SYSTEM UNDERSTANDING, NUTRIENT-RELATED MEASURES AND ALGAE REMOVAL IN LAKE VOLKERAK-ZOOM 2021-2050

Researching effective nutrient-related methods in Microcystis removal and the science-policy communication around Lake Volkerak-Zoom.

Thesis study

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PEFACE

In front of you, the bachelor thesis of my four-year educational study watermanagement – aquatic ecotechnology at HZ University of Applied Sciences, located in Middelburg. Writing my bachelor thesis was an informative process in which I could apply my knowledge and experiences of the past four years of my bachelor studies. An interesting research which was well adapted to my previous knowledge; however, it still had some interesting additions that gave me the chance to learn and implement some under-developed subjects. In addition, I have learned many more new aspects on working on a project within a knowledge institute, Deltares. Unfortunately, it was a difficult time to get the experience at the organization itself since all the work has been executed at home. However, I definitely experienced the way of working at Deltares, especially within the department sea and coastal systems. Most contact I have had during my internship period was with my in-company coordinator, Arno Nolte. Therefore, I would like to thank my in-company coordinator for the help with integrating in the way of working at Deltares and the help and feedback on the process of writing my bachelor thesis. Besides, that I would like to thank the other colleagues for the help, giving feedback and with the implementation of my data within the D-HYDRO model. In addition, also a special thanks to friends and family for the support during the time of writing my thesis at home.

I wish you a pleasant time reading my bachelor graduation thesis.

Sanne Haan
Middelburg, May 24, 2021

ABSTRACT

This research examines the water quality of Lake Volkerak-Zoom, focusing on annual returning blue-green algae (*Microcystis*) blooms. In addition, this research is focused on the possibility to sustainably remove 50% blue-green algae (*Microcystis*) from Lake Volkerak-Zoom using nutrient-related measures, taking into account possible climate change effects until 2050. This research is mostly conducted by desk research. A system analysis of Lake Volkerak-Zoom with its ecosystem components was conducted from a previous study of Deltares, (2021). This system analysis is used as the basis of this research to visualize what components are most important for the growth of blue-green algae (*Microcystis*). A further desk research is based on these important ecosystem elements, with as most important element; nutrients and the growth impacts of blue-green algae (*Microcystis*). These most important elements were placed within a DPSIR approach and further researched. Subsequently, two possible nutrient-related measures could be researched on its possibility and effectiveness. The chosen measures within this research are a 20% reduction of the discharging rivers from Brabant (Dintel and Vliet) on Lake Volkerak-Zoom and a nutrient removal of 60% total-N and 50% total-P in 500 hectares wetlands in Lake Volkerak-Zoom. To include the climate change in the model, an average temperature increase is chosen of 1,8˚C until 2050. Since this measure is included within the model, this can more or less be seen as one of the measures, although, climate change is not nutrient-related.

Most important results from this research were the algae removal percentages the two nutrient-related measures resulted. Both measures were similar in its results. Eventually could be concluded that on average, both measures are effective for the removal of 30% blue-green algae (*Microcystis*) in lake Volkerak-Zoom. In addition, climate change effects were included. This possible change until 2050 gave interesting results in terms an algal removal efficiency of 10% – 20% could be concluded. Although, some interesting removal efficiencies are concluded, these do not meet the requirements stated in the main research question of this research, to remove 50% blue-green algae (*Microcystis*). To reach this 50% blue-green algae (*Microcystis*) removal efficiency, a further nutrient reduction will be required.

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1 INTRODUCTION

1.1 Introduction

Blue-green algae are an annual recurring problem during the summer months in Lake Volkerak-Zoom. Before 1987, Lake Volkerak-Zoom was an estuary with a mix of river water from the Hollandsch Diep and salt water from Grevelingen and the Eastern Scheldt. In 1987, new dams were constructed, the Oesterdam and the Philipsdam as part of the Delta program that was set-up after the flood in 1953 (Watersnoodmuseum, 2020). The Oesterdam and Philipsdam created a division between lake Grevelingen and the Eastern Scheldt. Thereby, a new freshwater lake originated: Lake Volkerak-Zoom. Geographically seen, Lake Volkerak-Zoom exists of two lakes, Lake Volkerak and Lake Zoom, with as connection a canal named Scheldt-Rhine. Although Lake Volkerak-Zoom is now a freshwater lake, the morphology is still typical for a tidal system: a gradual, relatively steep slope to a deep tidal gully in the middle of the lake (Tosserams et al., 2000).

Since the enclosure of Lake Volkerak, the water in the lake transitioned from a saltwater system to a freshwater system. The entire ecosystem of Lake Volkerak-Zoom changed. Until 1990, the lake was of relatively good freshwater quality and a rising biodiversity of flora and fauna in and around the lake was observed (Tosserams et al., 2000). However, after 1990, the water quality and ecological quality of lake Volkerak-Zoom came in a period of degradation, most visibly in the occurrence of harmful blue-green algae blooms and culminating in extensive bird kills in 2003. After the introduction of the exotic Quagga mussel, the blue-green algae blooms decreased, although, never disappeared (Weeber et al., 2018 and Dionisio Pires, 2020).

A high amount of nutrients got discharged in Lake Volkerak-Zoom which started a yearly appearance of algae bloom during summers. Besides a bad smell and a green layer over the water, a larger problem was occurring in the lake. The water quality and ecological quality was changing and stakeholders such as agriculture, fishery and recreation faced problems with this yearly occurring phenomenon (De Vries & Postma, 2013). This blue-green algal (Microcystis) growth in the lake resulted in a nuisance for the ecosystem as well as for humans. Blue-green algae (*Microcystis*) release toxins when it dies. Furthermore, can blue-green algal blooms release a rotting, smelly layer on top of the surface of the lake which causes a freshwater lake that is not suitable for the irrigation of agricultural crops, drinking water for cattle and the recreational waters (Ministerie Infratructuur en Milieu, 2014).

Nowadays, blue-green algae (*Microcystis*) are still considered a big concern for Lake Volkerak-Zoom. In recent years, the blue-green algae problem appears to increase in Lake Volkerak-Zoom in which no clear cause can be stated and no increase in concentration of occurrence can be derived from available measurements (Dionsio Pires, 2020 & Weeber et al., 2018).

Now an introduction to this research is given, will the next paragraph state the research problem. In addition, the research focus and scope and limitations of this research will in the following paragraphs be described.

1.2 Problem statement

Lake Volkerak-Zoom faces a variety of problems that result from closing of the lake. One of the problems possibly exist of the relatively high inflow of nutrient rich river water in combination with a residence time that is long enough to provide suitable growing conditions for blue-green algae (*Microcystis*) in Lake Volkerak-Zoom. Nutrient limitation is a driving force in the development of ecosystems (Koerselman & Meuleman, 1996). However, nutrients are not limiting in Lake Volkerak-Zoom. Therefore, these nutrient concentrations cause algal bloom during the summer months. In addition, weather and climate patterns are changing, which may cause an extra impact on the *Microcystis* growth in Lake Volkerak-Zoom. Blue-green algae (*Microcystis*) contain toxins. These toxins are harmful to the ecosystem and beyond. Therefore, extra problems may occur for recreation, nature, fisheries and the use of the fresh water for agricultural irrigation. (Kramer et al., 2016). Although, literature states that nutrient concentrations became lower, there is no clear cause why the blue-green algae (*Microcystis*) are still considered a relevant problem in Lake Volkerak-Zoom.

1.3 Research focus

This research will focus on the blue-green algae (*Microcystis*) growth in Lake Volkerak-Zoom and possibilities to effectively remove 50% of the blue-green algae using nutrient-related measures. Furthermore, a future climate perspective will be analyzed to visualize to what extend the blue-green algae (*Microcystis*) growth might be affected by climate change. Finally, these nutrient-related measures and climate perspectives will be placed within a communication system called: DPSIR. The DPSIR communication approach is added to research and visualize whether this research is understandable and reaches the required effect to the stakeholders of the Lake Volkerak-Zoom area.

1.4 Scope and limitations

As been stated in the paragraph ‘research focus’, this research will focus on the yearly returning blue-green algal bloom in Lake Volkerak-Zoom. A relation will be investigated between blue-green algae, climate change and nutrient loads in Lake Volkerak-Zoom. Furthermore, this research will focus to what extend it is possible to reduce the blue-green algae with 50%. In addition, nutrient-related measures will be researched on its effectiveness. Effective in this context means that the nutrient-related measures must reach an algae removal close to the 50%.

Within this research is focused on a blue-green algae (*Microcystis*) removal efficiency of 50%. Although, algal blooms occur in high numbers of single algae, the *Microcystis* concentration is measured in mg/l. By the use of literature, models and data analysis, nutrient-related measures could be investigated on nutrient removal efficiencies which further indicate whether the chosen measure reaches the 50% blue-green algae removal. The 50% target level is set more or less arbitrarily as an indication of a substantial decrease in harmful blooms. Identifying a required target for sustainable system functioning is outside the scope of this research.

1.5 Justification

This paper is composed of nine chapters that are divided into several paragraphs, which all include information that eventually leads to the answer to the main research question and the thereon based sub-questions for a better understanding and definition. The following paragraph of this chapter indicates the research question and corresponding sub-questions.

Chapter two: the theoretical framework, lays out the theoretical dimensions of the research that are of relevance for the blue-green algae growth in Lake Volkerak-Zoom.

Chapter three is concerned with the methodology of the research used for this study. Most important for the method is the explanation of how the information of the results is derived and what a DPSIR is, and how the DPSIR method will be used within this research.

The fourth chapter represents the findings and results of this research. In first, a focused DPSIR has been created, with information in every section that is of importance for the blue-green algae in state of Lake Volkerak-Zoom. In addition, is focused on the nutrient-related measures and the efficiencies. The efficiencies are used to implement in the used D-HYDRO model which is analyzed on a variety of datasets that were of importance to answer the main research question of this research.

Chapter five presents the conclusions that are based on the results, on which chapter six follows on the over-all research with the discussion. Based on the conclusion and discussion, chapter seven is created to give recommendations for further or new research within this field of knowledge.

Finally, this research will end with the references and appendices, which includes additional information that was not enough of relevance or too extensive to include in the main chapters of the research.

1.6 Research question

Based on the problem statement and research focus, the following research question will be examined:

“To what extend is the DPSIR approach to system understanding suitable to provide stakeholders sufficient insight to assess different nutrient-related measures to remove 50% of the blue-green algae from Lake Volkerak-Zoom until 2050?”

1.7 Sub-questions

The sub-questions within this research can be divided into two categories: 1). Providing insight to science-policy communication and 2). Providing measures/solutions for nutrients and blue-green algae (*Microcystis*).
In order to answer the main research question, the following sub-questions are set up, and will be researched:

1. How can the DPSIR system diagram be visualized based on Lake Volkerak-Zoom, with nutrients and blue-green algae as a central point in the system?
2. What are options to communicate and visualize the DPSIR approach to stakeholders?
3. How is it possible to provide insight in uncertainties in the DPSIR approach?

4. What is the relation between nutrients as nitrogen and phosphorus, and blue-green algae (*Microcystis*)?
5. What measures can be taken to reduce nutrient concentrations in Lake Volkerak-Zoom?
6. How much reduction of nitrogen and phosphorus is required to remove 50% of blue-green algae (*Microcystis*)?
7. What are expected trends of the relation nutrients and blue-green algae (*Microcystis*) until 2050?

2 THEORETHICAL FRAMEWORK

2.1 Lake Volkerak-Zoom; System description

Lake Volkerak is situated between the island of Goeree-Overflakee on the north-west and the province of Noord-Brabant on the south-east (figure 1). The lake is about 8145 hectares of which 25% is dry former saltmarsh. The average depth is 5,2 meters, with a maximum of 24 meters (Kramer et al., 2016). In between Lake Volkerak and Lake Zoom is the canal Scheldt-Rhine situated. This canal is important for shipping between the port of Rotterdam and port of Antwerp. In addition, this canal is important for the port connection between Antwerp and Germany (Kramer et al., 2016).

Figure 1: Overview of the area Lake Volkerak-Zoom. Surrounded by three provinces (Zeeland, Brabant and Zuid-Holland) and the important rivers (Hollandsch Diep, Dintel and Vliet) (Haan, 2021).

Fresh water inflow to Lake Volkerak comes from the river Hollandsch Diep and rivers from Brabant: the Dintel, Steenbergsche Vliet and the Zoom. The outflow is through the Bathse Spuisluis, the Kreekrak sluices and the Krammer sluices. In order to keep Lake Volkerak a freshwater lake, the outflow sluices are designed in such a way that the fresh and saltwater is always separated from each other in order to minimize the saltwater to infiltrate in the freshwater lake and canal (Kramer et al., 2016). This paragraph defined the geographical location of Lake Volkerak-Zoom. Based on the geographical information, the following paragraph will explain the system components that are of relevance for the system Lake Volkerak-Zoom.

2.2 System analysis; Connecting components

Relevant components of the system are introduced within the system diagram of Lake Volkerak-Zoom that is created according to previous research by Deltares (figure 2) (Deltares, 2021). Lake Volkerak-Zoom is a dynamic system with many different influences from outside the system that act on the components within the system. All relevant components that act in and around the system are included within figure 2.

Important external components that act on the system are abiotic factors; climate change, meteorology and influence of surrounding and discharging waters. Figure 2 visualizes that there is an influence by the surrounding waters and areas: Eastern Scheldt, Western Scheldt, Brabantse Delta, Scheldestromen and the Hollandse Delta (Deltares et al., 2020). Climate change has an indirect and direct influence on the system which can be seen for example in the increase of salt seepage. Meteorology has also both a direct and indirect influence on the system. Precipitation, light, wind and evaporation/evapotranspiration are relevant abiotic factors that are required for life within a system. Meteorological elements create water refreshment, currents, photosynthesis: the basis for a waterbody and its primary production (Campbell et al., 2018).

Within the system diagram can be seen that many elements are interconnected, which visualizes that these components have a cause and effect relationship. For example: nutrients are impacted by the systems water balance. Besides that, nutrients are required for primary production, and primary production is required for algae growth.
Primary producers as algae are required as energy source for zooplankton, in which zooplankton is required as energy source for small fish, and small fish for larger fish or birds.
Now the system analysis is explained by the use of the system diagram (figure 2), a further, more detailed explanation on most relevant system components that are related to the research question; nutrients and blue-green algae (*Microcystis*) will be given within the following paragraphs of the theoretical framework.

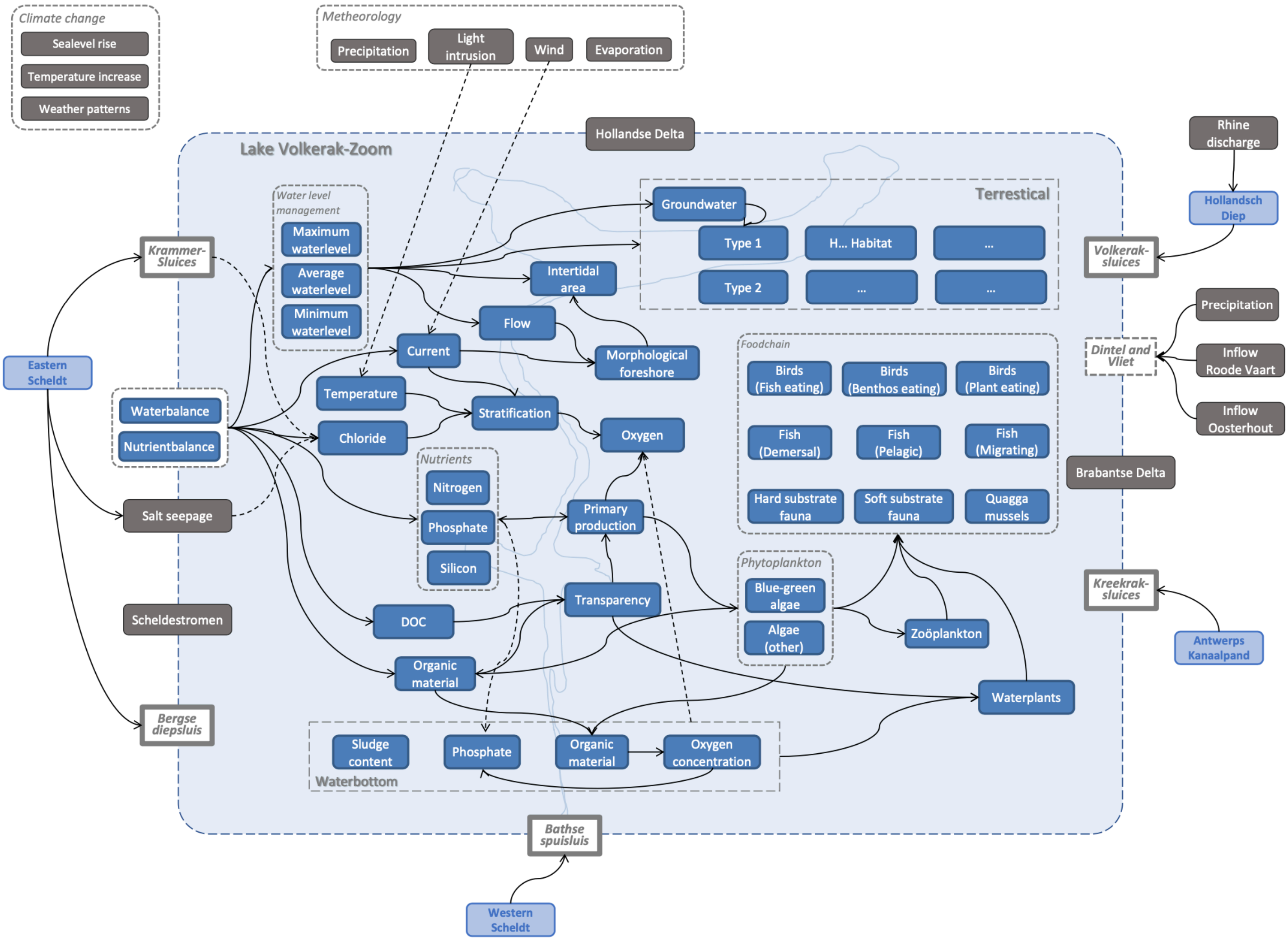

Figure 2: System analysis of Lake Volkerak-Zoom. Including leading biotic and abiotic components that influence each other or other components within the ecosystem (Deltares, 2021) (Modified by: Haan, 2021).

2.3 Primary production

In most ecosystems, the amount of light energy is converted into chemical energy (in the form of organic compounds) by autotrophs during a given time period. This energy build-up is the ecosystem's primary production (figure 3). Primary production within an ecosystem is driven by autotrophs which are called primary producers. Most autotrophs can be categorized as photosynthetic organisms that use light energy to synthesize sugars and other organic compounds which is used for cellular respiration and as building material for growth. Most common autotrophs are plants and algae (Campbell et al., 2018).

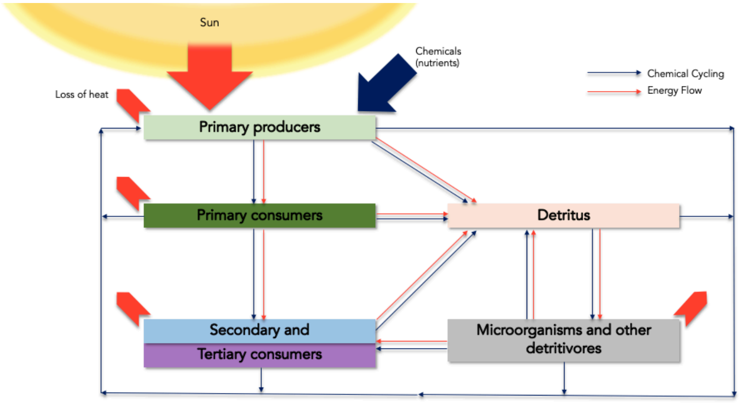

Figure 3: Overview of energy and nutrient dynamics in an ecosystem. Flows of chemical cycling and energy flows are visualized in how this occurs in an ecosystem under trophic levels. energy is kept in the system and some energy is lost (Campbell et al., 2018) (Modified by: Haan, 2021).

2.4 Heterotrophs, detritivores and microorganisms

Now the primary producers are defined, it will be discussed what further elements can be found within the trophic levels of an ecosystem. Organisms that derive their energy from primary producers are called heterotrophs. Heterotrophic organisms can be placed within the system as primary consumers (herbivores), secondary consumers and tertiary consumers (carnivores). In addition, is another group of heterotrophs, detritivores also an important factor within an ecosystem. Detritivores are decomposers which decomposes non-living organic matter such as feces, dead organisms, wood and leaves (Campbell et al., 2018). In figure 3, this process is further visualized. Since the primary process of ecosystem formation is described, will the following paragraph connect all abiotic and biotic components to the formation of a dynamic ecosystem.

2.5 Species interaction; the development of a dynamic ecosystem

Ecosystems do not exist on their own, they develop. Based on abiotic circumstances and chemical cycles, small scale molecules develop into cells that belong to organisms, which create a population and form together with other populations a community. Together, these communities can be called an ecosystem. An ecosystem consists of all living things (biotic) in a particular area along with all non-living components (abiotic) such as: soil, water, atmospheric gases and light that interact (Campbell et al., 2018). All components that are involved in the system understanding of Lake Volkerak-Zoom.

2.6 Nutrients

Figure 3 describes what energy sources are required for growth within a trophic level. Besides light energy, one of the nutrient cycles within an ecosystem is the chemical cycle (figure 4). The chemical cycle exists of nutrients that are required for ecosystem development within all trophic levels. Nutrients are a key source for primary production and forming of proteins. Most important nutrients for plants and algae are nitrogen (N) and phosphorus (P). The following paragraphs will define both nutrients nitrogen and phosphorus as element and its different forms.

2.7 Nitrogen (N)

Nitrogen is an element in form as a neutral gas, which exists of two atoms (N_2). 80% of the air exist of the component nitrogen (N_2) (Sikkema, 2020, and Siepman, 2018). Nitrogen (N_r) can be formed to NH_3 (Ammonia), NH_4 (Ammonium), NO (Nitric oxide), NO_2 (Nitrogen Dioxide), NO_3 (Nitrate) and N_2O (Nitrous Oxide) which can be placed in a cycle. As shown in figure 4, nitrogen starts as N_2 in the air, in gaseous form. Nitrogen fixing bacteria have the ability to convert nitrogen into NH_3. From NH_3, nitrifying bacteria activate, which can form in two directions. In first, nitrifying bacteria are able to produce NO_2, and is NO_2 converted again by nitrifying bacteria, a process called nitrification. NO_2 takes also part in the ammonification process, which starts on the land. Cattle manure or artificial fertilizers contain forms of nitrogen which are by the process ammonification converted into NH_4, which can in their place convert into NO_2. Secondly are nitrifying bacteria able to convert NH_3 into NO_3. NO_3 can be taken up by plant roots and is called assimilation. From NO_3, denitrifying bacteria convert again to N_2. This process is called denitrification (Fowler et al., 2013).

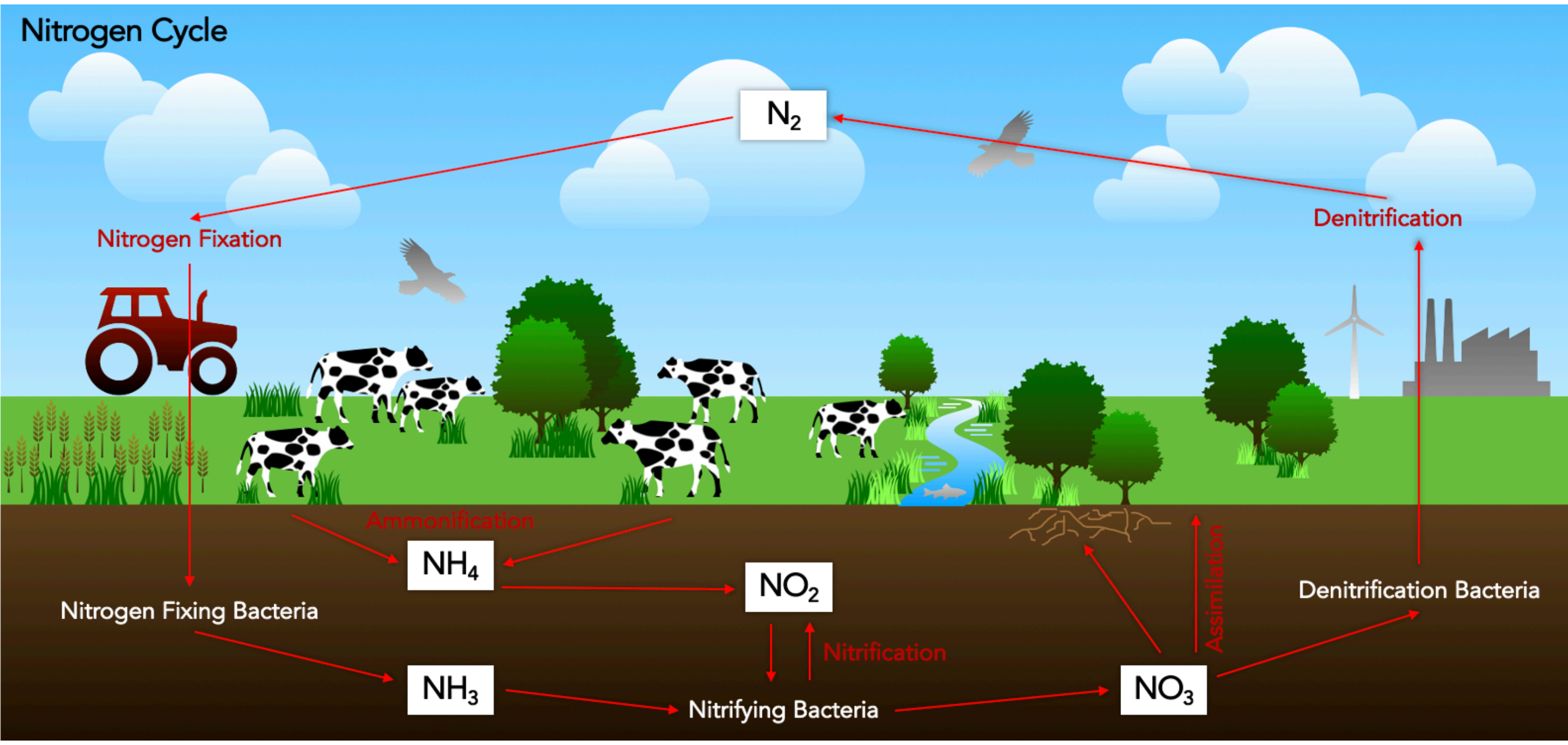

Figure 4: Visualization nitrogen cycle, with all forms of nitrogen (N_2, NH_4, NH_3, NO_2, NO_3) and forming processes that are interconnected to form a cycle (Haan, 2021).

2.8 Phosphorus (P)

Phosphate is an element which is essential to all living organisms. Plants take up phosphates out of the soil and humans and animals take up phosphates by the consumption of crops, meat and dairy products. Phosphate is a required mineral for the bones and teeth. Besides that, does phosphate have an important role in the energy build-up. This process runs by the conversion of phosphate lipids that eventually form DNA. An essential element to many biological processes (Vergouwen, 2010).

2.9 Algae

Now the basic elements for algae growth are described, the following section will discuss how both elements: nitrogen and phosphorus are related to algae growth. In specific is focused on blue-green algae (*Microcystis*), which is an abundant algae specie in Lake Volkerak-Zoom.

2.10 Blue-Green algae (*Microcystis*)

Blue-green algae can be harmful for humans and animals. Lake Volkerak-Zoom is already impacted for years by blue-green algae (*Microcystis*) during summer periods. The blue-green algae type in Lake Volkerak-Zoom is *Microcystis* (Verspagen et al., 2005). *Microcystis* is a combined name for several blue-green algae types of which: Cyanobacteria, Cyanophycean and Chroococcales. All of the *Microcystis* types can form massive algal blooms that produce toxins (Levine & Fleurence, 2018). The toxins that are made by algal blooms are *Microcystins* which are small gaseous blisters that are filled with air. These gaseous blisters are lighter than water, which makes it possible for these *Microcystins* to ascend to the surface of the waterbody. The high number of *Microcystins* are called algal bloom (*Microcystis*) and create a floating layer on top of the water surface. These floating layers can only be created during periods with the ideal circumstances such as: low windspeed, long water renewal time, high solar radiation and optimum nutrient numbers with N:P ratio of 1:16 (Dobson & Frid, 2009 & Verspagen et al., 2005).

Blue-green algae (*Microcystis*) are primary producers in which the named ideal circumstances are of high importance. These ideal circumstances are placed in a seasonal pattern since algae bloom primarily exist during summer periods. The growth of algal bloom can be explained in four phases, which are visualized in figure 5. Starting with the photo inhibition phase, in which high light levels at the surface restrict the photosynthetic maximum to an intermediate depth. This production results in an increase in biomass. Secondly, the self-shading phase, which is caused by the increase of biomass in phase one. A reduction of light at the upper layers is created by self-shading. The maximum photosynthesis only occurs towards the surface. In the third phase, a rapid population growth is caused that exploits the available nutrients in the waterbody. Finally, in the last phase, occurs nutrient depletion which causes the population to sink until it is concentrated above the thermocline. In this phase, the density of blue-green algae is high and nutrient availability is slightly elevated due to water mixing. A stage in which the high number of blue-green algae may be called algal bloom. In addition, photosynthesis is at lower levels in the lake (almost) not possible, depending on how much light can reach to the bottom layers of the lake (Dobson & Frid, 2009).

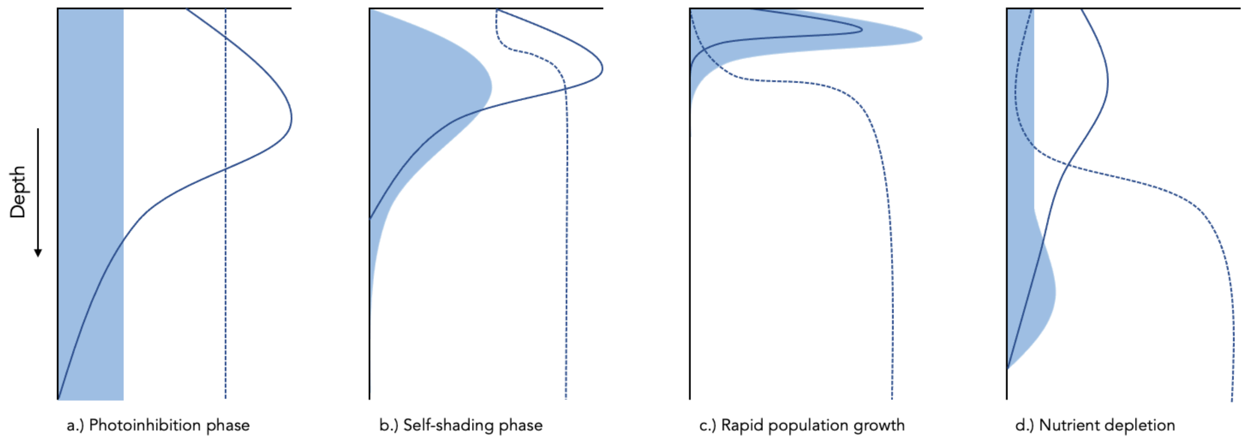

Figure 5: Process of algae bloom development, illustrating algal biomass (shaded), daily net photosynthetic rate (solid line) and nutrient concentration (dashed line) (Dobson & Frid, 2009) (Modified by: Haan, 2021).

Within the ecosystem, blue-green algae (*Microcystis*) are poisonous for birds and fish which primarily causes liver diseases. In addition, are *Microcystis* problematic for human health. The most important causes of the massive blue-green algae growth in Lake Volkerak-Zoom were the large inflow of nutrients via the discharging rivers from Brabant (Verspagen et al., 2005). Since 2005, the water quality of Lake Volkerak-Zoom improved, which might have been a possible cause of the lowering of phosphorus. However, this could not be fully declared (Kramer et al., 2016). In addition, the quagga mussel (*Dreissena polymorpha*) was introduced to Lake Volkerak-Zoom as an exotic species. According to the research of Kramer et al., (2016), did this newly introduced mussel cause a decline in the blue-green algae population. However, in the summer of 2010, were floating layers of algal bloom already observed and did the quagga mussel population stabilize in 2011-2012. Assumed is that blue-green algae concentrations therefore would not further decline. Nowadays, by observation, there is more nuisance of blue-green algae in Lake Volkerak-Zoom of which no specific reason is known (Weeber et al., 2018 and Dionisio Pires, 2020). Thereby, the slow renewal time of the water is also an important cause for the development of the blue-green algae in the lake. Based on the renewal time, the water quality will change (Dionisio Pires, 2020). The blue-green algal blooms refer to a eutrophic stage of Lake Volkerak-Zoom; dense algal bloom, periodic low oxygen and possible fish kills (Newman, 2005). However, cannot yet be determined that a change in biodiversity is applicable to Lake Volkerak-Zoom (Dionisio Pires, 2020).

So far, this theoretical framework analyzed the energy flows, development of an ecosystem and its components, of which blue-green algae that are of relevance for this research. The following section will focus on the external factors that act on the ecosystem, regarding meteorological factors, water dynamics and influences and possibilities.

2.11 Weather and climate

Within the system diagram (figure 2), is visualized that meteorological factors are of importance for the development of an ecosystem. The following paragraphs will define both concepts weather and climate. Weather and Climate are elements that influence and change a system in many different ways. Weather can be defined by temperature, humidity, air pressure, sunshine, cloudiness and precipitation on a specific time of the day. Whereas climate can be defined as average weather patterns over a 30-year time span (KNMI, n.d.).

2.12 Climate change

Likewise, as organisms in a natural system, do humans interact with the environment as well. Sometimes, these interactions do have consequences for the environment. The most well-known example is the mining of fossil fuels (coal, oil and gas). The burning of these fossil fuels increased the carbon dioxide emission (CO_2) and other gasses that were taken up to a high extend in the atmosphere (Houghton, 2005). Global warming is not the only factor in climate change. Wind and precipitation patterns are also shifting, and extreme weather events occur more often (Campbell et al., 2018). The extensive use of these fossil fuels and thereby the ongoing global warming resulted in climate change. Expected is that the temperature in 2100 is risen with 3˚C on average if the current speed of climate change will continue (Campbell et al., 2018). According to the KNMI climate scenario report (2014), a general change in weather is expected. Temperatures will rise, precipitation events will be more extreme, wind speed will increase, there will be more sun days and sea level will rise. Now the weather patterns are explained, a basis is created for the concept that will be explained within the following paragraph: water dynamics.

2.13 Water dynamics

Lakes are dynamic by its many influences related to abiotic factors and biotic factors; everything comes together within this specific ecosystem. An important factor that takes place in the abiotic dynamics of deep lakes is stratification. Stratification can be defined as the development of relatively stable light and warm layers above colder deeper layers within the waterbody. Thermal stratification is related to the waterbodies density and affected by incoming heat, water depth and the degree of mixing within the waterbody (Fairbridge et al., 2012). The waterbody can therefore be divided into three parts. The upper part is where the water is warm and where it has a low density. Then a layer of water where mixing starts to increase: the thermocline. The temperature of the water starts to decline, and the density of the water becomes higher. Then the lowest part of the waterbody: the hypolimnion. In this part of the waterbody the water temperature is at its lowest and density at its highest point (Dobson & Frid, 2009).

Most of all, the paragraphs within this chapter demonstrates biotic and abiotic factors that interact within the ecosystem Lake Volkerak-Zoom. The next paragraph will focus on the area's stakeholders and the possible removal methods for blue-green algae that are abundant in Lake Volkerak-Zoom, which are of importance for the further development of this research.

2.14 Influences and possibilities

Lake Volkerak-Zoom knows a variety of stakeholders and has many different policies applied by national authorities: Province of Zeeland, Brabant and Zuid-Holland. All provinces have different interests by the lakes. Most relevant stakeholders around lake Volkerak-Zoom include: Agriculture, Nature, Recreation, Fishery, Shipping and Industries. These stakeholders have interests and opinions that matter for them and their existence. Policies and qualities of Lake Volkerak-Zoom are of importance and matter in the way rules and legislations are communicated.

The system Lake Volkerak-Zoom is influenced naturally by abiotic and biotic factors as explained and shown in the system analysis and diagram. The system is also influenced by management, policies and by human use such as recreation and shipping. As this research will be focused on nutrients and blue-green algae growth, there are many possibilities known that can lower algae growth or remove the blue-green algae to a certain extend from the waterbody. Important for blue-green algae or nutrient removal methods, is that these methods should be effective, easy to apply, sustainable and not expensive.

Removal methods can be divided as follows:
- Direct physical techniques
- Indirect physical techniques
- Chemical methods
- Biological methods
- Policy methods

The mentioned methods can be divided into several solutions. Furthermore, these solutions can be divided into solutions that are nutrient based or blue-green algae-based removal methods on which will be focused within this research.

The next chapter: research method, will describe and explain how research is conducted and what measures are used to get to the results and conclusions of this research.

3 RESEARCH METHOD

So far, is focused on the theoretical concepts that are of importance for this research. The following chapter will discuss the used methodology of conducting information required to answer the main research question and additional sub-questions.

3.1 Research methodology

The following methods result in a final answer to the main research question. The methods for this research will be both qualitative and quantitative.

The quantitative research will exist of desk research that is set up to answer the majority of the sub-questions and will be set up in the method as follows:
- DPSIR approach *Microcystis* in Lake Volkerak-Zoom
- Nutrient-related measures: inventory of possible solutions

The first part of the desk research will consist of science-policy communication which includes the DPSIR-method and a peer-assessment on DPSIR understanding. The qualitative research will exist of the inventory of literature research of the relation between climate change, nutrients and the growth of blue-green algae in Lake Volkerak-Zoom.

The quantitative research will further develop on relation climate change, nutrients and blue-green algae growth by using a Deltares/Rijkswaterstaat model: D-HYDRO.

3.2 Stakeholder communication and policy: DPSIR-method

The DPSIR framework is a tool created for reporting and analyzing environmental problems on different scales (Carr et al., 2009). The general system analysis will be specifically targeted to blue-green algae by the use of the DPSIR-method (figure 6). DPSIR stands for Driver – Pressure – State – Impact – Response, see figure 3. This method is an analytical model that interprets the indicators that are connected within a system and used as conceptual framework to structure and communicate policy-relevant research information about environmental aspects (Svarstad, 2009 and Rijkswaterstaat, 2021). A DPSIR reports a reproduction of existing inequalities between actors and stakeholders within current approaches (Carr et al., 2009). Therefore, economic, social and environmental conditions are interconnected and can be placed within one approach (Rijkswaterstaat, 2021).

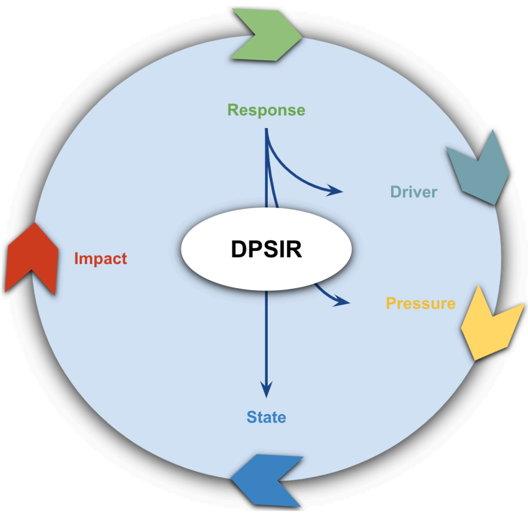

Figure 6: DPSIR method including drivers, pressures, state, impacts and responses. With system connections from responses (Haan, 2021).

Now the basic element of DPSIR is explained, the following sub-paragraphs will go in depth of the approach and explain each DPSIR component.

3.2.1 Driving forces
Driving forces are defined as the anthropological activities and processes that occur within or around a system regarding social, economic or environmental developments (including industries, agriculture, fisheries, spatial planning, recreation) (Svarstad, 2009 and Rijkswaterstaat, 2021).

3.2.2 Pressure
Within a system, there is a pressure on anthropological and natural resources. (chances in hydro morphology or the emission of agricultural fertilizers) (Rijkswaterstaat, 2021).

3.2.3 State
The state within the DPSIR-method describes the function of the pressure that acts on the natural and human resources whereby, the state the general condition of the system represents. (habitat for flora and fauna or the concentration agricultural fertilizers that act on surface water bodies).

3.2.4 Impact
The impacts are the direct functions of the pressure on humans and nature with thereby the changes to society and the natural environment (death rate in surface waters caused by high nutrient pollution or algae blooms).

3.2.5 Response
The response function refers to the political and sociological choices that are made to reduce or mitigate the societal and/or environmental impacts. This function is interconnected with the driving forces, pressure, and state, which means that choices that are made within the politics can have an effect on the driver, pressure and state.

3.3 Response: science to policy communication
Now the concept response is defined, this paragraph will introduce the method science to policy communication. Based on the main research question, it is decided to include a social aspect to this research by describing this method in the form of an approach to a peer-review group. The intention with this communication approach was to contact a variation of stakeholders that work and/or live in the region Lake Volkerak-Zoom. Although, due to the covid-19 situation, contact with stakeholders was difficult. Therefore, a peer-review group was questioned on what their questions, feedback and further recommendations were on the created DPSIR approach with blue-green algae in state.
The experiment science to policy communication within this research should focus on how this DPSIR is changed from a method to an approach. Thereby, this communication aspect defined to what extend this approach is understandable for the various stakeholders in the area lake Volkerak-Zoom.

3.4 Nutrient-related measures: inventory of possible measures and future perspectives
To further elaborate on the responses that are included within the DPSIR approach, a literature study is conducted on what nutrient-related measures exist that may reduce the algae growth in Lake Volkerak-Zoom. The literature data is based on nutrient removal efficiencies of two chosen nutrient related measures: nutrient reduction in the rivers Dintel and Vliet, which discharge on Lake Volkerak-Zoom and, a nutrient reduction by wetlands that are placed in Lake Volkerak. In addition, climate scenarios are included within the literature research to research the long-term effectiveness, until 2050, of the nutrient-related measures.

3.5 D-HYDRO: nutrient reductions and future perspectives modeled

***Disclaimer: D-HYDRO Suite is a software model of which rights are owned by Deltares and Rijkswaterstaat. The version of the D-HYDRO Suite results that are included within this research were created within a pre-release. Be aware that results may differ and that results only may be used with a license of Deltares-Rijkswaterstaat.**

Following up on the literature research, the removal efficiencies are compared and based on one average number for each nutrient measure (nitrogen or phosphorus) included within the D-HYDRO model. D-HYDRO is a successor of Deltares' models SOBEK, Duflow, Simona and Delft3D and, based on the historical data of previous Rijkswaterstaat models (Deltares, 2015). The model is specifically used for this research to model water quality data of nutrients in Lake Volkerak-Zoom and its discharging rivers. Literature information on efficiencies of nutrient-related measures is further calculated within D-HYDRO. To include a time perspective is chosen to include a climate change element by including temperature rise until 2050. By the use of the model results, both weather and climate data and nutrient-related measures data are further analyzed in excel to specifically focus on important information that is visualized in the figures. In addition, this further analyzation is important for a better understanding of the data.

The described methods within this chapter will be used for the analyzation of the results. The next chapter will represent all results that are obtained by this research.

4 RESEARCH RESULTS

4. 1 DPSIR APPROACH MICROCYSTIS IN LAKE VOLKERAK-ZOOM

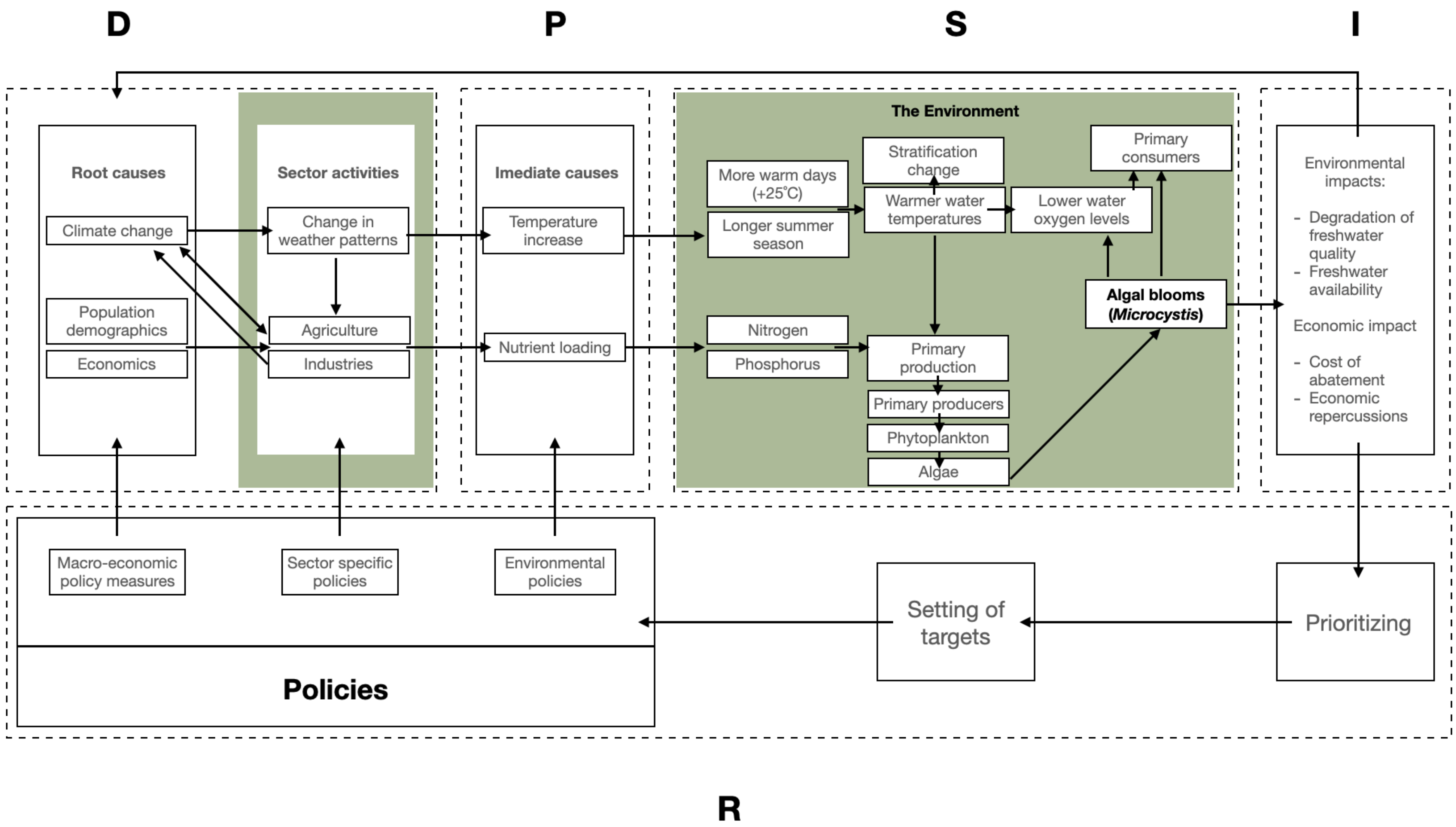

Figure 7: DPSIR approach specified to the research of blue-green algae (Microcystis) in state. With drivers that are of specific influence on Lake Volkerak-Zoom (Haan, 2021).

The following paragraphs will give an explanation on the DPSIR and the included components which are visualized in figure 7.

4.1.1 Driving forces

This paragraph will go in depth of the division that is made between root causes and sector activities in driving forces. Root causes are climate change, population demographics and economics. One of the most important sector activities in the area surrounding Lake Volkerak-Zoom is agriculture, which is driven by population dynamics and economics (socio-economics). The root causes and sector activities are divided within the topic driving forces based on the main causes and effects that drive the systems pressures.

The population in the Netherlands is increasing. Expected is that this population will rise with about 100.000 people per year. For the year 2050 is expected that this population growth will increase until 21 million inhabitants (CBS, 2021). This number does not count specifically for the area Lake Volkerak-Zoom. However, this is an impact on a variety of sectors that are of importance in the Volkerak-Zoom area. The more people, the higher the food demand. Thereby, is questioned for diverse and high-quality standards (safe, environment friendly, welfare and ethics) that is still affordable (European Commission, 2019). Therefore, agricultural fields are of crucial relevance, also in the area Lake Volkerak-Zoom.

The agricultural fields in Brabant cover about 62% of the entire province. Several types of fertilizes are used for these agricultural fields. Via Groundwater run-off these nutrients end up in surface waters (Rozemeijer & Boers, 2007). Agriculture is responsible for 61% of the total nitrogen emissions. The average values of nitrogen emission exist of 60% ammonium (NH_3) and 40% nitrogen oxides (NO_x) (TNO, 2019). The maximum permissible concentrations for nutrients in waterbodies via agricultural groundwater runoff are on average set to 50 mg/l NO_3, which is comparable to 11,3 mg/l N_2. These standards are still too high to maintain a good ecological water quality of surface waters since this standard does not give a clear representation to protect surface water bodies from eutrophication. Therefore, total-N and total-P concentrations are more relevant. Nutrient concentrations in surface waters during summer periods are set to 2,5 mg/l total-N on average (RIVM, 2020). For total-P, these maximum numbers are set to 0,15 mg/l for fresh surface water bodies that are not for drinking water consumption. If the surface water body is intended to be used for drinking water, the total-P concentration may not be higher than 0,9 mg/l (RIVM, 2021). According to a study of Rozemeijer & Boers, (2007), are the average discharge concentrations from the rivers Dintel and Vliet to Lake Volkerak-Zoom 10,34 mg/l for total-N and 0,564 mg/l for total-P. Both numbers are above the maximum permissible concentrations. Although, trends in total-N and total-P show a decline (figure 8 & 9) (RWS, 2012).

Since agriculture is of such importance for the area Lake Volkerak-Zoom however, an impacting factor on climate change. As well as climate change is an impact on agriculture. Therefore, the Netherlands created a legislation to reduce the nitrogen, most important, in agricultural areas. Although, since 2019, this program did not meet the European regulations for nature protection. Therefore, this act is declared invalid in 2019. The Netherlands has a problem with a degraded nature and the set-up of a new act to reduce nitrogen emissions in mostly the agricultural sector. The rules within this legislation are strict which results in problems for most agricultural companies since the number of cattle and use of fertilizers must be reduced (Strien et al., 2020). After the former legislation was introduced, nutrient concentrations in Lake Volkerak-Zoom did decrease.

The following sub-section will provide information about the nutrient concentrations nowadays and to what extend these concentrations meet the maximum permissible nutrient concentrations.

According to a research of Deltares, (2020), the DIN (Dissolved Inorganic Nitrogen) can be determined on 3,0 mg/l average. The DIN concentration is based on components NO_2 + NO_3 + NH_4. Organic phosphate concentrations slightly increased since 2014. On average, are phosphate concentrations nowadays between 0,06 mg/l and 0,08 mg/l. Since these concentrations only cover phosphate, can be assumed that total-P values are slightly higher (between 0,1 mg/l and 0,2 mg/l). Based on the nutrient concentrations of more recent years, a decline is visible that more or less meets the maximum acceptable concentrations (2,5 mg/l total-N and 0,15 mg/l total-P). Beside Brabant, also the province of Zeeland has a large agricultural sector that is situated around Lake Volkerak-Zoom (Elferink et al., 2010). However, numbers of agricultural nutrient runoff via the province of Zeeland are not important to further investigate since this is not of relevance for the further development of this research.
Besides agriculture, does transportation contribute to 21% of the total nitrogen emissions and do industries contribute with 9% of the nitrogen emissions (TNO, 2019). Transportation and industries have an effect on climate change and emission of N_2 in form of N_2O (CBS 2018). N_2O ends up in the atmosphere, where this denitrified into N_2. N_2 can via air, rain and soil come back in the surface waters (nitrogen deposition). Transportation and industries do have an impact on the atmospheric nitrogen deposits and the addition of greenhouse gasses (Augustyn et al., 2020). Although, transportation and industry are indirect impacts to the nitrogen deposition. Therefore, is this topic not of further relevance to discuss for the answer to the main research question.

4.1.2 Pressures

Now the relations between root causes and sector activities are explained, this paragraph will emphasize the pressures that act on the system Lake Volkerak-Zoom.
The existing industrial and agricultural sectors, together with climate change, cause a pressure on Lake Volkerak-Zoom. Both nutrients, nitrogen (N) and phosphorus (P) are added as leading components in fertilizers. Due to the high concentration nitrogen in cattle feed, a large concentration nitrogen is also found in manure and fertilizers which contain a high nitrogen loading (Sikkema, 2019).

In the upper 50 cm of the agricultural fields in The Netherlands, 5000 kg phosphate per hectare is captured. Every growth season, another 50 - 100 kg per hectare is added. Per hectare, around 1000 kg phosphate is used (Van ’T Hoog, 2017). However, there is such high surplus of phosphate that it will be washed out of the soil into the surrounding surface waters. The annual phosphorus from agricultural fields to surface waters is 1 - 2 kg per hectare. Therefore, is a phosphate reduction in agriculture required to prevent leaking of phosphate into surface waters (Van ’T Hoog, 2017). Nutrient concentrations in surface waters do not become higher, these even decrease (Rozemeijer & Boers, 2007). Although, according to TNO, (2019), are nitrogen depositions in The Netherlands highest compared to other countries in Europe. However, in the soil is a large surplus of nutrients which is in a lowering trend as can be seen in figure 8 & 9. In 1990, a surplus of 150 - 400 kg/ha for total-N is found, whereas the surplus of total-N in 2008 is 130 - 240 kg/ha (Van Puijenbroek et al., 2010).

Since 2019, new measures for nutrients in agricultural fields are taken. For total-N this means that there is a maximum use between 170 - 230 kg/ha. For total-P this number is much lower, meaning there is a maximum use of 75 kg/ha (RVO, 2019). Although nutrient concentrations became lower in the soil and surface waters, there is still 20 kg to 28 kg total-N per hectare per year captured in the soils around Lake Volkerak-Zoom (Strien et al., 2020). According to Erisman et al., (2015) and TNO, (2019), this nitrogen deposition is still 10 kg to 18 kg per hectare per year above the critical number.

On average in annual patterns can be stated that chlorophyl levels in µg/l declined until 2012. This number reached levels of about 100 µg/l in the summer of 2000. In 2012, these chlorophyl levels declined to below 25 µg/l in 2012 (De Vries & Postma, 2013).

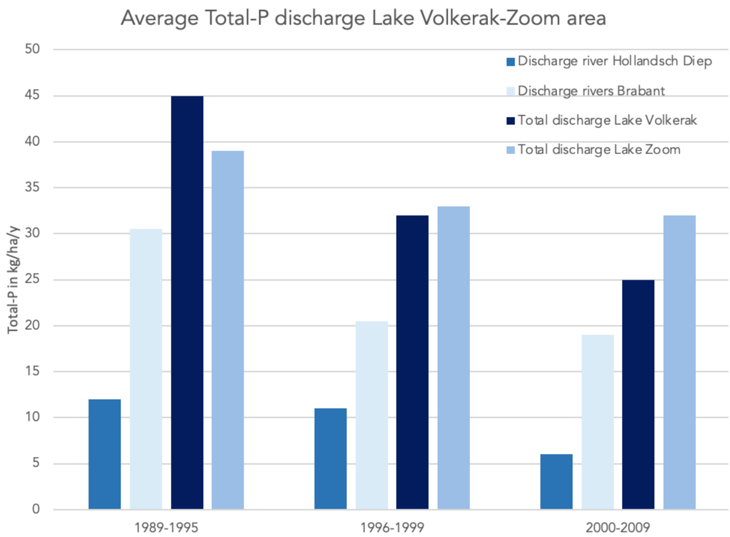

Figure 8: Total-P discharge in the Volkerak-Zoom area from 1989 to 2009 (RWS, 2012) (Modified by: Haan, 2021).

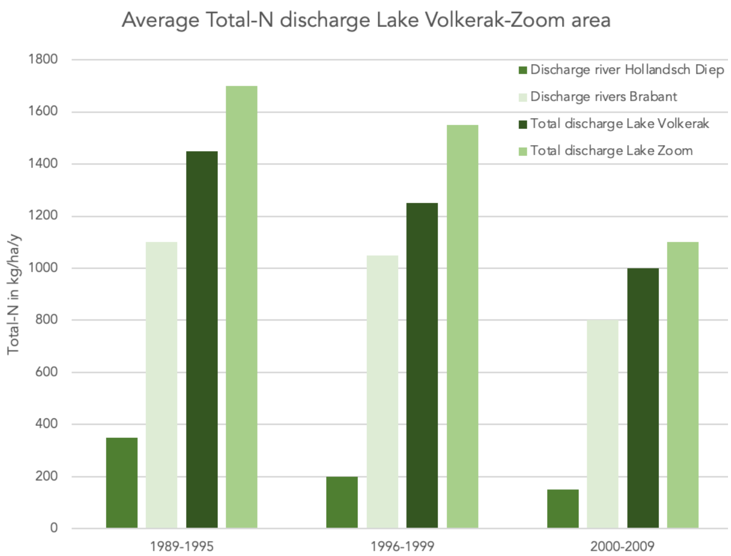

Figure 9: Total-N discharge in the Volkerak-Zoom area from 1989 to 2009 (RWS, 2012) (Modified by: Haan, 2021).

As been visualized in the DPSIR on figure 7, climate change and change in weather patterns are a driving force in the growth of blue-green algae. According to various research, a connection with meteorological aspects as wind, currents, temperature and light intrusion is determined, that influences the growth of blue green algae (Campbell et al, 2018, Dobson & Frid, 2009 and Verspagen et al., 2005). Therefore, the following section will state climate change aspects that can be of relevance to the growth of blue-green algae in Lake Volkerak-Zoom.

Temperature has on an average basis risen with 1,8˚C in the period 1880-2012 (KNMI, 2014). Until 2050 is in the warm-low scenario and the warm-high scenario expected that temperature will rise with 1,5˚C to 2˚C (KNMI, 2014). Temperature increase has a possible effect on growth season and number of summer days. Both climate factors tend to increase in a moderate-low scenario, as well as in a warm-high scenario (figure 13 & 14) (KNMI, 2014).
Besides temperature, also precipitation increased with 14%. All seasons except summers became more wet. For the period until 2050, precipitation will even increase with 2,5% to 5,5% (figure 11). In addition, precipitation intensity changed over the years. A warmer climate means more evaporation, which results in more weather events or an increase in precipitation intensity. Stated by the KNMI, is that the precipitation intensity per hour will increase with maximum ± 25% from ± 15 mm/h to ± 19 mm/h (figure 10) (KNMI, 2014). Research models of the KNMI, (2014), stated that the extreme precipitation events rise with 12% per degree Celsius the temperature rises. However, precipitation is increasing, is also a seasonal precipitation shortage expected during the months May to September with shortages varying from 3% to 31% (figure 12). Although, precipitation is not that much of an important factor for blue-green algae, this meteorological factor is important for the nature and agriculture in the area Lake Volkerak-Zoom. However, precipitation data and the relation to stakeholders in the area Lake Volkerak-Zoom will not be further emphasized within this research.

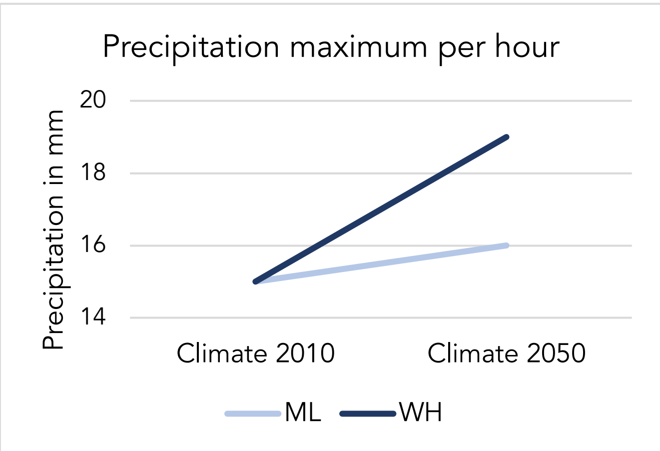

Figure 10: Maximum precipitation per hour in mm, modeled change from 2010 to 2050. Based on KNMI, 2014 climate scenario's mean-low scenario and a warm-high scenario (Haan, 2021)

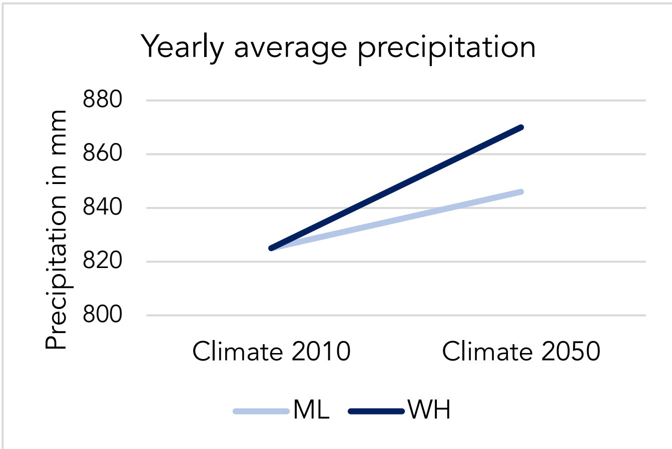

Figure 11: Annual average precipitation in mm/year modeled change from 2010 to 2050. Based on KNMI, 2014 climate scenario's mean-low scenario and a warm-high scenario (Haan, 2021)

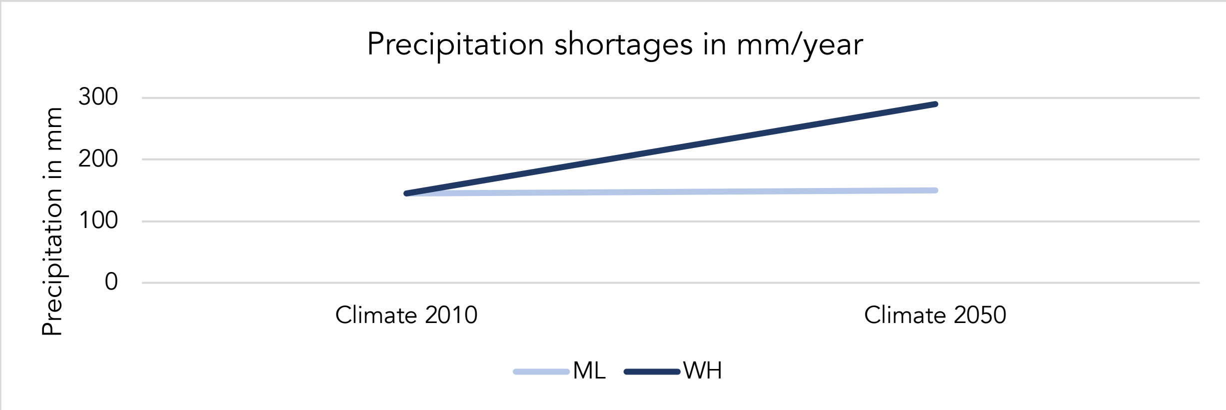

Figure 12: Precipitation shortages in mm/year, modeled change from 2010 to 2050. Based on KNMI, 2014 climate scenario's mean-low scenario and a warm-high scenario (Haan, 2021)

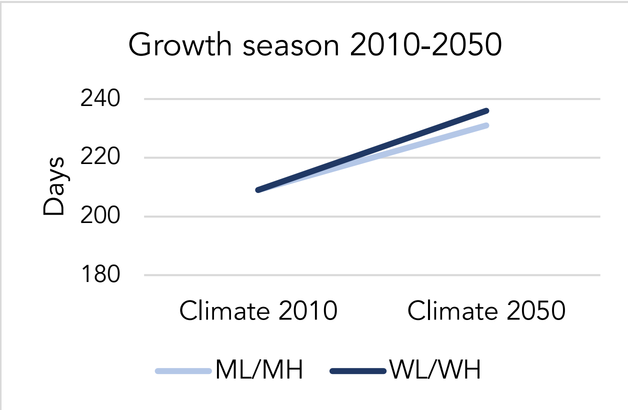

Figure 13: Growth season increase in days, modeled change from 2010 to 2050. Based on KNMI, 2014 climate scenario's mean-low scenario and a warm-high scenario (Haan, 2021)

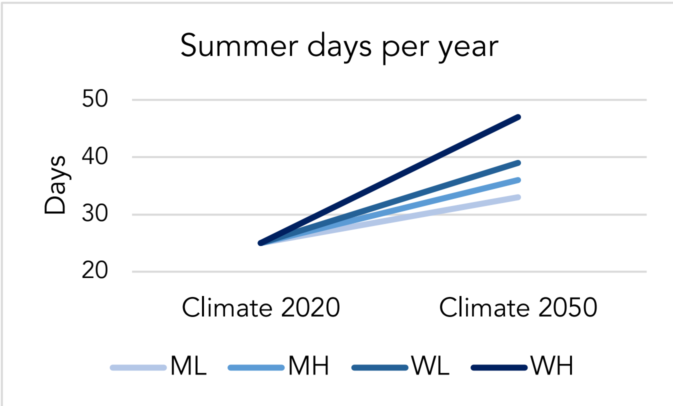

Figure 14: Total increase in summer days modeled change from 2020 to 2050. Based on KNMI, 2014 climate scenario's mean-low and mean-high scenario and a warm-low and warm-high scenario (Haan, 2021)

4.1.3 State

This paragraph will describe the state of Lake Volkerak-Zoom. The state of the lake is influenced by the drivers and pressures that are described in the previous two paragraphs. Together, both components driving forces and pressures create a state, which can be interpretate as the condition of Lake Volkerak-Zoom.

Phosphorus (P) and nitrogen (N) are required nutrients for the growth of plants and algae. High concentrations of N and P lead to eutrophication of the surface waters. Eutrophication occurs mostly in surface waters with a low velocity and low refreshment rate. A high eutrophication rate typically leads to extensive algae growth. As a result of this phenomenon, the oxygen level of the waterbody may drop and plants disappear, which, in some years (before 2005) possibly caused fish deaths and bird kills (Wolfstein, 2003). Nowadays, no changes in biodiversity are visible, however, this is still a topic of research at the moment this report is written. Additionally, extensive algae growth causes negative effects for recreation. Swimming and other water-sports activities are not possible (Van Puijenbroek et al., 2010).

Primary productivity on aquatic ecosystems is limited by the availability of nutrients. Which means that when there is a limitation of nutrients algae will not grow anymore which results in a decline of algae in the water (Beardall et al., 2001). Nutrient limitation is a driving force in the development of ecosystems (Koerselman & Meuleman, 1996). However, this is not the case in Lake Volkerak-Zoom. The high concentration of nutrients, and low refreshment rate of Lake Volkerak-Zoom are a primary source for the growth of primary produces in Lake Volkerak-Zoom, including algae species. Nutrients in Lake Volkerak-Zoom are year-round discharged in the lake via the run-off of the rivers Dintel and Vliet. This continuous discharge of nutrients leads to the critical point no nutrient limitation takes place. The increasing temperature and fewer currents during summer periods give blue-green algae (*Microcystis*) the chance to bloom and dominate the lake during the summer months and possibly even during the end of spring and during the beginning of the fall.

Figure 15: Algal bloom in Lake Volkerak-Zoom in 2018. One of the warmest and driest summers since 1976 (Zuidwestelijke Delta, 2018).

4.1.4 Impacts

This paragraph is based on the impacts that are caused by the state of Lake Volkerak-Zoom. Due to the annual returning blue-green algal blooms during summer, various stakeholders are affected in the area Lake Volkerak-Zoom.

During summer periods, the island of Schouwen-Duiveland uses freshwater from Lake Volkerak-Zoom. On average basis, during a dry summer (when less precipitation is measured than required or when less precipitation is measured than evapotranspiration is measured), for 150 days per year an extra freshwater supply is required. Based on a full capacity is in the research of Spielmann & Dekens, (2021), assumed that this would be around 60 days with a discharge of 2 m^3/s, which is on a yearly basis 10,4 million m^3. For open supply systems, this required number is different since evaporation is also a factor that counts in water supply. Therefore, is calculated with 90 days with a discharge of 5 m^3/s per year, which is 38,9 million m^3 per year (Spielmann & Dekens, 2021). These numbers are assumed; however, this is a high amount of fresh water of which 2/3 is supplied by Lake Volkerak and the Scheldt-Rhine canal. Blue-green algae and additional freshwater supply, both go together during summer, which means also during crop growing season. High concentrations of blue-green algae may make the water poisonous for flora and fauna, which also includes the crops on the surrounding agricultural fields.

Neurotoxins influence the signals in nerve cells of which are several types that are able to influence the nerves within muscles of animals. In addition, are Hepatotoxins, cytotoxins and dermatoxins a problem which may cause liver, kidney, lung, eye and skin problems Newman, 2015). Therefore, Lake Volkerak-Zoom is closed off during periods algal bloom occur to prevent human contact with cyanotoxins (Van Puijenbroek et al., 2010).

The possible impacts for Lake Volkerak-Zoom and the surrounding area are described in the context with blue-green algae bloom in state. The next paragraphs will cover the possible nutrient-related responses to remove blue-green algae in Lake Volkerak-Zoom.

4.2 Responses: inventory of possible nutrient-related measures and establishment of assessment

This paragraph demonstrates used nutrient-related measures to remove blue-green algae and possible measures that will be further investigated within this research.
As been stated within the paragraph 'influences and possibilities', are several algae removal methods possible. The measures that will be researched are nutrient-related. One of the nutrient related methods that is researched before, especially in Lake Volkerak-Zoom, is the method to remove blue-green algae (*Microcystis*) by the use of a relatively newly introduced species. With, in specific the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostriformis*). Related to the ecosystem dynamics is the quagga mussel (*Dreissena rostriformis*) a primary consumer in which the quagga mussel consumes blue-green algae (*Microcystis*). However, the quagga mussel (*Dreissena rostriformis*) is not abundant enough to stop the yearly algal bloom in lake Volkerak-Zoom (Dionisio Pires, 2020). Therefore, is chosen to not further elaborate on this specific method on the reduction of blue-green algae (*Microcystis*).

Another possible method that reduces blue-green algae (*Microcystis*) is the reduction of nutrients at the source. For instance: agricultural run-off that is discharged on rivers that end up in Lake Volkerak-Zoom. Within this method, a range of possibilities can be applied to reduce nutrient inflow into rivers:

- Fertilizers can be used specifically for each crop type and a balanced N:P ratio.
- Applying fertilizers during the right weather circumstances to prevent extensive runoff of water with fertilizer (Verdonschot et al., 2017).

For this measure is chosen in a way to focus on a policy aspect of a specific nutrient reduction in river discharge of the rivers Dintel and Vliet.

Besides direct measures for the agriculture, special plants or reeds can be placed in rivers, ditches or in canals that discharge to Lake Volkerak. At aquafarm, many studies have been executed on the use of aquatic plants that naturally purify the water by taking up nutrients that are required for these plants (Aquafarm, 2018). Within aquafarm, also many studies have been executed to use aquatic plants for the use of purifying or biological water treatment for industries. This way, industries can purify or treat the water before it ends up in the rivers (Aquafarm, 2018). This source is taken into account for the following measure that is further elaborated on, the introduction of wetland plants in Lake Volkerak-Zoom.

4.3 Temperature and summer days 2020 - 2050

One of the key factors for algae growth is temperature. In first, air temperature data is used from the KNMI weather station in Vlissingen. Thereby, will according to the KNMI, the temperature on average basis rise with 1,8˚C until 2050. In addition, stated by the KNMI is that the number of summer days will rise with 32% to 88%. Based on the average summer days, which is now ~25 days, will this possibly rise to ~47 days. Although, Vlissingen is situated in the south-west of the Netherlands and influenced by the North Sea winds and water temperatures. Therefore, average temperatures and summer days in Vlissingen are not comparable with the temperatures and summer days that are stated within the average temperature data of the Netherlands (table 1).

However, the percentage rise of summer days is more or less comparable for the air temperature data in Vlissingen. In addition, the average temperature rise of 1,8˚C is modeled until 2050. In the table below is shown how this temperature rise will affect the rise in number of summer days, which means days that reach 25˚C or more.

Table 1: Number of summer days at Vlissingen station (days of 25˚C or higher) in 2007 to 2012 compared to 2050 with a temperature increase of 1,8˚C and 2,0˚C (Haan, 2021)

Year	Days of 25˚C	Days of 25˚C (2050 + 1,8˚C)	Days of 25˚C (2050 + 2,0˚C)
2007	4	9	11
2008	8	17	18
2009	9	27	27
2010	12	16	19
2011	5	20	21
2012	11	20	21
Average	8 days	18 days	19 days

This analysis is executed with the KNMI data from weather station Vlissingen for the years 2007 - 2012. For all the years is a temperature data set available and is the air temperature measured per hour. In table 1 can be seen that on average in the years 2007 - 2012, 8 days with temperatures of 25˚C or higher occurred. For the same data of the years 2007 - 2012, with the +1,8˚C, a rise in the average summer days is visible to 18 days in total. As explained is this not close to 47 days that are predicted, this number also does not reach the 25 days that occur even nowadays in parts of the Netherlands. However, 18 days is close to the maximum rise of 88% more summer days. In addition, 2012 will be the modeled year, which is the year that is most relatable to the model data from Deltares for blue-green algae (*Microcystis*) growth in Lake Volkerak-Zoom. Additionally, the best year to visualize the maximum temperature rise of 88%. Since the comparison of 2012 with the +1,8˚C shows an increase in days of +9 summer days which equals an increase of 81,8%. Besides an increase of 1,8˚C is also the scenario of +2,0˚C analyzed. However, the 2,0˚C might even be a possible temperature increase to 2050, this temperature is not relevant, since most numbers will deviate from the percentages (between 32% and 88%) that are obtained by the data of the KNMI.

This paragraph analyzed model data from KNMI and Deltares on temperature increase and summer days. Aspects that are required to eventually visualize how the blue-green algae (*Microcystis*) concentration might change in Lake Volkerak-Zoom until 2050. The next paragraph will inform on the chosen nutrient-related measure: nutrient reduction in the supply waters to lake Volkerak-Zoom.

4.5 Nutrient-related measures in the inflowing waters to Lake Volkerak-Zoom

This research is focused on two nutrient-related measures that are of potential use in the surrounding of Lake Volkerak-Zoom. These potential measures can be divided into two categories; 1.) Nutrient-related measures in the inflowing waters to Lake Volkerak-Zoom, and 2.) Nutrient-related measures in Lake Volkerak-Zoom.

According to the European Union guidelines (2011), some rules and policies are set up regarding the emissions in air, water and soil which can lead to pollution of one to another climate component. Instead of protecting the environment in its entire state, will the climate components be protected on its own to detect pollutions faster so there can be anticipated or prevented faster. Therefore, is provided in an integrated approach in prevention of emissions in air, water and soil by the use of waste management, energy efficiency and prevention of causalities. These regulations are created for a uniform condition regarding climate performances.

In the Netherlands, one of the regulations that prevents a surplus of nutrients in surface waters is the 'KWR' which stands for water guideline. To reach the 'KWR'-requirements for regional surface waters a lowering in the nutrient load of nitrogen and phosphorus is required (Van Gaalen & Van Grinsven, 2017 and Rijkswaterstaat, 2020).
The first measure stated is lowering nutrients within politics, so by law. In 2019/2020, new guidelines were set up for nitrogen emissions. However, there are new guidelines, to meet the KWR-requirements, nitrogen emissions have to decrease with 10-20% on an average basis. On sandy soils, the total-N emissions even have to decrease with 40-70%. For phosphorus, the emissions have to decrease with 10-40% on average basis. All these variations in percentages are based on climate and weather conditions, but most important soil types (Van Boekel et al., 2017).

For the further execution of this research will the nutrient reductions in the discharging rivers on Lake Volkerak-Zoom (Dintel and Vliet) be based on the stated KWR numbers. Therefore, both total-N and total-P, will be lowered by 20% in both discharging waters. Later on, in this research, this removal efficiency number will be used to analyze whether this nutrient reduction is efficient enough to remove 50% of blue-green algae from Lake Volkerak-Zoom.

4.6 Wetlands and nutrient reduction in Lake Volkerak-Zoom

Wetlands are natural ecosystems which improve water quality by using energy from sunlight and ambient temperature, without adding materials (Mihelcic & Zimmerman, 2014). Wetlands are land areas that are wet during (part of) the year, depending on the wetland's location. Wetland is a combination name for many types of land called swamps, marshes, bogs, fens or sloughs. These names were dependent on the existing plants, water conditions and geographic settings. A wetland is mostly a transition between the terrestrial systems and (flooded) aquatic systems (Kadlec & Wallace, 2008). Nowadays, wetlands do not occur only naturally, but also in a constructed way: constructed wetlands. Constructed wetlands are created for many purposes. This might be for the environmental benefits as well as for social benefits. Proved is that wetlands are of large environmental improvement by its ability to remove nutrients and other pollutants (Monier, 2013 and Mihelcic & Zimmerman, 2014). In addition, wetlands also contribute to the balancing of the sediment load in waterbodies. This alters the hydrology and biogeochemistry in the system. All of these benefits result in a reduce of property damage and loss of life. This way, the environmental quality increase, improves the social and recreational activities in and around the lake. This research focused on the environmental benefit: reduction/removal of nutrients in surface waters constructed treatment wetlands can be classified into two main classes: Surface Flow and Subsurface Flow. Both of these classes can even be divided into plant- and flow types. Surface flow can be divided into floating plants, submerged plants and emergent plants. As in which the subsurface flow can be divided into horizontal flow and vertical flow (Mihelcic & Zimmerman, 2014).

Three main wetlands are widely used:

- Free Water Surface (FWS) are wetlands with areas of open water and similar to natural marshes.
- Horizontal Subsurface Flow (HZZF) are typically gravel bed wetlands, planted with wetland vegetation in which water is kept below the surface of the wetland bed.
- Vertical Flow (VF) wetlands distribute water across the surface of a sand or gravel bed with vegetation. The water is treated as it percolates through the plant root zone (Mihelcic & Zimmerman, 2014).

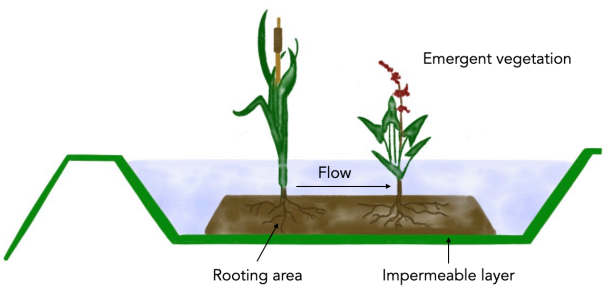

Figure 16: Visualization Free Water Surface wetland (Haan, 2021).

This research will particularly assume the FWS wetland as measure for nutrient removal. The FWS wetland does mostly look like a natural marsh. Marshes are classified as wetland type in which grasses and/or sedges dominate the area and therefore fits best within the system of Lake Volkerak-Zoom and the surrounding rivers (Begon et al., 2014). FWS wetlands have a wetland surface area where plants are rooted in the soil or sand below water surface, or float on top of the waterbodies surface. This research is focused on the removal of nutrients in surface water which does not primarily requires a pre-treatment step. The water requires a flow rate, to create an effective wetland.

In the rivers Dintel and Vliet this is the case, as well as in Lake Volkerak-Zoom. The water travels over the soil and through the plant stems. In an open area, where no plants reach the surface, a potential for oxygen to change in gaseous form to aqueous form is created. In this place of the figure (17): Visualization wetland zones and plant types waterbody , it is possible that fully submerged plants can grow which enhance the dissolved oxygen. The fully vegetated and shallow zones can function as an anaerobic settling chamber in which the roots of the plants take up nutrients. The open zone (deep part) is most important for algae growth. Therefore, this zone may not be too shallow, and does it depend on climate and temperature. Moreover, this open zone of the wetland requires a hydraulic retention time this long, that the algae cannot form. Typically, this time can be assumed to be 2 to 3 days (Mihelcic & Zimmerman, 2014).

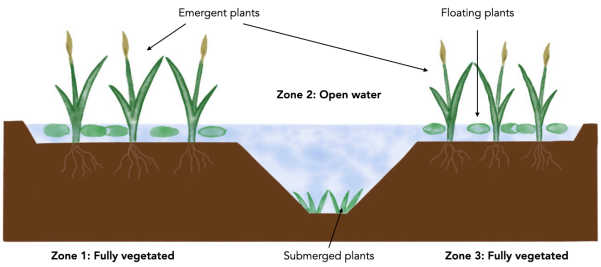

Figure 17: Visualization wetland zones and plant types (Haan, 2021).

Wetlands are used in part of the world since 1950. According to a research of Verhoeven & Meuleman, (1999), removal efficiencies of wetlands for total-N were 35% and for total-P this was around 25%. These results are already a little outdated. However, this research is still relevant nowadays. The possibility for nutrient removal efficiencies will optimize to 50% for total-N and 40% for total-P. With these numbers in mind, other literature research is conducted. In the past years, studies proved that nutrient removal by wetlands is in specific a good option in agricultural areas. According to Lin et al., (2002), wetlands are essential for wastewater treatment and the protection of receiving waters from eutrophication. The research of Lin et al., (2002), proved nitrogen removals between 86% and 98% for ammonium-nitrogen (NH_4-N). In addition, were the total inorganic nitrogen (TIN) removal efficiencies between 95% and 98%. Moreover, was the phosphate removal efficiency 32% to 71%. Variations in removal efficiencies are based on the hydraulic retention time. For nitrogen, this is less of an effect than for phosphorus, which can particularly be seen in the results of Lin et al., (2002). Another research proved a nitrate removal efficiency of 90% to 93%. This same research had a removal efficiency for total-N varying between 57% and 63% (Beutel et al., 2009). A research of Land et al., (2016), generated data from 203 wetlands, which gives a precise representation on which removal efficiency is possible on each nutrient. Total-N had a removal efficiency of 93 g/m^2/year and on average, 37% removal. This removal rate was, as well as in the research of Lin et al., (2002), highly correlated with the hydraulic retention time. Total-P gave an average removal rate of 1,2 g/m^2/year, which could be compared to a removal efficiency of 46% (Land et al., 2016). In Lake Volkerak-Zoom, several wetland plant types can be placed. The study of Keizer-Vlek et al., (2014), proved that floating plants are effective in removing nutrients as nitrogen and phosphorus. These floating plants had a removal efficiency of 74% for total-N and a removal efficiency of 60% for total-P. On average, higher than the removal efficiencies in the previous studies. This increase in efficiency is a possible result of the dependency of a hydraulic retention time rooted plants require. Floating plants do not depend that much on this factor since these plants have the ability to cope with the fluctuations in water level (Keizer-Vlek et al., 2014).

The efficiencies can be combined, and an assumed efficiency can be stated to work with in the model. Lake Volkerak-Zoom is a large area, however, not the entire area can be used as wetland. Therefore, a basic research is carried out where wetlands could be placed in Lake Volkerak-Zoom. This suitability is based on a spatial availability assumption (not in parts where water inlets are situated, where the sailing routes are situated and where natural areas are and were activities take place regarding fishing and recreation). Within this scope is chosen to cover 500 hectares with wetland in Lake Volkerak-Zoom.
This paragraph demonstrated nutrient reduction efficiencies. The following section will implement this information within an analysis on what average nutrient removal efficiency would be acceptable to apply to Lake Volkerak-Zoom.

Lake Volkerak-Zoom has a nutrient load for nitrogen and phosphorus. The nitrogen load in Lake Volkerak-Zoom is 1000 kg/ha/y. The phosphorus load in Lake Volkerak-Zoom is 25 kg/ha/y. Both numbers are based on nutrient measures in the years 2000 – 2009 (RWS, 2012).
For the conversion of the area in hectares to liters is a specific flow rate used. Both summer and winter vary in flow rate, since this is driven by the discharging rivers, which are driven precipitation. Assumed is that the winter flow rate in Lake Volkerak is 27 m^3/s and a summer flow rate of 17 m^3/s (Verspagen et al., 2005). Based on the research of Verspagen et al., (2005), a summer flow rate is most logical to use within this research, since the hydraulic retention time has an influence on both the efficiency of the wetlands and blue-green algae growth in Lake Volkerak.

As Total-N is 1000 kg/ha/y, 60% of this number is 600 kg/ha/y, which is the removal rate per hectare wetland. Assumed is that 500 hectares in Lake Volkerak can be used as wetland. This assumption means that in total 300.000 kg N can be removed from Lake Volkerak. For Total-P, is 25 kg/ha/y stated. 50% of this number is assumed to be removed. Which results in a removal rate of 12,5 kg/ha/y. In total, is assumed that the wetland area is capable of removing 6250 kg P. Calculations and final answers to add to the D-HYDRO model based on the numbers in this section are added to appendix 1.

This paragraph demonstrated assumptions on removal efficiencies for both nutrient-related measures. The assumptions were based on theoretical information that can be applicable to Lake Volkerak-Zoom. The next paragraph will explain how the theoretical information on nutrient removal efficiencies are analyzed and applied to the D-HYDRO model, based on Lake Volkerak-Zoom.

4.7 Nutrient reduction and temperature increase removal efficiencies

After the data was conducted and placed in the D-HYDRO model, the outcomes are further analyzed. In total, there are 38 sample locations in Lake Volkerak-Zoom, which are shown in figure 19, appendix 2. V-11 is a location in Lake Volkerak. Relatively close to the Scheldt-Rhine canal, however, it is located in the medium-deep part of Lake Volkerak. Location V-27 is located in the middle of the Scheldt-Rhine canal and sample location V-33 is located in the deepest part of Lake Zoom.

The data that is analyzed in this part of the results is the data from June 23 to August 31. In-between these dates, the peak growth of the blue-green algae (*Microcystis*) takes place. Therefore, is chosen to only represent these dates within this data analysis. Moreover, do not many changes take place on blue-green algae growth (*Microcystis*) in the spring, fall and winter season. The only change visible is an earlier start of the blue-green algae (*Microcystis*) peaks. However, in the modeled data of 2012, there is only one small peak during spring, which is not relevant enough to include within this data analysis. The output graphs of the D-HYDRO model did give some interesting results, which are explained in detail (see appendix 2 - 8). The D-HYDRO graph data is further analyzed since the graphs are rather difficult to understand and nutrient reductions fluctuate a lot within the graphs. Therefore, are all nutrient removal efficiencies for each modeled nutrient-related measure scenario visualized in table 2 and figure 18.
As can be seen in both table 2 and figure 18 is that most efficiency patterns show a similar result for each measure and each location. However, two of the efficiencies are interesting and show a divergent pattern. At sample location V-27, all efficiencies are highest. Although, not in the measure wetland reduction. This would be a logical result, since this nutrient reduction by the use of wetlands only takes place in Lake Volkerak. Therefore, is the wetland reduction method efficiency possibly also lowest for Lake Zoom since Lake Zoom is farthest away from the location this reduction method takes place. However, due to simplification, is the wetland nutrient reduction executed over the entire lake, including Lake Zoom. Therefore, this result might not fully accurate based on this analysis.

The removal efficiencies are interesting to see in terms of temperature-nutrient relationship and the reduction blue-green algae (*Microcystis*). However, temperature is important, and even shows a (*Microcystis*) removal efficiency, it is not most important in terms of blue-green algal growth. Nutrient increases have a higher effect on the growth of blue-green algae (*Microcystis*). Although, when combining temperature and even a nutrient reduction (both 2050 scenario's), a higher over-all blue-green algae (*Microcystis*) removal efficiency is visible. In this case, temperature becomes more of importance when nutrients are declining. Both components, temperature and nutrients are of importance in blue-green algae (*Microcystis*) growth as well as for a higher removal efficiency.

Table 2: Microcystis reduction efficiencies in percentages, categorized by each model output.

Sample Location	2050 temp. – 2012 nutrients	2012 temp. – 2050 nutrients rivers	2012 temp. – 2050 wetlands	2050 temp. – 2050 nutrients rivers	2050 temp. – 2050 wetlands
v-11	-11,1%	-17,1%	-16,3%	-26,0%	-24,6%
v-27	-22,5%	-32,9%	-16,3%	-37,9%	-38,1%
v-33	-7,3%	-7,1%	-10,5%	-20,8%	-33,8%

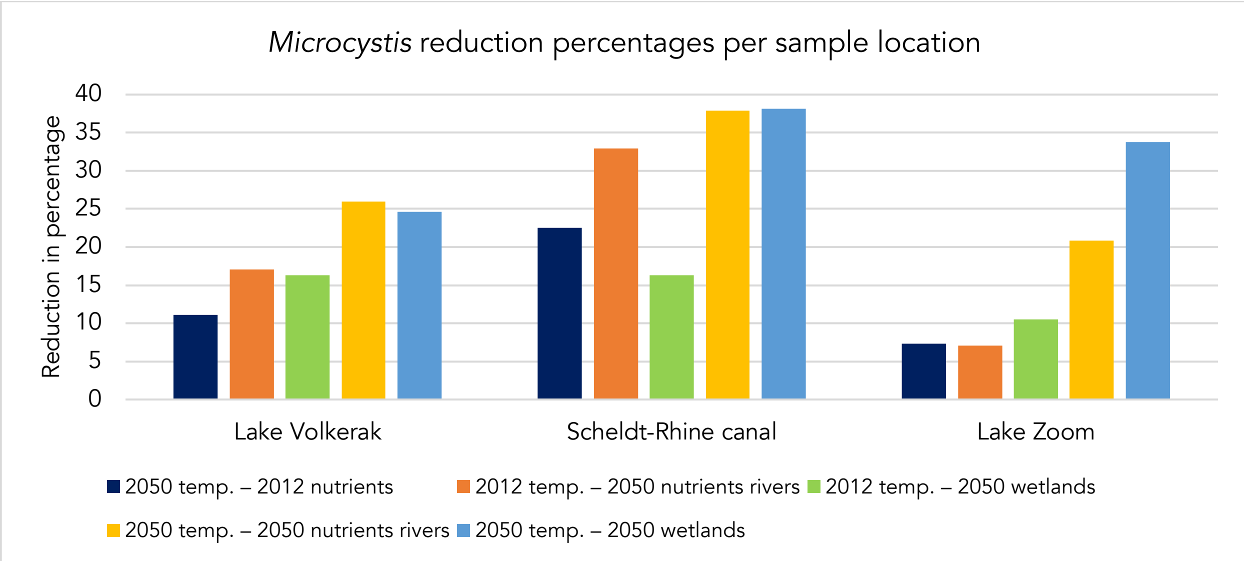

Figure 18: Microcystis reductions in percentages per sample location, categorized by each model output (Haan, 2021)

Now all results are included and analyzed, the chapter 'research results' will be followed by the conclusions that are based on the analyzed results.

5 CONCLUSION

Based on the problem statement the following research question has been stated:

"To what extend is the DPSIR approach to system understanding suitable to provide stakeholders sufficient insight to assess different nutrient-related measures to remove 50% of the blue-green algae from Lake Volkerak-Zoom until 2050?"

Based on the sub-questions can be concluded that a specific DPSIR approach can be created for Lake Volkerak-Zoom, with in state the blue-green algae (*Microcystis*). In addition, can be concluded that a DPSIR approach is a good communication method based on information by the peer-assessment that is conducted under the group of colleagues and others. However, a DPSIR approach has to be well adapted to the target stakeholder group for the desired understanding of the communication this DPSIR approach expresses. Furthermore, a DPSIR approach is highly suitable for creating insight in uncertainties of the target problem within a system. In this case, the blue-green algae (*Microcystis*) in Lake Volkerak-Zoom. A DPSIR method can be easily translated into an approach. Therefore, the possibility is created to express the blue-green algae (*Microcystis*) problem (state) in Lake Volkerak-Zoom with in addition, the causes (drivers & pressures) of the problem and the effects (impacts). Placing these elements in a DPSIR approach, gives a clear overview on what happens in the system and what the system requires to adapt or solve the problem (response).

To elaborate on the system responses, is examined what the relation is between nutrients blue-green algae (*Microcystis*), in specific for the area Lake Volkerak-Zoom. In literature from previous studies, was found that Lake Volkerak-Zoom does not have a nutrient concentration higher than the allowed concentration (Deltares, 2020 and RIVM, 2020). However, nutrients are not limited in Lake Volkerak-Zoom. From this research can be concluded that the nutrient concentrations in Lake Volkerak-Zoom are, especially during summer months, of relevance for peaks in blue-green algae (*Microcystis*) growth, algal bloom. Based on literature and modeled data, can be concluded that nutrients are, based on this research, most important cause/driver for blue-green algae (*Microcystis*) to grow (Campbell et al, 2018, Dobson & Frid, 2009 and Verspagen et al., 2005). Moreover, must be added that temperature is another cause/driver that truly impacts the growth of blue-green algae (*Microcystis*). Blue-green algae only grow during warmer days, some small peaks during spring, however the higher peak occurs mid-summer (July and August). These months have the most ideal circumstances for blue-green algae (*Microcystis*) to grow to an extend it can be called algal blooms. In addition, is climate change until 2050 taken into account in modeling data since temperature is such an influencing factor in the lifespan of blue-green algae (*Microcystis*). Furthermore, is investigated what nutrient-related measures are possible to reduce blue-green algae (*Microcystis*) with 50%. This research is focused on two nutrient-related removal types: 20% nutrient reduction via river discharge from Brabant on Lake Volkerak-Zoom and a 60% total-N and 50% total-P reduction by the use of wetlands on 500 hectares of Lake Volkerak-Zoom. For this part of the research can be concluded that there are effective and sustainable nutrient-related measures that reduce the algae growth in Lake Volkerak-Zoom. However, these used nutrient-related reduction measures were, based on modeled data, not effective enough to reduce the blue-green algae (*Microcystis*) with 50%. Based on the modeled results, can be concluded that the blue-green algae (*Microcystis*) reduction show for both nutrient-related measures a maximum reduction of 20% – 38%.

Based on the answers to the sub-questions can the main research question be answered. A DPSIR approach is a suitable method to explain a system and thereby the problem that is of interest within this system. However, must be considered to what target stakeholder the DPSIR approach will be communicated since a DPSIR can be crated and interpretated differently for every stakeholder. Moreover, is the DPSIR in this research adapted to the problem blue-green algae (*Microcystis*) in Lake Volkerak-Zoom. This water quality problem is for every stakeholder different. Therefore, other system components may be of interest for other stakeholders than for agriculture, which is mostly focused on within this research. Effective nutrient-related measures to remove blue-green algae (*Microcystis*) do exist. However, can be concluded that the researched nutrient-related methods do not meet the result of reducing the blue-green algae (*Microcystis*) with 50%.

6 DISCUSSION

With a conclusion to the stated research question of this research, some subjects and inaccuracies will be further clarified within this chapter.

To start with the DPSIR approach and the first intention of communication to stakeholders with the DPSIR approach. In first, was the intention to create a stakeholder group to review the DPSIR and create understanding of the problem and the proposed nutrient-related measures.
The stakeholder questionnaire was intended as follows: The surrounding area Lake Volkerak-Zoom includes various stakeholders. Therefore, it would have been important to adapt the DPSIR on the communication with the specific stakeholder (agriculture, industries, nature, recreation) to communicate effective and specifically to the target group. The intention was to question each stakeholder group individually. After each individual questionnaire was analyzed, possible nutrient-related measures would have been chosen, based on the stakeholders' intentions and opinions. A follow-up meeting would have been organized with all stakeholders together to see what differences each stakeholder group has in their intentions and opinions about Lake Volkerak-Zoom. During this meeting, the possible nutrient-related measures would have been presented and asked to the stakeholders' opinions and possible consequences it would have to them and the surrounding area Lake Volkerak-Zoom. This way, the DPSIR would have been more adapted to the particular stakeholders and would the chosen nutrient-related measures possibly have been more adapted to the stakeholders' interests.
Unfortunately, getting into contact with stakeholders was not possible, that this part of the research is changed into a review of the DPSIR by colleagues and other people that were easy to contact. This way, it was possible to include the science-policy communication aspect of the research.

The DPSIR approach in this research is specified to an extend that it was possible to conduct this research within the timespan that was planned. Therefore, is the state of the DPSIR approach focused on the blue-green algae (*Microcystis*) in Lake Volkerak-Zoom. Moreover, is this specification applied to the drivers and pressures in which is mainly focused on agriculture and nutrients that are of influence on Lake Volkerak-Zoom via agriculture. In addition, is for nutrients only focused on the most relevant: nitrogen and phosphorus. The DPSIR approach includes a variety of impacts on which is focused on the basics to a variety of impacts. However, there might be more impacts of interest, was the relevance not high enough to further elaborate on within this research.

This research includes a variation of analyzed data. The data that is conducted for this research is mainly conducted via literature studies and obtained via the database of Deltares.
Starting with temperature data. In first, the temperature data related to climate change is based on annual nationwide model data. In further research on how this data could be compared to weather and climate data from the region Lake Volkerak-Zoom, were differences visible. Weather and climate data in the area Lake Volkerak-Zoom stated clearly lower air temperatures than the annual nationwide data. Since temperature data was most relevant for this research is this data analyzed and further used to an extend this is relevant for this particular research.
Within the results of nutrient-related measures are two measures further researched. The first one is: 20% nutrient reduction via river discharge from Brabant on Lake Volkerak-Zoom. This method is based on sources that propose this exact number to be effective in reducing blue-green algae (*Microcystis*) to an extend this would be enough to maintain the water quality standards.

However, no further research is conducted on why this number would be effective and if this would be effective enough to reduce blue-green algae (*Microcystis*) with 50% in Lake Volkerak-Zoom. The effectiveness of this number is research by the analysis of the output of the modeled data. The second nutrient-related measure was: a 60% total-N and 50% total-P reduction by the use of wetlands on 500 hectares of Lake Volkerak-Zoom. This nutrient-related method is chosen for its sustainable, natural, and effective characteristics. However, these percentages on effectiveness are proved within literature studies. No further research has been conducted on what the effectiveness would be and what type of wetland plants would be possible to use and would be most effective in lake Volkerak-Zoom.

7 RECOMMENDATIONS

All results are obtained, conclusions are stated, and a discussion is written on this research. As been stated in this research discussion, is a DPSIR approach used to include a communication aspect and science to policy communication method with stakeholders. The science to policy communication could give a more social input to the results, which are important for the future development of the region. Due to the specific situation, the research communication aspect was included alternatively. To better understand the implications of the obtained DPSIR results, future studies could address the science to policy communication as intentioned to build up on the technical elements that created by the DPSIR itself.

Following up on the DPSIR are nutrient-related response measures researched on the possibility to remove 50% blue-green algae (*Microcystis*) by reducing nutrient concentrations. The nutrient related measures are chosen based on its socio-political characteristic and its biological characteristics. Although, no research has been conducted on how efficient, sustainable and applicable these measures were within the context nutrient reduction for 50% blue-green algae removal in Lake Volkerak-Zoom. Therefore, further research is needed to determine aspects on the applicability of the measures, sustainability of the measures, practical research on efficiency of the measures in Lake Volkerak-Zoom.

8 REFERENCES

Augustyn, A., Zeidan, A., Zelazko, A., Eldridge, A., … (2020, May 27). *Nitrogen cycle. Encyclopedia Britannica.* https://www.britannica.com/science/nitrogen-cycle

Aquafarm. (2018, March). Waterzuivering en biomassaproductie: complementaire waterzuivering met planten en dieren – Fase 1 (1). Author. Retrieved from https://www.aquafarm.nl/wp-content/uploads/2018/06/Aquafarm_eindrapport_enkel.pdf

Beardall, J., Young, E. & Roberts, S. Approaches for determining phytoplankton nutrient limitation. Aquat. sci. 63, 44–69 (2001). https://doi.org/10.1007/PL00001344

Begon, M., Howarth, R. W., & Townsend, C. R. (2014). *Essentials of Ecology*. Hoboken, NJ, United States: Wiley.

Beutel, M. W., Newton, C. D., Brouillard, E. S., & Watts, R. J. (2009). Nitrate removal in surface-flow constructed wetlands treating dilute agricultural runoff in the lower Yakima Basin, Washington. *Ecological Engineering*, *35*(10), 1538–1546. https://doi.org/10.1016/j.ecoleng.2009.07.005

Campbell, N. A., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Reece, J. B. (2018). *Biology: A Global Approach, Global Edition, eBook, Global Edition* (11th ed., Vol. 2018). Harlow, England: Pearson Education.

Carr, E. R., Wingard, P. M., Yorty, S. C., Thompson, M. C., Jensen, N. K., & Roberson, J. (2007). Applying DPSIR to sustainable development. *International Journal of Sustainable Development & World Ecology*, *14*(6), 543–555. https://doi.org/10.1080/13504500709469753

Centraal Bureau voor de Statistiek. (2018, April 13). Nutriëntenoverschot landbouw. Retrieved April 14, 2021, from https://www.cbs.nl/nl-nl/maatschappij/natuur-en-milieu/groene-groei/milieu-efficientie/indicatoren/nutrientenoverschot-landbouw

Centraal Bureau voor de Statistiek. (2021, March 18). Bevolkingsgroei. Retrieved April 7, 2021, from https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/bevolkingsgroei/groei

Elferink, E. V., van Well, E. A. P., & Vlaar, L. N. C. (2010, December). *Landbouw en Klimaat in Zeeland* (CLM 749–2010). CLM Onderzoek en Advies BV. Retrieved from https://agroenergiek.nl/system/files/documenten/boek/landbouw_en_klimaat_zeeland_def.pdf

De Vries, I., & Postma, R. (2013, May). *Quick scan waterkwaliteit en ecologie Volkerak-Zoommeer* (1207783–000). Deltares/Rijkswaterstaat Waterdienst. Retrieved from https://www.zwdelta.nl/sites/all/files/default/quick_scan_waterkwaliteit_en_ecologie_volkerak-zoommeer_juni_2013.pdf

De Vries, I., ter Maat, J., & van Velzen, E. (2012, March). *Toekomstbestendigheid besluit Volkerak-Zoommeer: een robuuste beslissing?* (1205971–000). Retrieved from https://www.zwdelta.nl/sites/all/files/default/publicaties/toekomstbestendigheid_besluit_volkerak-zoommeer_2012.pdf

Deltares. (2015, December). *1D/2D/3D Modelleersoftware voor integrale wateroplossingen*. Author. Retrieved from https://www.deltares.nl/app/uploads/2015/12/Brochure-D-HYDRO-Suite.pdf

Deltares, Rijkswaterstaat & Wageningen University and Research. (2020, December 9). 7 Waterkwaliteit en bodemkwaliteit | Concept Systeemrapportage Volkerak Zoommeer. Retrieved April 4, 2021, from https://www.testsysteemrapportage.nl/VolkerakZM/waterkwaliteit-en-bodemkwaliteit.html#nutr%C3%AFenten

Deltares, (2021); Haan, S, (2021). Systeem diagram Volkerak-Zoommeer.

Erisman, J. W., Dammers, E., van Damme, M., Soudzilovskaia, N., & Schaap, M. (2015). Trends in EU Nitrogen Deposition and Impacts on Ecosystems. EM Magazine, (31). http://www.louisbolk.org/downloads/3070.pdf

European Union. (2011, January 14). Notices From European Union Institutions, Bodies, Offices and Agencies. Retrieved April 20, 2021, from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2011:011:0001:0072:EN:PDF%20%20

European Union. (2019, September). *Global food supply and demand; Consumer trends and trade challenges*. EU Agricultural Markets Briefs. Retrieved from https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/market-brief-food-challenges-sep2019_en.pdf

Dionisio Pires, M. (2020, December). *Plan van aanpak Onderzoek blauwalgen Volkerak-Zoommeer 2021-2025* (11203741–001). Delft, Nederland: Deltares.

Dobson, M., & Frid, C. (2009). *Ecology of Aquatic Systems*. Oxford, United Kingdom: Oxford University Press.

Fairbridge, R. W., Jönsson, L., Håkanson, L., White, W. R., Mikos, M., Herschy, R. W., . . . Håkanson, L. (2012). Stratification in Lakes. *Encyclopedia of Lakes and Reservoirs*, 743–747. https://doi.org/10.1007/978-1-4020-4410-6_12

Fisher, J., & Acreman, M. C. (2004). Wetland nutrient removal: a review of the evidence. *Hydrology and Earth System Sciences*, *8*(4), 673–685. https://doi.org/10.5194/hess-8-673-2004

Fowler, D., Coyle, M., Skiba, U., Sutton, M. A., Cape, J. N., Reis, S., . . . Voss, M. (2013). The global nitrogen cycle in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1621), 20130164. https://doi.org/10.1098/rstb.2013.0164

Houghton, J. (2005, June). *Global Warming* (Volume 68, Number 6). Reports on Progress in Physics. Retrieved from https://iopscience.iop.org/article/10.1088/0034-4885/68/6/R02/meta

Kadlec, R. H., & Wallace, S. (2008). *Treatment Wetlands* (2nd ed., Vol. 2009). Abingdon, Verenigd Koninkrijk: CRC Press.

Keizer-Vlek, H. E., Verdonschot, P. F., Verdonschot, R. C., & Dekkers, D. (2014). The contribution of plant uptake to nutrient removal by floating treatment wetlands. *Ecological Engineering*, *73*, 684–690. https://doi.org/10.1016/j.ecoleng.2014.09.081

Koerselman, W., & Meuleman, A. F. M. (1996). The Vegetation N:P Ratio: a New Tool to Detect the Nature of Nutrient Limitation. *The Journal of Applied Ecology*, *33*(6), 1441. https://doi.org/10.2307/2404783

KNMI, 2014: KNMI'14-klimaatscenario's voor Nederland; Leidraad voor professionals in klimaatadaptatie, KNMI, De Bilt, 34 pp, https://repository.tudelft.nl/islandora/object/uuid:d7a3208b-86ac-4aec-9fcb-925e53fadad1

KNMI. (n.d.). KNMI - Klimaat. Retrieved April 5, 2021, from https://www.knmi.nl/kennis-en-datacentrum/uitleg/klimaat/

Kramer, L., Los, H., Troost, T., Geseberger, M., Thiessen, M., & Boderie, P. (2016, January). *3D model van het VolkerakZoommeer voor waterkwaliteit en primaire productie* (1220070–000). Deltares. Retrieved from http://publications.deltares.nl/1220070_000_0034.pdf

Land, M., Granéli, W., Grimvall, A., Hoffmann, C. C., Mitsch, W. J., Tonderski, K. S., & Verhoeven, J. T. A. (2016). How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. *Environmental Evidence*, *5*(1). https://doi.org/10.1186/s13750-016-0060-0

Levine, I., & Fleurence, J. (2018). *Microalgae in Health and Disease Prevention* (Vol. 2018). Maarssen, Netherlands: Elsevier Gezondheidszorg.

Lin, Y. F., Jing, S. R., Lee, D. Y., & Wang, T. W. (2002). Nutrient removal from aquaculture wastewater using a constructed wetlands system. *Aquaculture*, *209*(1–4), 169–184. https://doi.org/10.1016/s0044-8486(01)00801-8

Mihelcic, J. R., & Zimmerman, J. B. (2014). *Environmental Engineering* (2nd ed.). Hoboken, NJ, United States: Wiley.

Ministerie van Infrastructuur en Milieu. (2014, October). *Milieueffectrapport bij de Rijksstructuurvisie Grevelingen en Volkerak-Zoommeer*. Author. Retrieved from https://www.zwdelta.nl/sites/all/files/default/nr._02_-_mer_rapport.pdf

Monier, S. (2013, October). *Constructed Wetlands redefined as Functional Wetlands* (1202415–047). Deltares. Retrieved from http://publications.deltares.nl/1202415_047.pdf

Newman, M. C. (2015). *Fundamentals of Ecotoxicology: The Science of Pollution, Fourth Edition* (4th ed.). Boca Raton, United Sates: CRC Press.

Newman, R. J. (2005, November). *Eutrophication in Rivers: An Ecological Perspective*. Centere for Ecology and Hydrology. https://doi.org/10.13140/2.1.3711.5208

Rijkswaterstaat. (2012, April). *Milieueffect Rapportage. Waterkwaliteit Volkerak-Zoommeer*. Retrieved from https://www.deltaexpertise.nl/images/e/ed/Ontwerp-Milieueffectrapport_Waterkwaliteit_VZM_april_2012.pdf

Rijkswaterstaat. (2020, March). *Kaderrichtlijn Water, Natura 2000 & Programmatische Aanpak Grote Wateren Jaarrapportage ecologische waterkwaliteit en natuur 2019* (PPO0320ZB129). Ministerie van Infrastructuur en Waterstaat. Retrieved from https://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/kaderrichtlijn-water/

Rijkswaterstaat. (2021). Korte uitleg DPSIR methode. Retrieved February 2, 2021, from https://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/kaderrichtlijn-water/uitvoering/rijn-west/we/krw/dpsir/

RIVM. (2020). *Landbouwpraktijk en waterkwaliteit in Nederland; toestand (2016–2019) en trend (1992–2019); De Nitraatrapportage 2020 met de resultaten van de monitoring van de effecten van de EU Nitraatrichtlijn actieprogramma's* (projectnummer M/270109). https://doi.org/10.21945/RIVM-2020-0121

RIVM. (2021). Fosfaat | | Risico's van stoffen. Retrieved June 4, 2021, from https://rvszoeksysteem.rivm.nl/stof/detail/2518

Rozemeijer, J., & Broers, H. (2007). The groundwater contribution to surface water contamination in a region with intensive agricultural land use (Noord-Brabant, The Netherlands). *Environmental Pollution*, *148*(3), 695–706. https://doi.org/10.1016/j.envpol.2007.01.028

RVO. (2019, November). *Hoeveel mest gebruiken. Hoe rekent u dat uit?* Author. Retrieved from https://www.rvo.nl/sites/default/files/2019/11/Hoeveel%20mest%20uitrijden%20hoe%20rekent%20u%20dat%20uit%2028-11-19%20v1.pdf

Siepman, M. (2018). Stikstof: essentieel maar lastig – deel 1: de natuurlijke stikstofkringloop. *Permacultuur Magazine*, *2018*(10). Retrieved from https://marcsiepman.nl

Sikkema, A. (2020, August 2). De stikstofproblematiek in vijf vragen. *Resource*, *14*(20). Retrieved from https://resource.wur.nl

Spielmann, P., & Dekens, B. (2021, February). *Zoetwateraanvoer Schouwen-Duiveland*. Witteveen+Bos. Retrieved from https://www.zeeland.nl/sites/zl-zeeland/files/rapport_verkenning_zoetwateraanvoer_schouwen-duiveland.pdf

Strien, W., van Strien, W., Doornbos, S., Foppen, R., Meyling, A. G., Herder, J., . . . Roos, M. (2020). *Living Planet report Nederland : natuur en landbouw verbonden* (Vol. 2020). Zeist, Nederland: Wereld Natuur Fonds.

Svarstad, H., Petersen, L. K., Rothman, D., Siepel, H., & Wätzold, F. (2008). Discursive biases of the environmental research framework DPSIR. *Land Use Policy*, *25*(1), 116–125. https://doi.org/10.1016/j.landusepol.2007.03.005

Tangelder, M., Winter, E., & Ysebaert, T. (2017). Ecologie van zoet-zout overgangen in deltagebieden: literatuurstudie en beoordeling van een scenario in het Volkerak-Zoommeer. *Ecologie van Zoet-Zout Overgangen in Deltagebieden: Literatuurstudie En Beoordeling van Een Scenario in Het Volkerak-Zoommeer*, *C116/17*, 5–39. https://doi.org/10.18174/436428

TNO. (2019, October). *Emissies en Depositie van Stikstof in Nederland*. Author. Retrieved from https://www.tno.nl/nl/over-tno/nieuws/2019/10/factsheet-stikstofemissie/

Tosserams, M. W. A., Lammens, E. H. R. R., & Platteeuw, M. (2000). *Het Volkerak-Zoommeer* (2e exemplaar ed., Vol. 2000.024). Lelystad, Nederland: Ministerie van Verkeer en Waterstaat, Directoraat-Generaal Rijkswaterstaat, Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling RIZA.

Van Boekel, E. M. P. M., Groenendijk, P., & Renaud, L. V. (2017, July). *Maatregelen voor het verlagen van de nutriëntenbelasting uit landbouwpercelen* (2824). Wageningen University & Research. https://doi.org/10.18174/419390

Van Gaalen, F., & van Grinsven, H. (2017). *Vijf vragen over Nutriënten en Waterkwaliteit* (2916). PBL Planbureau voor de Leefomgeving. Retrieved from https://www.pbl.nl/sites/default/files/downloads/pbl-2017-nutrienten-en-waterkwaliteit-2916.pdf

Van Puijenbroek, P. J. T. M., Cleij, P., & Visser, H. (2010). *Nutriënten in het Nederlandse zoete oppervlaktewater: toestand en trends* (500208001). Planbureau voor de Leefomgeving (PBL). Retrieved from https://www.pbl.nl/sites/default/files/downloads/pbl-2010-nutrienten-in-het-nederlandse-zoete-oppervlaktewater-toestand-en-trends-500208001.pdf

Van 'T Hoog, A. (2017). Fosfaatkringloop niet sluitend, straks is het op. *WageningenWorld*, *2017*(04), 10–15. Retrieved from https://edepot.wur.nl/430188

Van Vliet, L. J. P., Bittman, S., Derksen, G., & Kowalenko, C. G. (2006). Aerating Grassland before Manure Application Reduces Runoff Nutrient Loads in a High Rainfall Environment. *Journal of Environmental Quality*, *35*(3), 903–911. https://doi.org/10.2134/jeq2005.0266

Vergouwen, A. A. (2010). *Resultaten workshop 20 mei 2009 en achtergrondgegevens fosfaat, van leegloop naar kringloop* (Vols. 2010–12). Amersfoort, Nederland: STOWA.

Verhoeven, J. T., & Meuleman, A. F. (1999). Wetlands for wastewater treatment: Opportunities and limitations. *Ecological Engineering*, *12*(1–2), 5–12. https://doi.org/10.1016/s0925-8574(98)00050-0

Verspagen, J. M. H., Boers, P., Laanbroek, H. J., & Huisman, J. (2005, March). *Doorspoelen of opzouten? Bestijding van blauwalgen in het Volkerak-Zoommeer 2005*. Universiteit van Amsterdam. Retrieved from https://puc.overheid.nl/rijkswaterstaat/doc/PUC_121758_31/

Watersnoodmuseum. (2020). Deltaplan – Watersnoodmuseum. Retrieved February 10, 2021, from https://watersnoodmuseum.nl/kennisbank/deltaplan/

Weeber, M. P., Nolte, A. J., Troost, T. A., Genseberger, M., Kramer, L., Tiessen, M. C. H. (2018). Data-analyse en modelvalidatie van het Volkerak-Zoommeer ecosysteem: Met focus op blauwalgen en quaggamosselen. Deltares rapport 11201168-000-ZKS-0007-v3.

Zuidwestelijke Delta. (2018, October 4). *Welke gevolgen had de droogte voor het Volkerak-Zoommeer?* [Photo]. Retrieved from https://www.zwdelta.nl/nieuws/welke-gevolgen-had-de-droogte-voor-het-volkerak-zoommeer

9 APPENDICES

Appendix 1: Removal efficiencies wetlands and calculations nutrient removal Lake Volkerak-Zoom

Table 3: Nutrient removal efficiencies wetlands per included source of research.

Source	Nitrogen efficiency	Phosphorus efficiency
Verhoeven & Meuleman	35%	25%
	50%	40%
Lin et al.	86% - 98%	32% - 71%
Beutel et al.	57% - 63%	
Land et al.	37%	46%
Keizer-Vlek et al.	74%	60%
Average (minimum based)	55%	40%
Average (maximum based)	60%	50%

Regarding the 3D model, some input data has to be considered. Lake Volkerak-Zoom has a nutrient load for nitrogen and phosphorus. The nitrogen load in Lake Volkerak-Zoom is 1000 kg/ha/y. The phosphorus load in Lake Volkerak-Zoom is 25 kg/ha/y. Both numbers are based on nutrient measures in the years 2000 – 2009 (RWS, 2012). For the conversion area in hectares to liters is a specific flow rate used. Both summer and winter vary in flow rate, since this is driven by precipitation. Assumed is that the winter flow rate in Lake Volkerak is 27 m^3/s and a summer flow rate of 17 m^3/s (Verspagen et al., 2005). Based on this research, is a summer flow rate most logical since the hydraulic retention time an influence on both the efficiency of the wetlands and blue-green algae growth in Lake Volkerak.

As Total-N is 1000 kg/ha/y is 60% of this number 600 kg/ha/y, which is the removal rate per hectare wetland. Assumed is that 500 hectares in Lake Volkerak can be used as wetland. This assumption means that in total 300.000 kg N can be removed from Lake Volkerak. For Total-P, is 25 kg/ha/y stated. 50% of this number is assumed to be removed. Which results in a removal rate of 12,5 kg/ha/y. In total, is assumed that the wetland area is capable of removing 6250 kg P.

Table 4: Total-N removal in kg/ha/year in Lake Volkerak-Zoom over 10.000 m^2.

Total-N	
1000 kg/ha/year = 1.000.000.000 mg	
10.000 m^2	
= 100.000	mg/m^2/year
= 373,97	mg/m^2/day
= 0,003	mg/m^2/second

Table 5: Total-P removal in kg/ha/year in Lake Volkerak-Zoom over 10.000 m^2

Total-P	
25 kg/ha/year = 25.000.000 mg	
10.000 m^2	
= 25.000	mg/m^2/year
= 6,849	mg/m^2/day
= 0,00008	mg/m^2/second

Table 6: Total-N removal in total kg/year in Lake Volkerak-Zoom over 5.000.000 m²

Total-N	
300.000 kg/year = 300.000.000.000 mg	
5.000.000 m^2	
= 60.000	$mg/m^2/year$
= 164	$mg/m^2/day$
= 0,0019	$mg/m^2/second$
= 0,164	$g/m^2/day$

Table 7: Total-P removal in total kg/year in Lake Volkerak-Zoom over 5.000.000 m²

Total-P	
6250 kg/year = 6.250.000.000 mg	
5.000.000 m^2	
= 1250	$mg/m^2/year$
= 3,42	$mg/m^2/day$
= 0,00004	$mg/m^2/second$
= 0,0034	$g/m^2/day$

Table 8: Total-N removal in total kg/year in Lake Volkerak-Zoom over 60.000.000 m²

Total-N	
300.000 kg/year = 300.000.000.000 mg	
60.000.000 m^2	
= 5000	$mg/m^2/year$
= 13,698	$mg/m^2/day$
= 0,0137	$g/m^2/day$

Table 8: Total-P removal in total kg/year in Lake Volkerak-Zoom over 60.000.000 m²

Total-P	
6250 kg/year = 6.250.000.000 mg	
60.000.000 m^2	
= 104,16	$mg/m^2/year$
= 0,285	$mg/m^2/day$
= 0,0003	$g/m^2/day$

Based on the calculations, will the wetland (500 ha) be able to remove 0,164 $g/m^2/day$ Total-N and is it capable of removing 0,00342 $mg/m^2/day$ Total-P.
Spread over the entire area (6000 ha), the removal rate for Total-N will be 0,01370 $g/m^2/day$ and for Total-P, this will be 0,0003 $g/m^2/day$.

Appendix 2: Map measuring locations Lake Volkerak-Zoom

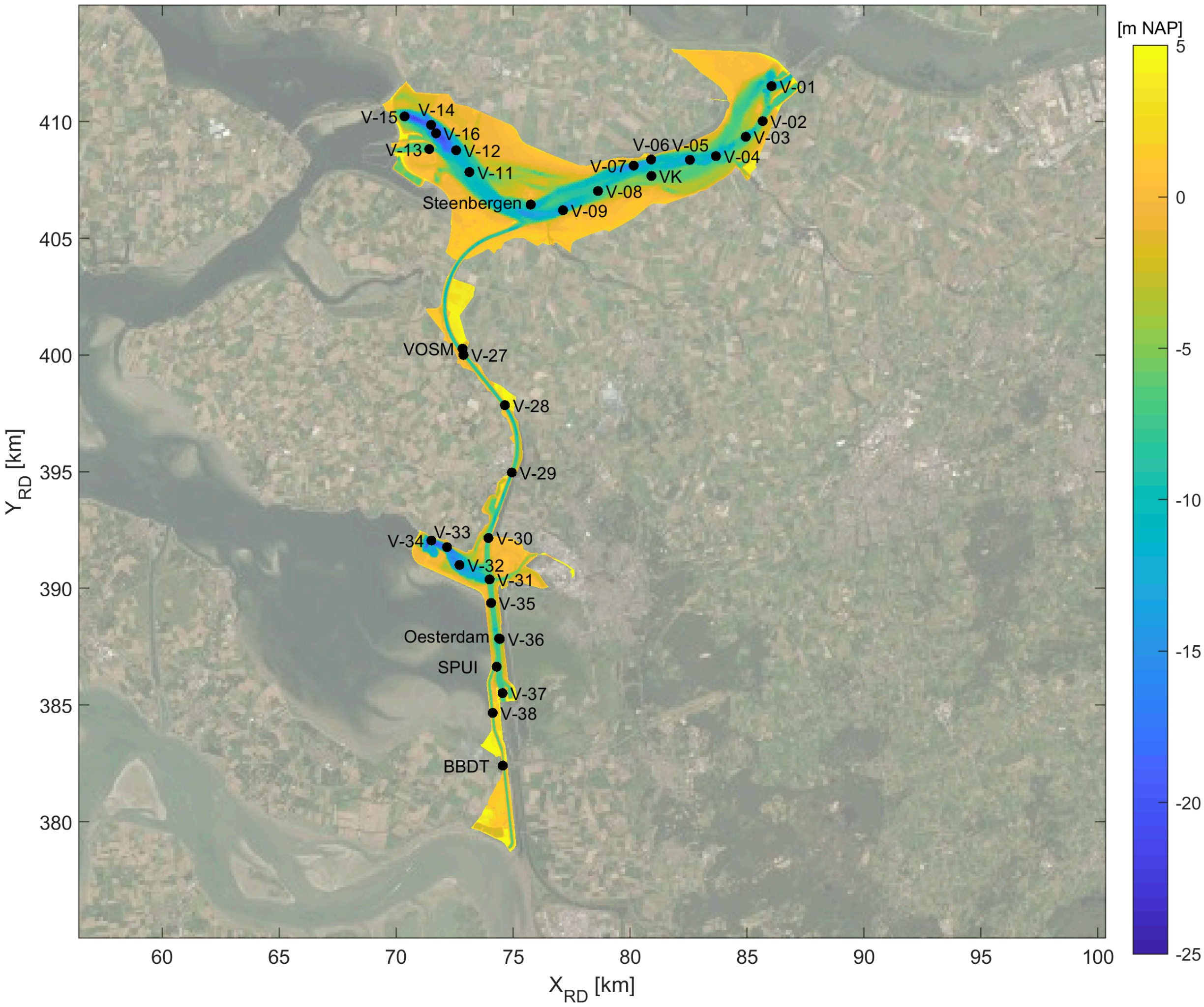

Figure 19: Sample locations water quality measures (Deltares, 2021).

On the map in figure 19 are several sample locations placed in Lake Krammer-Volkerak as well as Lake Zoom. The map pictures the entire Volkerak-Zoom area in km and its water depths in m NAP. The numbers in the lakes represent a sample location for a variety of parameters (oxygen, chlorophyll a, algae types, NH4, NO3, PO4, Total-N, Total-P, salinity, temperature).

As shown in figure 19, are 38 locations visualized. Every location has its own specific characteristics based on water depth, flow rate, e.g., that influence the water. Therefore, are per measured parameter several graphs of different locations analyzed and further explained based on the data that is placed in the model D-HYDRO. The choice of graphs that are used are based on an average good representation of the entire Lake Volkerak-Zoom area.

Appendix 3: Time series blue-green algae (*Microcystis*) 2011 – 2016

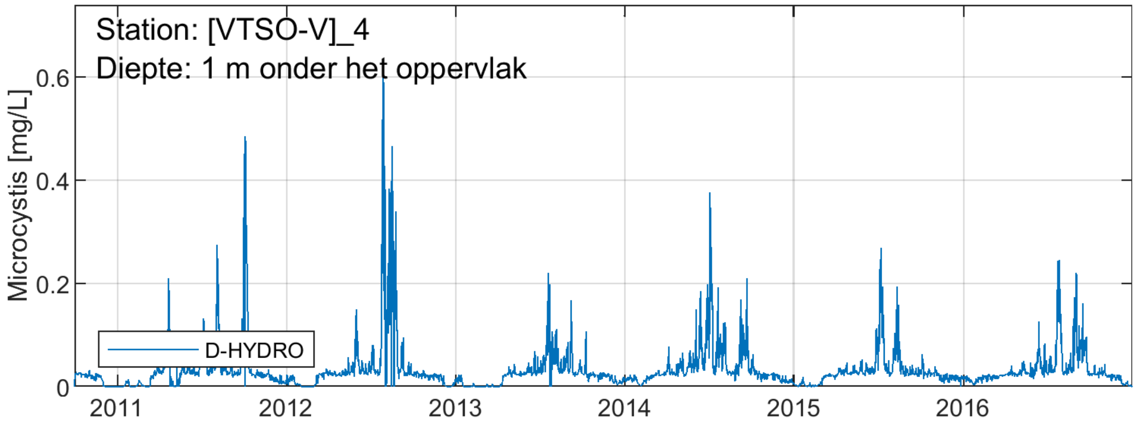

Figure 20: Sample location v-4, Microcystis data measures in mg/l, 2011 to 2016 (Deltares, 2021).

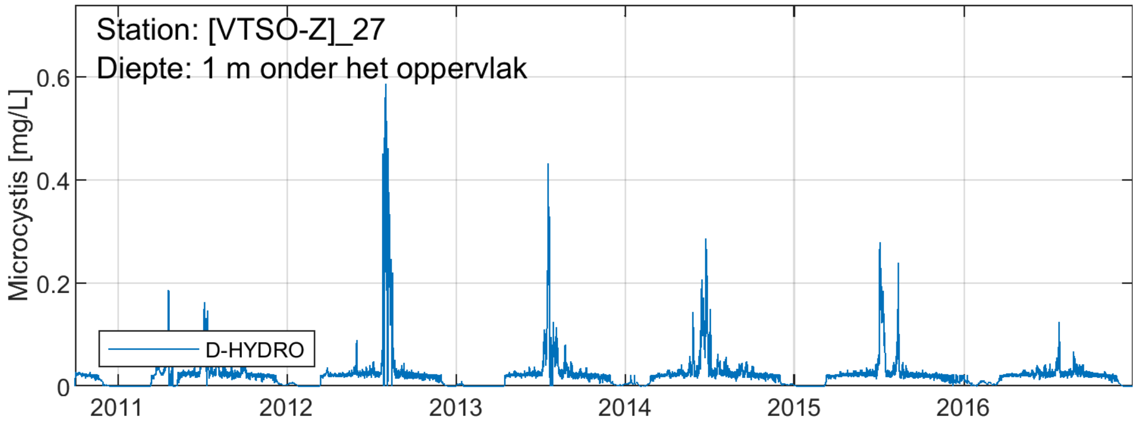

Figure 21: Sample location v-27, Microcystis data measures in mg/l, 2011 to 2016 (Deltares, 2021).

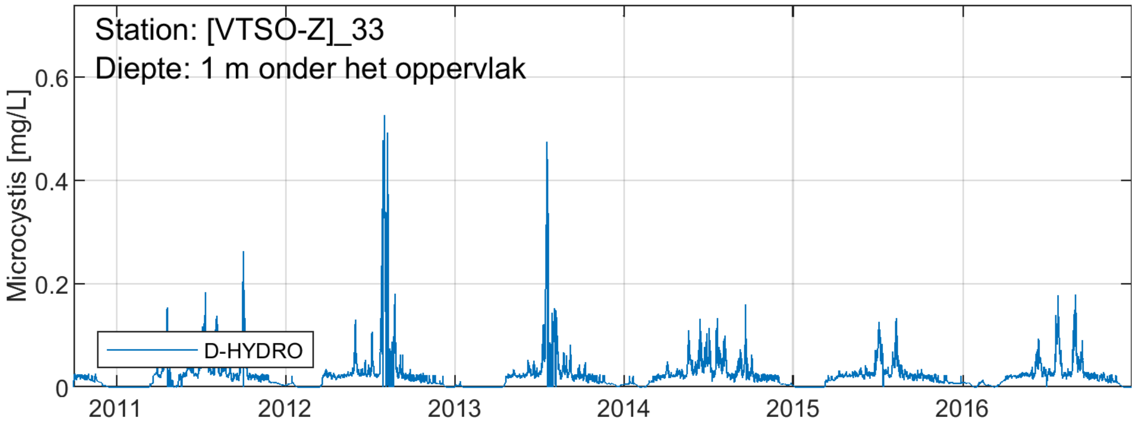

Figure 22: Sample location v-33, Microcystis data measures in mg/l, 2011 to 2016 (Deltares, 2021).

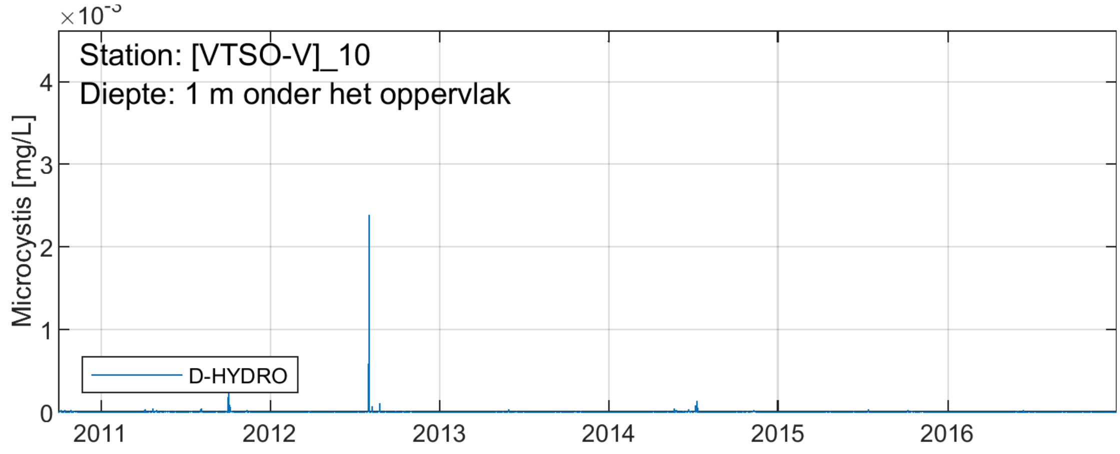

Figure 23: Sample location v-10, Microcystis data measures in mg/l, 2011 to 2016 (Deltares, 2021).

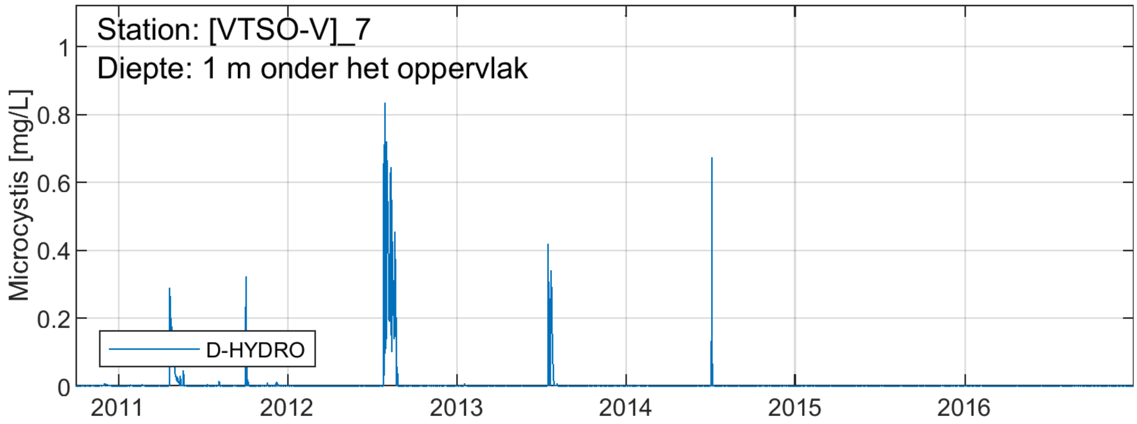

Figure 24: Sample location v-7, Microcystis data measures in mg/l, 2011 to 2016 (Deltares, 2021).

Before running the D-HYDRO model, the input algae had to be set up. Within this research is the algae type blue-green algae (*Microcystis*) researched on its abundance in Lake Volkerak-Zoom. Therefore, is the data input of this algae type (*Microcystis*) set in the D-HYDRO model. Several stations are analyzed on what the blue-green algae abundance was in mg/l in the years 2011 - 2016. As can be seen on all graphs within "*Time series blue-green algae (Microcystis) 2011 - 2016*" is that 2012 is the year with the highest blue-green algae (*Microcystis*) growth. Therefore, is chosen to use 2012 as the model year, with 2011 as 'balance' year.

As can be seen in the figures 20 - 24 is that all give different patterns. Every graph is data from a different sampling location. Figure 20 represents sampling location v-4, which is situated near the river Dintel. This causes higher fluctuations since it is influenced by the river. Moreover, are the peaks in *Microcystis* (in mg/l) slightly higher than the figures of the other sampling locations. Typical for figure 21 (sampling location v-27) is that the concentration *Microcystis* is comparable with sampling location v-4. This high concentration is caused by the fact that sampling location v-27 is situated in the Scheldt-Rhine canal, which is small and relatively shallow. However, there are fewer peak moments in sampling location v-27 compared to v-4. This is caused by the low influence of rivers and the location in the relatively small canal this sampling location is situated in. Sampling location v-33 (figure 22) is situated in the deeper part of Lake Zoom. This location represents more peak moments than location v-27, but a lower concentration *Microcystis* than both location v-27 as v-4. This as a result of that this sampling location is situated in the deeper part of the lake where mixing occurs slightly more often and the bottom layer of water at the sampling location has a lower temperature. Then sampling location v-10 (figure 23) which represents an entire different graph than the locations v-4, v-27 and v-33. Sampling location v-10 is situated in the middle of Lake Volkerak near the inlet/outlet Scheldt-Rhine canal. This sampling location is situated along the sailing route and close to the marshes. Due to its location and no influence of discharging rivers is the *Microcystis* concentration extremely low compared to the other sampling locations. Sampling location v-7 shows on the other hand an extremely high *Microcystis* concentration, compared to the other sampling locations. This might be the result of the fact that location v-7 is located in Lake Volkerak, in between the two discharging rivers. This location has therefore possibly one peak moment during the summer due to the high agricultural runoff and relatively lower flow rate. However, in spring and in the start of the fall, this location has no concentration *Microcystis* which is possibly the result of a higher flow rate in the rivers and a higher flow rate entering Lake Volkerak via the river Hollandsch Diep. More water enters the system at that moment, which means that the *Microcystis* do not get a chance to grow anymore since it is not able to adapt to these higher flowrates and water movements.

Appendix 4: Time series water temperature 2011/2049

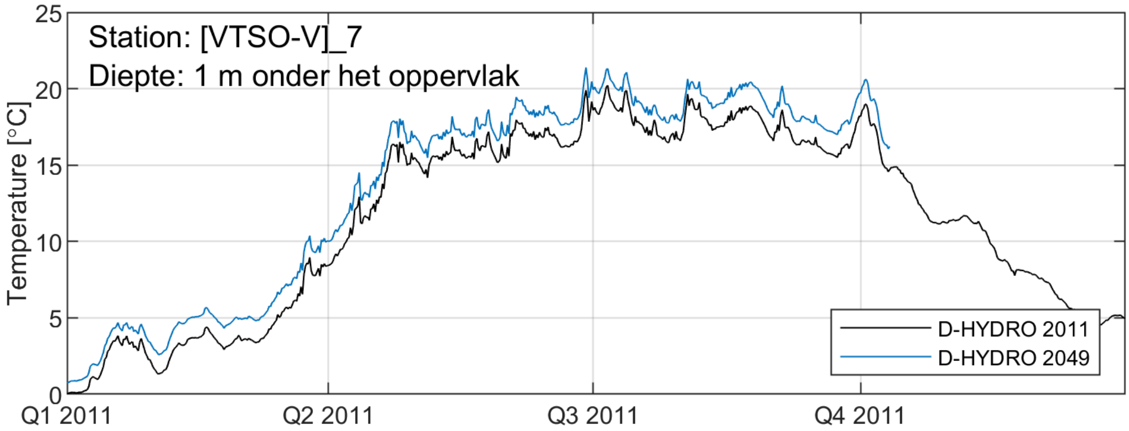

Figure 25: Sample location v-7, Water temperature data of 2011 and 2049 (air temperature increase of 1,8˚C) (Deltares, 2021).

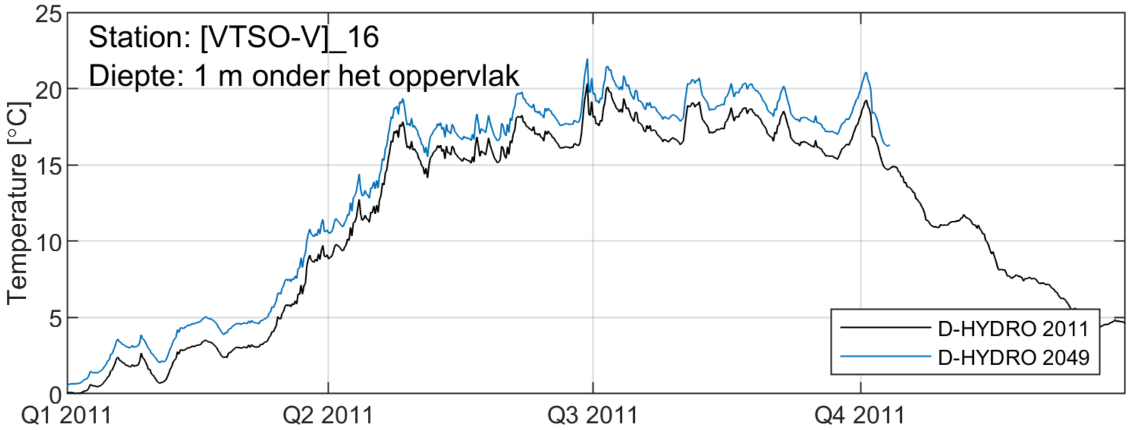

Figure 26: Sample location v-16, Water temperature data of 2011 and 2049 (air temperature increase of 1,8˚C) (Deltares, 2021).

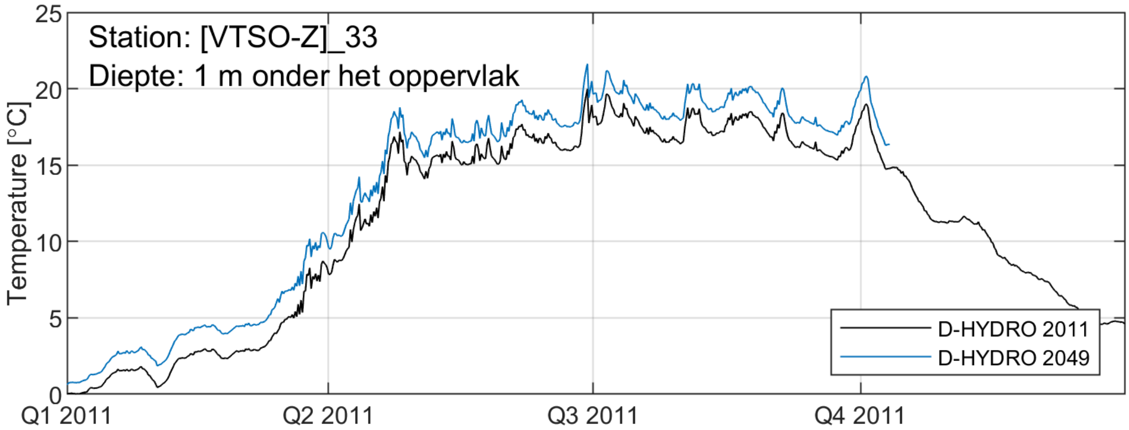

Figure 27: Sample location v-33, Water temperature data of 2011 and 2049 (air temperature increase of 1,8˚C) (Deltares, 2021).

Appendix 5: Time series water temperature 2012/2050

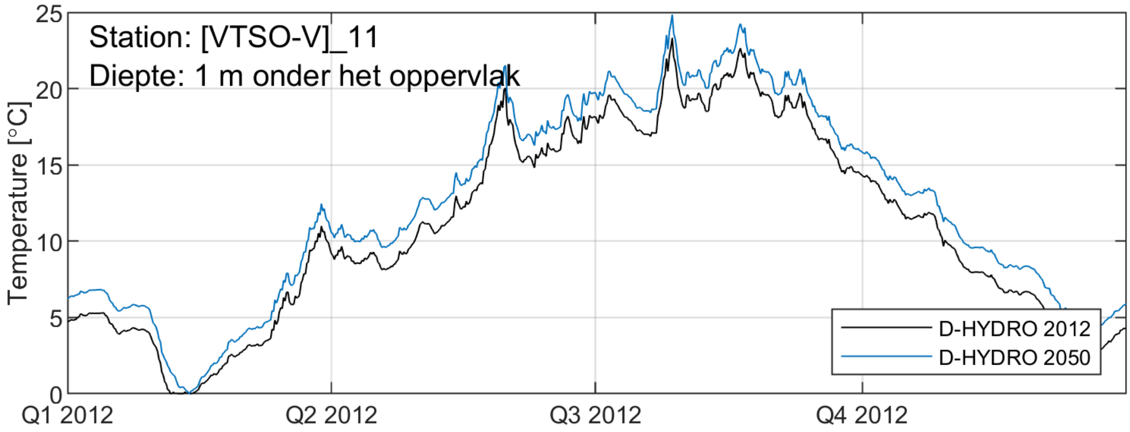

Figure 28: Sample location v-11, Water temperature data of 2012 and 2050 (air temperature increase of 1,8˚C) (Deltares, 2021).

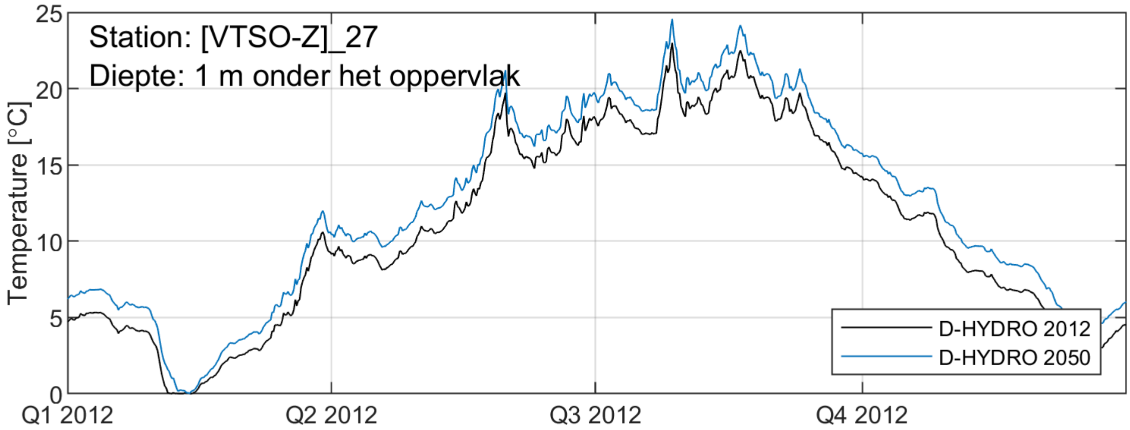

Figure 29: Sample location v-27, Water temperature data of 2012 and 2050 (air temperature increase of 1,8˚C) (Deltares, 2021).

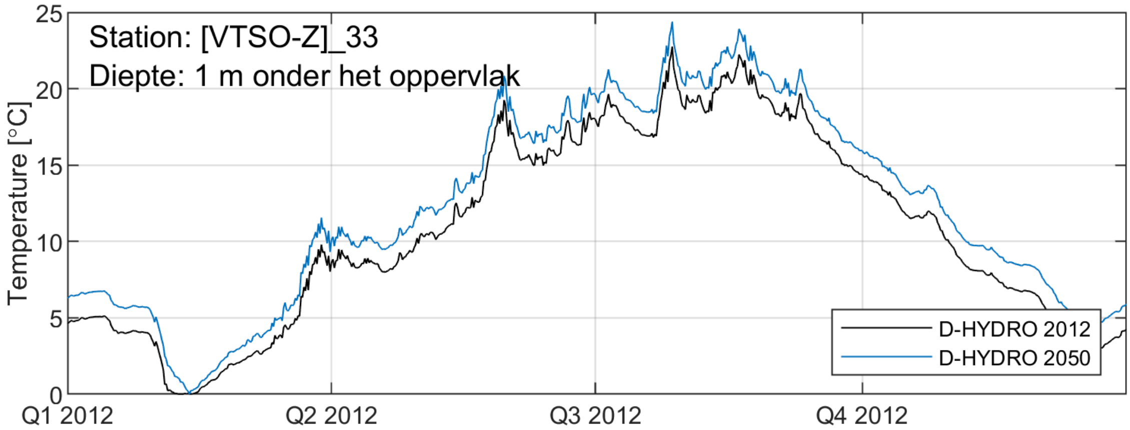

Figure 30: Sample location v-33, Water temperature data of 2012 and 2050 (air temperature increase of 1,8˚C) (Deltares, 2021).

In water temperature is not so much a difference visible in the years 2011/2049 – 2012/2050. However, do the different sampling locations represent some small differences for all of the locations. Sampling location v-11 is not shown before. This location is situated in Lake Volkerak in between the Scheldt-Rhine canal and the outlet to Lake Grevelingen (see figure 28). In addition, sampling location v-16, which is not shown and analyzed before. This location is located at the deepest part of Lake Volkerak and closely situated near lake Grevelingen. Related to water temperature are the graphs very much alike, only some minor results are visible. Related to all the other graphs is location v-33 most divergent in the time series 2011/2049 and 2012/2050, since this location shows a less stable fluctuation of temperature. Most logical caused by the location; in the deep part of Lake Zoom.

In relation to water temperature, show all locations an expected result. Modeled is that the air temperature will increase with 1.8˚C on average over the year. Water temperature does respond to this change, however, not always with the 1,8˚C increase. This seems logical since water does not warm up and cool down that fast as air temperature. This results in lower differences in water temperature at the lowest temperatures (Q1) as well as in the highest peaks (Q2 & Q3). This pattern is shown in all of the water temperature graphs.

Appendix 6: Time series relation temperature - blue-green algae (*Microcystis*) 2011/2049

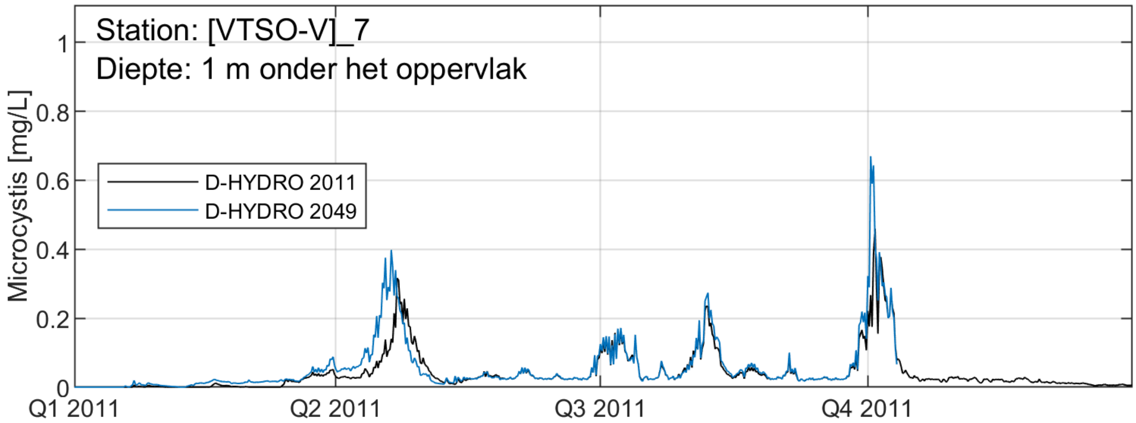

Figure 31: Sample location v-7, Water temperature data of 2011 and 2049 (air temperature increase of 1,8°C) related to Microcystis concentration in mg/l (Deltares, 2021).

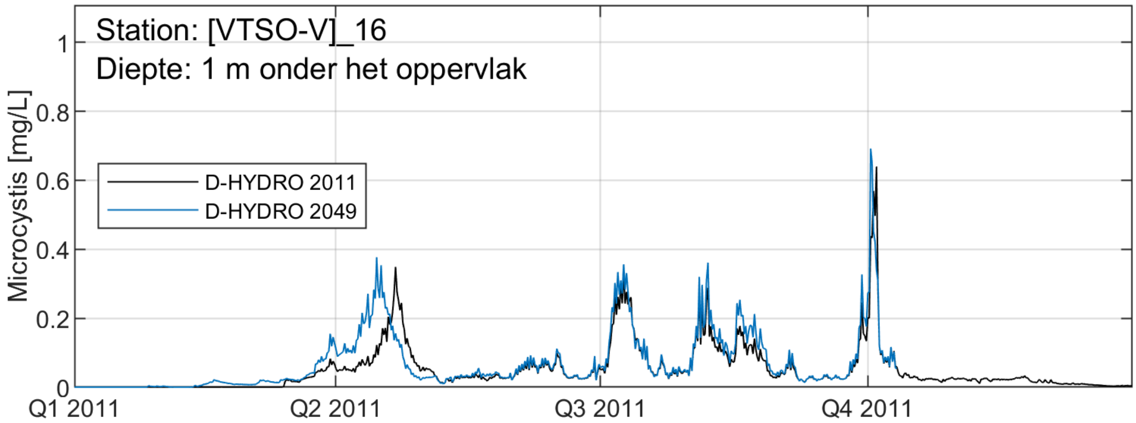

Figure 32: Sample location v-16, Water temperature data of 2011 and 2049 (air temperature increase of 1,8°C) related to Microcystis concentration in mg/l (Deltares, 2021).

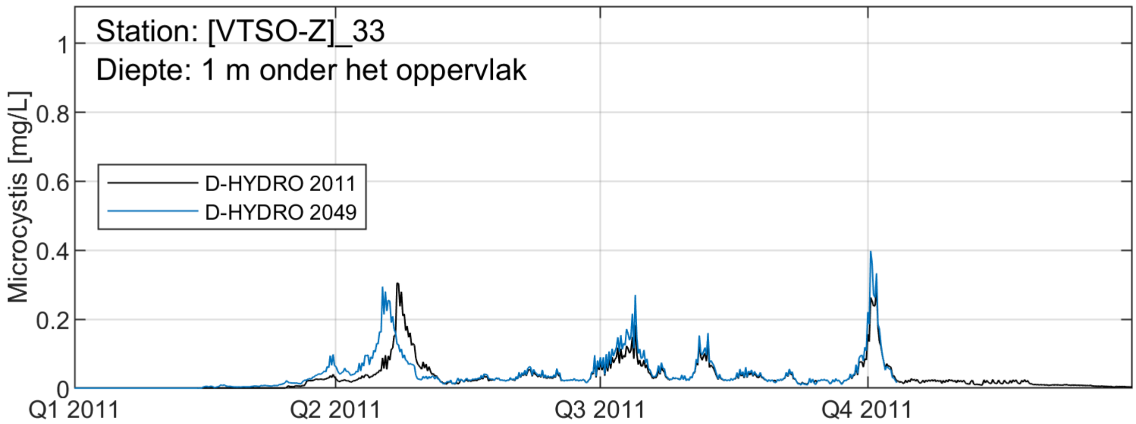

Figure 33: Sample location v-33, Water temperature data of 2011 and 2049 (air temperature increase of 1,8°C) related to Microcystis concentration in mg/l (Deltares, 2021).

For the relation temperature - (*Microcystis*), the pattern is expected on forehand. The temperature is risen with 1,8˚C on average over the year. According to the KNMI, (2014), will the summer season be extended. Summers start earlier and end later. That summers start earlier is proved by the graphs in “*Time series relation temperature - blue-green algae (Microcystis) 2011/2049*”. In addition are the peaks higher, which is a logical outcome when the average temperature increases with 1,8˚C uniformly. Although, this is the expected change that is modeled, peaks and the start of the summer will differ from the reality based on natural influences.

Appendix 7: Time series relation temperature and nutrient reduction discharging rivers - blue-green algae (*Microcystis*) 2012/2050

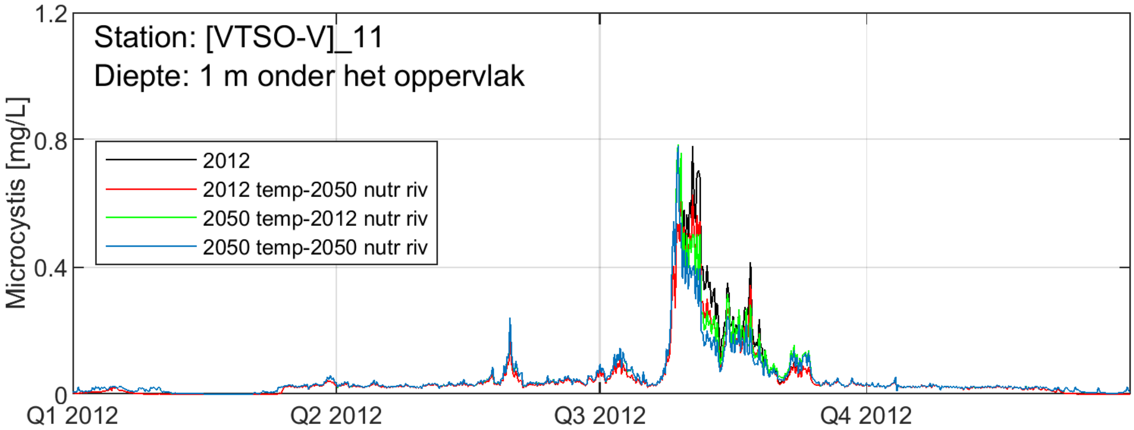

Figure 34: Sample location v-11, Scenario Microcystis concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

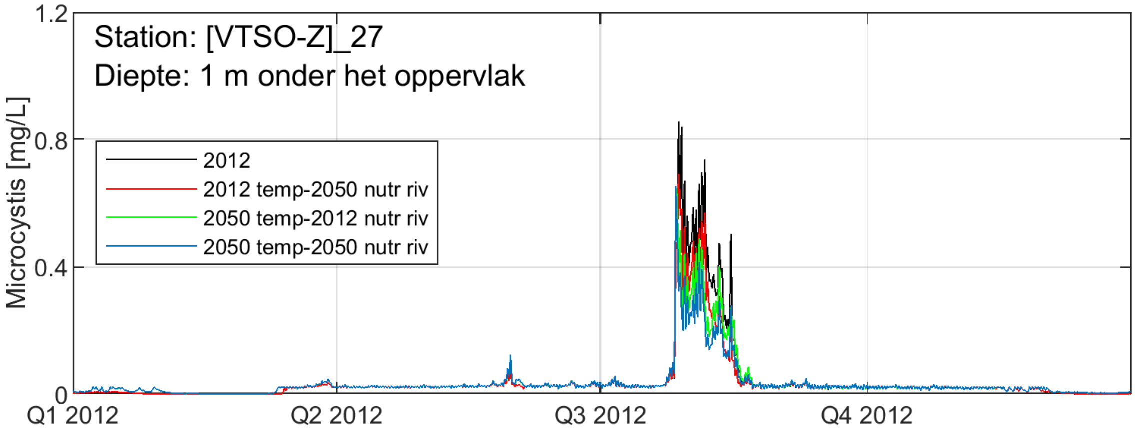

Figure 35: Sample location v-27, Scenario Microcystis concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

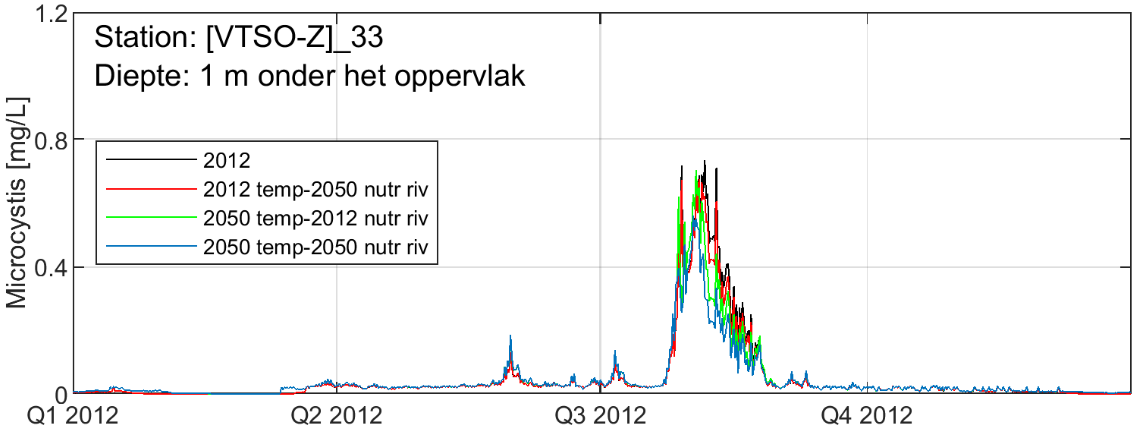

Figure 36: Sample location v-33, Scenario Microcystis concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

In these graphs is the relation temperature and the lowering of the nutrients in the rivers modeled against each other. In most of the graphs is the (*Microcystis*) concentration of 2012 the highest, or the same as the other lines in the graph. On forehand, was expected that the highest concentration (*Microcystis*) would be measured with the 2050 temperature (1,8˚C increase) and a nutrient concentration of the one measured in 2012. However, both 2012 temperature and 2050 nutrients (red) and 2050 temperature and 2012 nutrients (green) show a similar pattern, in which most of the cases the line of 2012 temperature and 2050 nutrients (red) shows a higher (*Microcystis*) concentration in the summer peak. The blue line represents the 2050 temperature and the 2050 nutrient concentration (20% nutrient reduction from discharging rivers). As expected, does this line show the lowest (*Microcystis*) concentration over the year. Temperature is of a large influence on (*Microcystis*) growth. However, the concentration of nutrients is of a larger importance for (*Microcystis*) growth.
Within the different sampling locations is a slight difference visible in the peak moments, especially in Q3. Sample location v-11 has a peak that is more spread over quartal 3. This is caused by the location. V-11 is located in not a deep and not a shallow part, but in the open lake in Lake Volkerak. Therefore, the velocity does not have as much of an influence as in deeper parts of the lake or in the canal or Lake Zoom. The *Microcystis* have more time to reproduce and therefore takes a longer time before the *Microcystis* disappear from the location. Location v-27 is a location in which only one period of high peaks occurs. This is caused by the narrow and shallow canal. A high peak occurs and disappears relatively fast, compared to location v-11. This fast disappearance of the *Microcystis* is probably caused by the higher water during fall, winter and spring. When the rainy season starts, the peak *Microcystis* disappears directly since the flow rate increases faster in the canal. Location v-33 is comparable to location v-11; however, the last peaks are smaller at location v-33. Most logically caused by the influence of the locations water depth and the smaller lake. This results in faster mixing of warm and cold water and a faster flow rate earlier in the fall period.

Appendix 8: Time series relation temperature and nutrient reduction discharging rivers - Chlorophyl-a 2012/2050

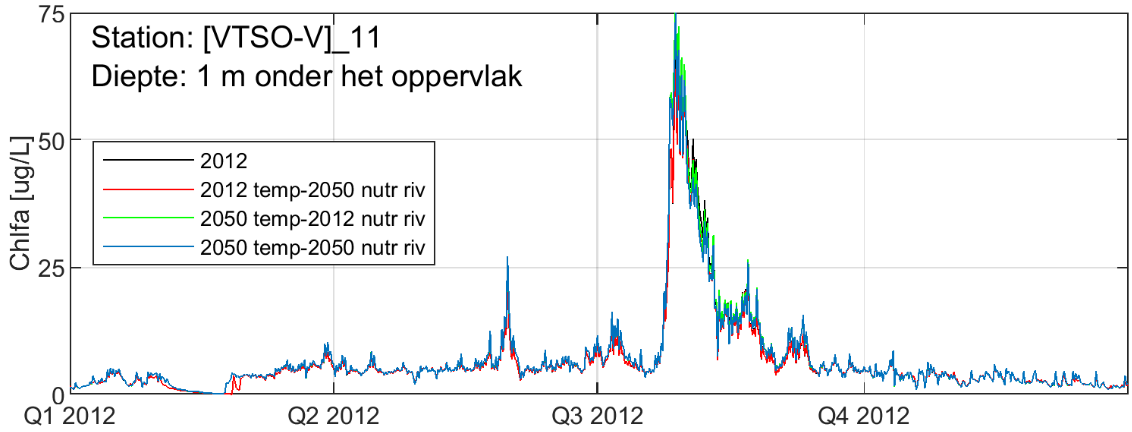

Figure 37: Sample location v-11, Scenario Chlorophyl-a concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

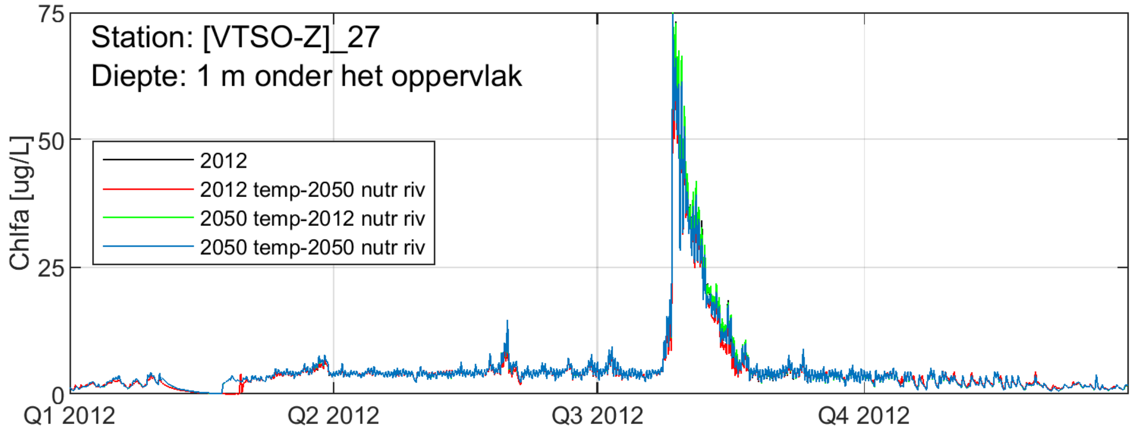

Figure 38: Sample location v-27, Scenario Chlorophyl-a concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

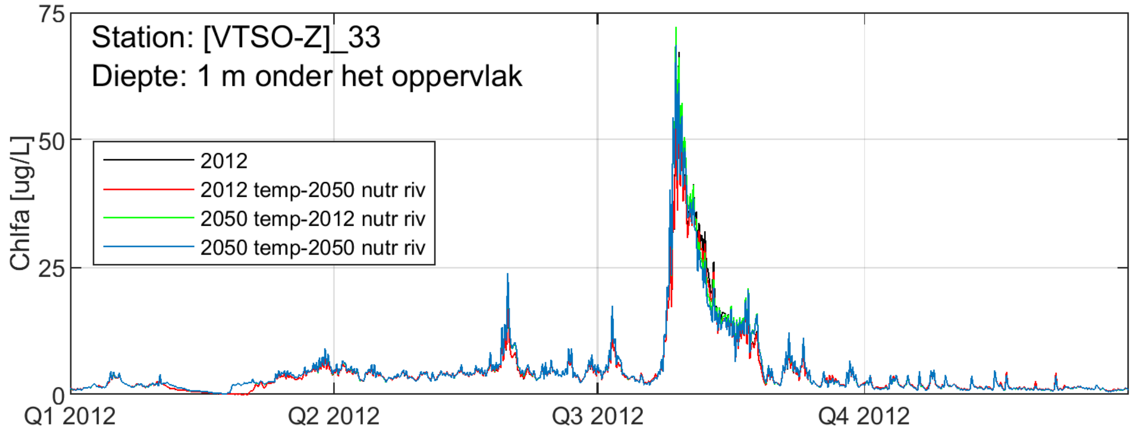

Figure 39: Sample location v-11, Scenario Chlorophyl-a concentration in mg/l 2012, scenario temperature 2012 and 20% nutrient reduction rivers (2050), scenario temperature 2050 (air temperature increase of 1,8˚C) and nutrient concentration in mg/l rivers 2012, and scenario temperature and 20% nutrient reduction rivers (2050) (Deltares, 2021).

The graphs that are represented for the relation temperature and nutrient concentrations in relation to the concentration chlorophyl-a are comparable to the results of *Microcystis* 2012/2050. However, there are more peaks, also during spring. This is caused by the measuring of chlorophyl-a which covers the measuring of all the algae types that grow in Lake Volkerak-Zoom. Furthermore, are the graphs for chlorophyl-a 2012/2050 of the same locations as the *Microcystis* 2012/2050. Therefore, all graphs show the same cause-effect relationship as the graphs in “Time series relation temperature and nutrient reduction discharging rivers - blue-green algae (*Microcystis*) 2012/2050”.

Appendix 9: Removal efficiencies

The following tables are created based on analysis after the data was placed in the D-HYDRO model. These tables are more extended since the peak is calculated over the entire period June 23 to August 31. The average peaks are calculated over a period of time only a reduction was visible in the graphs. Since the peak periods are not measured over a certain time period, this data is not fully reliable. Therefore, this data is not further analyzed and placed in the actual report. For further analysis, this data might be interesting. Therefore, it is implemented within the appendices.

Table 9: Microcystis concentration in mg/l 2012 over Microcystis concentration in mg/l with temperature 2050 and 20% nutrient reduction river discharge 2050 (Haan, 2021)

Sample place	Average	Average peaks	
v-11	-26,0%	-37,3%	
v-27	-37,9%	-44,5%	-79,6%
v-33	-20,8%	-40,2%	

Table 10: Microcystis concentration in mg/l 2012 over Microcystis concentration in mg/l with temperature 2050 and wetland nutrient reduction 2050 (Haan, 2021)

Sample place	Average	Average peaks	
v-11	-24,6%	-36,2%	
v-27	-38,1%	-46,9%	-73,0%
v-33	-33,8%	-49,9%	