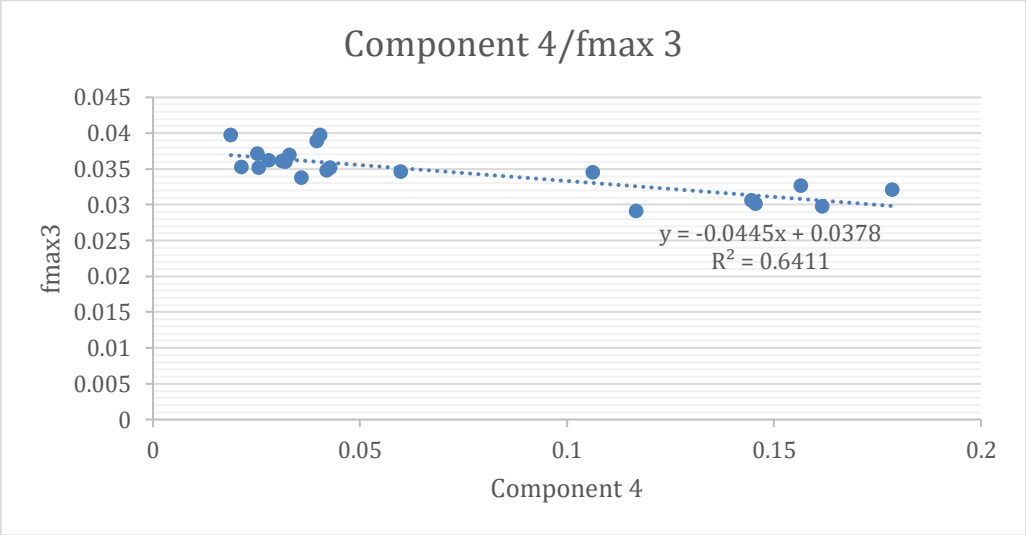

Figure 29. A scatter plot that shows the correlation between fmax 3 and Component 4.

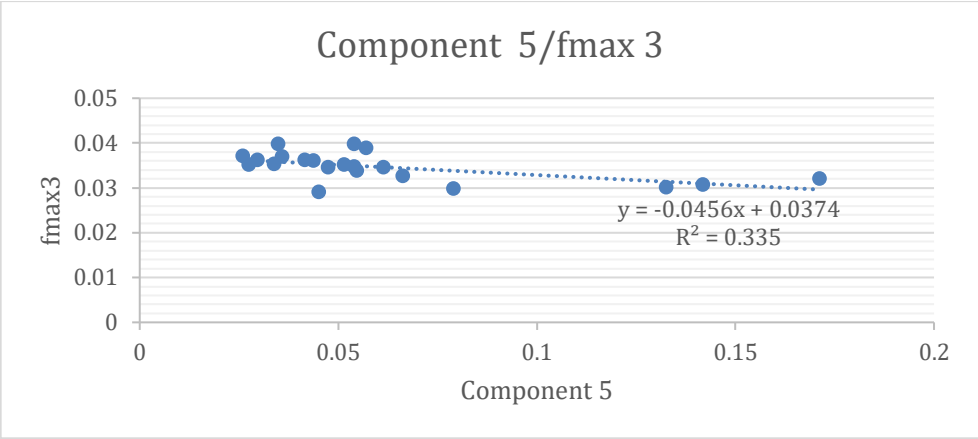

Figure 30. A scatter plot that shows the correlation between fmax 3 and Component 5.

A weak correlation was found between Component 4, Component 5 with fmax 1 and fmax 3 respectively, see Figure 27-30. All these correlation coefficients (R^2) are above or close to 0.4 which indicates a moderate correlation. The correlation in Figure 28 with fmax 1 and Component 5 is guided by a few extreme points but will likely be even more correlated if these are not considered.

5 Discussion

In this section, the research questions and hypotheses are discussed in relation to the results. Uncertainties and recommendations for future research are also addressed.

5.1 Detected algae components

The results of the identified algae Component 4 and 5 showed the highest signal in the beginning of the sampling period, which was unexpected and not according to the hypothesis. That the signal went up during the last sampling occasions was more expected due to the warmer temperatures. In other words, the trend in signal intensity did not follow the air temperature. This suggests that the algae are dependent on other factors than only temperature, such as hours of sunlight or wind direction.

The identified components had peak emissions around 680 nm and 580 nm. The peak at 680 nm confirms the presence of chlorophyll *a* which indicates one or several algal species. The other peak at 580 nm indicates phycoerythrin which suggests a presence of either cyanobacteria or red algae. Since the fluorescence spectral data cannot separate phytoplankton species, there is a lack of information to denote how many different phytoplankton species are found in the water. The fluorescence data clearly showed presence of phytoplankton, and the ranges in peak emission wavelength insinuates more than one species present, although this cannot be proven without more elaborate analyse.

Regarding the wind direction, the results indicate that east wind could be a possible explanation for stronger fluorescence signals. The highest signal in found components occurred at the first sampling occasion (7/3) when there was indeed eastern wind. The weather conditions that day, and the previous 24 hours, had been rather extreme with heavy snowfall and strong eastern winds. The following sampling occasion (13/3) high signal cannot be due the wind direction since it was not east. Yet, it is likely that there was remaining effects by the previous weeks extreme weather conditions since the temperature had turned over to plus degrees and the snow was melting very rapidly. This likely increased the flow of the runoff-streams to the lake which brought a lot of humic substances with it, providing nutrient to possible algae. The three last sampling occasions (3/4, 11/4, 24/4) did show increasing fluorescence signals and the wind direction was east or close to it. This points to that wind direction could be one possible explanation for increased organic material in raw water. However, there is a need for a longer set of measuring data to confirm this.

The removal ratio for Component 4 and 5 shows that the chloramine can reduce the organic material before it reaches the plant. Since the removal differ between Component 4 and 5, this speaks for that there are different algae species with different properties. During the 29/3 there was a negative removal of Component 5, meaning that this substance was instead produced in the pipe to the treatment plant.

5.2 Sand filter performance and microscope images

The relative removal of fmax components over the sand filters were often negative, suggesting that material was produced in the sand filters rather than removed. The sand filter that most frequently had lower removal or more negative removal in several fluorophore components were sand filter 2. Interestingly, sand filter 2 has been renovated this past year. Upon putting it into operation, the plant personal noticed more dirt in these filters compared to the other filters in operation. Therefore, it is suggested that the new sand put in the filters is not completely clean and have likely been stored outside causing them to be somewhat polluted. Whether this previous pollution is still showing effect several months later is debateable. It is more likely that something else is affecting the performance of this filter and would be interesting to investigate further.

Sand filter 2 had especially high peaks on the 14/3 and 12/4. The peak in 14/3 is probably due to snow melt as previously stated. During 12/4 there was south-east wind and a higher temperature than at the previous sampling occasion, which likely are contributing reasons. Component 4 and Component 5 were found to have a moderate correlation with fmax 1 and fmax 3. Consequently, monitoring of fmax 1 and 3 could be used to predict problems with increasing phytoplankton concentration.

Regarding the notations on filter being backwashed the latest 24 hours, no trend that the sand filters could be linked to higher or lower outcomes in signal intensity could be found in the results.

The microscope images found diatoms, and many shells from previous living diatoms. The shells probably remain because their structure is very resistant. Green algae were also found. Thus, the microscope images reinforce the results from fluorescence that there is chlorophyll in form of phytoplankton in the raw water, and that there are several species present. Since the presence of phytoplankton is confirmed, it is very likely that algae are causing the problems with the sand filters and occasional unpleasant taste and odour of the outgoing water. The found fmax-components are not effectively removed by the sand filters but will continue through the treatment processes and affect the outgoing water. Note that phytoplankton are not pathogens and does not cause health risks, but merely affects properties lake taste and odour of water.

5.3 Uncertainties and future research

The treatment plant is experiencing problems with their sand filters during spring or early summer - but not during late summer which is otherwise quite common. That the problems occur in spring could be due to factors discussed earlier. Namely that there is a snowmelt and increased flow in runoff streams that brings nutrient to the lake which enables phytoplankton growth. It is also likely that the sun warms the water, leading to a temperature difference between the warm and colder water. This will likely start a turnover, which brings up nutrient from the bottom that has been gathered during the winter, to the surface. In the summer the water will likely be very stratified with little mixing, and even though there might be algae growth on the surface it will not reach the water intake if it is located deep enough. This could be a possible explanation as to why the plant is experiencing problems in the spring season.

The main uncertainty in this study is that it was performed during a limited period of time and the results are rather weather dependent. This spring can be considered as relatively cold, perhaps more so than recent spring seasons. Long winters and cold temperatures will likely influence the extent of phytoplankton bloom and thereby the results from samples gathered during this time. Another uncertainty is the sampling itself. The samples from the outflow of each sand filter and after the UV radiation were taken at taps with a rather splashing flow, and air was mixed in when the water was gathered. This means that the samples might not be completely representative from especially the sand filters. Recent backwashing of the sand filters can also be considered as an uncertainty. Even though no clear connection could be made, it possibly affected the result. Furthermore, the data from this period could be insufficient due to that the sampling was not performed frequent enough, and there was also a gap in between 12-24/5 due to illness. At optimal, sampling should be performed every 2-3 days to account for short-lived peaks of microbes and algae (Kavagutti et.al, 2023). This was not possible due to the extent of this project, working hours at the plant and the traveling distance between sampling and laboratory.

Future studies are recommended to study algae bloom during spring season in freshwater as well as in drinking water plants. Another interesting aspect is the effect of chlorination on phytoplankton, which occurs at the Borgunda treatment plant but was not included in the scope of this thesis. Because one of the dates, the 14/3, generated one of the highest signals in the fluorophore components yet could not be explained by wind direction, it is likely that other external circumstances affect the result. The snowmelt is a possible explanation, which would need more research to connect how and if snow melting and increased runoff can contribute to algae bloom in early spring season.

6 Conclusion

There is presence of chlorophyll in the raw water, incoming and outflowing water which had a fluorescent signal at wavelengths above 550 nm, which implies algae. From the fluorescence data the PARAFAC model could identify two components corresponding to either two different algae species or two parts of one algae specie, reflecting fluorescence differently. The signals from Components 4 and 5 were highest at the first two sampling occasions and at the last three. The emission peak at 680 nm represents chlorophyll *a*, and thereby presence of one or several algal species. The peak at 580 nm suggests cyanobacteria or red algae although a more elaborate analysis would be needed to confirm this. Still, the range in wavelengths insinuates that there is more than one phytoplankton species present.

From microscopic images several shells and living diatoms, including one green alga could be identified during the visible algae outbreak on the surface of sand filter 6 on the 21/3. This further emphasizes that there is a diversity of phytoplankton in the raw water source. The presence of several phytoplankton species means that algae are, with high probability, the reason for the occasional unpleasant taste and odour in the outgoing water and for causing the problems with the sand filters.

Out of the sand filters, filter 3 was performing best in respect to the relative removal of several fluorophore components. Sand filter 2 indicated the worst performance during this sample period since it was producing signals or had a lower removal of several fluorophore components, compared to the other sand filters.

There was no clear indication that the temperature during the sampling period influenced the fluorescent signal and thereby algae bloom. A correlation could however be found between the eastern wind and increased fluorescent signal in the raw water, although it was weak.

By using fluorescence spectroscopy, information could be gathered about the DOM composition of the water at Borgunda. Knowledge and monitoring of water characteristics can predict problems and lead to optimisation of current or future treatment processes. Future studies on phytoplankton bloom in fresh water during spring season can contribute more knowledge in the field and be beneficial also for other surface water treatment plants.

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