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Recreational boats on the Reeuwijkse Plassen, an underestimated environmental pressure?

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Graduation teacher: Sander Harting

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A study on the environmental effects of recreational boating on the Reeuwijkse Plassen

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Gouda, 01 July 2022

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Foreword

This thesis is a study on the effects of recreational boating on the water quality of the lake system the Reeuwijkse Plassen using currently available monitoring data being gathered by the regional water authority (RWA) Rijnland and sources available on the internet. This thesis is my graduation project for the study Applied Biology at the Aeres Applied University of Sciences Almere. The research and writing of this thesis were done between December 2021 and May 2022.

The research subject was devised with the assistance of my graduation teacher Sander Harting and inspired by my internship at the RWA Rijnland. Thanks to the assistance of Sander Harting and my internship supervisor I was able to complete this study.

This study was written with professionals working with the Water Framework Directive (WFD) in the Netherlands in mind.

I would like to sincerely thank both Sander Harting, Annet Pouw and Brous Ernst for their assistance and contributions, without which I would not have been able to complete this thesis. Additionally, I would like to thank my parents and my friends, specifically Jeroen and Natasja Carol-Visser. Their support and input were of great value to my and helped me a lot while writing my thesis.

Sincerely,

Fin Morrison

Gouda, July 01st 2022

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Summary

The shallow peat lake system the Reeuwijkse Plassen are part of the Water Framework Directive. The Regional Water Authority has been attempting to improve the water quality and ecological status of the lakes over the last two decades. After a series of measures the lakes however still score quite poorly. Especially the clarity of the water and the abundance of submerged vegetation in the lakes are in a very poor state. Recreational boating which is quite prevalent on the lakes was not included however in the status reports of the lakes, leading to the question if recreational boating might be an overlooked contributing factor to the poor quality of the lakes.

To research this question a literature study was done. A system analysis with ecological key factors (EKF) devised by the STOWA was also done using monitoring data supplied by the RWA and reports available on the internet. The analysed lakes were selected based on the amount of activity to be expected on the lakes. This led to mixed results, three of the four analysed EKFs, EKF-1 water productivity, EKF-2 lighting conditions and EKF-8 Toxicity, showed an influence of boating activity. For EKF-1 and EKF-2 this being an increase in suspended phosphorous and detritus during the summer months when there was more boating activity in the lakes. For EKF-8 this being a noticeable gradient in the concentration of the metals zinc and copper from the lakes with the most harbours and boating activity to the lakes with no harbours and little boating activity.

The conclusion was that due to wind seemingly not being a driving force behind resuspension it could be possible boating could be a driving force behind poor lighting and habitat conditions.

Additionally due to the lakes being a relatively unique habitat, only very little research was available relating to recreational boating effects on shallow peat lakes. This means there is a lot of potential research to be done on this type of system.

It is recommended to do additional monitoring efforts relating to boating especially on shallow peat lakes. Most importantly a system tracking the intensity of boating activity on the lakes, something that was sorely lacking during this study. Additionally, measures could be taken to reduce boating activity on the lakes and increase awareness and enforce boating restrictions on the lakes.

Samenvatting

Het ondiepe veenplassensysteem de Reeuwijkse Plassen is onderdeel van de Kaderrichtlijn Water. Het waterschap heeft de afgelopen twee decennia geprobeerd de waterkwaliteit en de ecologische toestand van de meren te verbeteren. Na een reeks van maatregelen scoren de plassen echter nog steeds vrij slecht. Vooral de waterhelderheid en de abundantie van de onderwatervegetatie in de meren zijn in een zeer slechte staat. In de rapporten over de toestand van de meren werd echter geen rekening gehouden met de recreatievaart, wat de vraag opbrengt of de recreatievaart wellicht een over het hoofd geziene factor is die bijdraagt tot de slechte kwaliteit van de meren.

Om deze vraag te onderzoeken werd een literatuurstudie verricht. Er is ook een systeemanalyse met ecologische sleutelfactoren (ESF) uitgevoerd, die door de STOWA is opgesteld aan de hand van door het RWA verstrekte monitoringgegevens en op het internet beschikbare rapporten. De geanalyseerde meren werden geselecteerd op basis van de hoeveelheid vaar activiteit die op de meren kon worden verwacht. Dit leidde tot gemengde resultaten: drie van de vier geanalyseerde ESF's, ESF-1 water productiviteit, ESF-2 Lichtomstandigheden en ESF-8 Toxiciteit, vertoonden een invloed van de vaaractiviteiten. Voor ESF-1 en ESF-2 was dit een toename van zwevend fosfor en detritus tijdens de zomermaanden, wanneer er meer bootactiviteit in de meren was. Voor EKF-8 was dit een merkbare gradiënt in de concentratie van de metalen zink en koper van de meren met de meeste havens en vaaractiviteit tot de meren zonder havens en met weinig vaaractiviteit.

De conclusie was dat, aangezien de wind blijkbaar geen drijvende kracht is achter de opwerveling, het mogelijk is dat het varen een drijvende kracht is achter de slechte licht- en habitatomstandigheden.

Aangezien de meren een vrij unieke habitat vormen, was er bovendien slechts zeer weinig onderzoeksliteratuur beschikbaar over de effecten van de pleziervaart op ondiepe veenmeren. Dit betekent dat er nog veel onderzoek naar dit type systeem kan worden gedaan.

Aanbevolen wordt om extra toezicht te houden op de pleziervaart, met name op ondiepe veenplassen. Het belangrijkste is een systeem dat de intensiteit van de vaaractiviteit op de meren bijhoudt, iets wat tijdens dit onderzoek ernstig ontbrak. Bovendien kunnen maatregelen worden genomen om de vaaractiviteit op de meren te verminderen en de aandacht voor en de handhaving van vaarbeperkingen op de meren te vergroten.

1. Introduction

Figure 1: Reeuwijkse Plassen. Source: Google Earth

The Reeuwijkse Plassen is a group of 11 lakes that are found between the city of Gouda and the village of Reeuwijk as shown in figure 1. These are peat lakes or “veenplassen” in Dutch, artificial lakes that can only be found almost exclusively in the Netherlands. The lakes were created during the 18th and 19th century due to peat mining, excluding the northern lake “Broekvelden en Vettenbroek” which was created by sand extraction in the latter half of the 20th century for the creation of a highway. The lakes have unusual angular shapes and contain unnatural long narrow islands. These strange shapes are due to the peat being dug out of strips of land called “long lot farms”, long narrow land divisions that were created in the west of the Netherlands after the great reclamation in the Middle Ages. The lakes cover an area of about 735 hectares. The depth of most lakes is on average about 2 meters. The lakes are defined as “moderately large shallow bog lakes”, designated as M27 in the STOWA reference guide. (Altenburg et. al, 2020). The most northern lake is part of the Natura 2000 network and is used by a variety of trekking birds. Most of the lakes are also part of the Dutch main ecological structure “Natuur Netwerk Nederland”. A more detailed map made by Stichting VEEN (2020) can be found under annex 1. The main use of the lakes is recreation especially in the spring and summer the lakes see a high level of recreational activities such as sailing races, swimming, and leisure boating.

These lakes are subject to the Water Framework Directive (WFD) of the European Union. Although the EU has been creating legislature about water since the 1970’s, however in 1995 the EU commission fundamentally rethought the existing water policy which led to the WFD. Since 2000 the Netherlands together with all other EU member states have adopted the WFD. This directive dictates that all EU member states must improve the quantitative and qualitative status of designated waterbodies from 2015 onward. The goal is to achieve a good ecological status based on a series of criteria. These entail biological quality, hydromorphological quality, physical-chemical quality, and chemical quality. The directive is carried out in three cycles, the first cycle took place during 2009 to 2015, the second cycle will end in 2021 and the third cycle will be completed in 2027.

The Reeuwijkse Plassen are under the jurisdiction of the regional water authority (RWA) Rijnland. During each WFD cycle the RWA generates a status report on each waterbody in its area of control. These provide a system analysis based on the Ecological Key Factors (EKF) for stagnant waters devised by STOWA. This type of analysis provides an overview of slow flowing water systems such as canals and lakes based on 9 EKFs. The Key Ecological Factors are a tool to analyse a waterbody based on parameters that are important for the WFD. These entail 9 different key factors in a hierarchical order starting from the nutrient load and lighting conditions of the water and soil and ending in the overarching view of the water quality in a societal context. The first three factors together

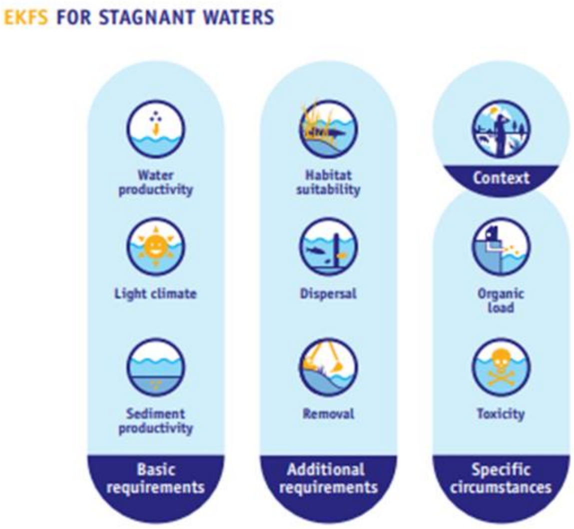

Figure 2: The EKFs for stagnant waters Source: STOWA

determine the basic requirements needed for a healthy ecosystem. The following three factors describe additional conditions needed for specific species of flora and fauna. The next two factors address additional aspects such as toxicity, that occur in specific circumstances such as a proximity to agriculture and industrial or urban areas. The last factor is the context factor mentioned earlier. These different factors are shown in figure 2. By analysing each factor, it is possible to get an idea of the pressures causing poor conditions in a waterbody. Each EKF (excluding the Context factor) is graded with either the colour green (pass) or red (fail). If all key factors are graded green the waterbody would be at a good ecological status in accordance with the WFD (ter Veld & van der Wal, 2015). The Reeuwijkse Plassen received failing grades on all the basic requirement EKFs, the habitat suitability EKF from the additional requirement group and the toxicity EKF from the specific circumstance group.

During the last two decades the RWA has taken multiple measures to improve the quality of the lakes. The lakes had a high nutrient load, due to both the intensive farming (Leentvaar., et al, 1978) and the large amount of bird faeces being produced by the numerous bird population on the lakes. There was an additional influx of pollution in the previous century due to sewage discharge from the housing surrounding the lakes (Reformatorisch dagblad, 1996). Bog lakes are however usually defined by a low nutrient level. The water transparency in the lakes was also quite poor due to dead algae and silt particles suspended in the water. This poor transparency prevents water plants from developing at the bottom of the lake. The chemical values of the lakes were also quite poor due to too much ammonium, but also remnants of fuel related substances. To combat these issues several measures and experiments were carried out. Between 2011 and 2015 most of the surrounding polders were cut off from the lakes to decrease the amount of nutrient rich waters flowing into the lakes. This helped decrease the amount of phosphorous flowing into the lakes by a significant amount. Additionally, the RWA implemented a more natural water level in the lakes. This means they can hold onto rainwater in the lakes for a longer time and do not need to pump in nutrient rich water from still connected polders during droughts. Experiments were also carried out on some of the lakes. The silt layer of one of the smaller lakes was dug out of the lake to increase the transparency and reduce the nutrient load of the lake. Unfortunately, the measures and experiments have only been of little success. During the second WFD cycle the RWA expected to see an improvement in the conditions of the lakes. Although the external inflow of nutrients has been strongly reduced, the lakes still have a high nutrient load, the visibility of the lakes is also still quite poor and has barely improved. As a result of these underwhelming results the waterboard decided to lower their goals for the following WFD cycle but even with these lowered standards the lakes score poorly. (Vuister, 2021)

As previously mentioned, one of the main uses of the lakes is recreation. The local nature organisation Stichting VEEN which also manages the boating licenses for the lakes issued over 3000 licenses for year-round use, with an additional 320 licences for a week or shorter use in 2019 (Stichting VEEN, 2019). Especially during the spring and summer months there is a high level of boat traffic. The reports of the waterboard mentioned that multiple stakeholders involved with the lakes want to avoid taking measures that impact the recreational use of the lakes due to its implied value (Vuister, 2021). However, there is no mention of the effects caused by boating mentioned in the reports.

Multiple studies show evidence that small recreational motorboats can cause an increase of phosphorous in shallow lakes and rivers (Yousef et al., 1980). Motorized boats can also cause the resuspension of sediments occurring in the lake (USACE, 1994; Beachler & Hill, 2003). Of note is that some research shows that especially during summer holidays with an increase of boat traffic, both turbidity and phosphorous loads in the water would increase (Asplund, 1996). This resuspension increases the turbidity of the water which in turn impedes the development of submerged vegetation (Vermaat & De Bruyne, 2006). Waves generated by boats can also damage and prevent the growth of vegetation (Sagerman, 2019).

Research also suggests that boats can be a source of toxic chemicals. Several types of protective coating for the hull of the boats have been shown to leach toxic chemicals into the water. One of the worst being antifouling coatings which are a type of biocide that inhibits the growth of algae weeds on the hull of the boats. These chemicals can leach into the sediment layers of the lakes and impede the development of submerged vegetation (Konstantinou & Albanis, 2004). Even though there are strict regulations concerning these antifouling paints in Europe several of the newer variants that are supposed to be within safe limits have been shown to also raise toxic levels within the water column (Machate et al., 2021; Martins et al., 2017; Lagertröm et al., 2020).

This raises the question if it is possible that the boats that make use of the lakes may also have a stake in the poor EKF scores. Motorized pleasure crafts can also have an impact on a variety of ecological and chemical parameters in the lakes and this seemingly has not been considered with the Reeuwijkse Plassen which has a high level of boating activity on multiple lakes. To add to this the RWA report only gives a single score encompassing all the lakes, without analysing individual lakes.

This leads to the formulation of the main question:

To what extent might boating activity influence the poor WFD scores of the Reeuwijkse Plassen?

To be able to answer the main question properly the following sub-questions have been devised:

1. What additional influence does boating have on the basic requirement EKF group, EKF 1,2 and 3?
2. To what degree does boating in the lakes disrupt habitat conditions, EKF-4?
3. Do recreational boats increase the concentration of toxic chemicals in the lakes and to what extent?

The expectation of this thesis is to bring to attention that the recreational boating activities on the lake might also have a stake in some of the poor water quality results. Boating might be an underestimated source of negative influence on the EKF scores of the Reeuwijkse Plassen.

Following the introductory chapter, the next chapter will detail the approach to how the research will be conducted and how the information will be collected. The chapter after this will detail the results for the research after which these results will be discussed in the following chapter. In the final chapter the conclusion of the main question and its sub-questions will be formulated after which recommendations will be made.

2. Approach

The research mainly entails a literature study, a system analysis of 4 lakes with different degrees of recreational activity and a comparative analysis. This chapter elaborates on the methods and materials which have been used.

As mentioned in the introductory chapter the RWA report on the WFD goals entails a system analysis encompassing all the lakes. The EKF's described in the report only discuss the averages of all the lakes grouped together and not individual conditions per lake.

To find a correlation between boating activity and the EKF conditions, the study analyses four individual lakes based on their general traffic levels and boating restrictions, these lakes have been selected based on personal knowledge and by analysing Superview satellite images from the site of the Netherlands Space Office. These lakes are described under chapter 2.2.

The system analysis of the Reeuwijkse Plassen was done with the use of the EKFs mentioned in the previous chapter. Data and articles from the RWA Rijnland on the Reeuwijkse Plassen will be used for the system analysis. The RWA report on the WFD goals entails a system analysis of the lakes as one large waterbody. In this study the EKF conditions were analysed for each lake individually.

The RWA provided two databases. The first contains all the chemicals and substances measured during the last 2 decades of 5 lakes. The second database contains all parameters logged at the routine measuring points during the last 6 years of 7 lakes. The routine measuring points in the lakes are shown in the map in Annex 2 (Hoogheemraadschap Rijnland). An additional report on the status of the embankments of the lakes between 2014 and 2018 from the RWA was also utilized.

2.1 Literature study

Both scientific articles and non-scientific articles and reports were used. The scientific articles were sourced through scientific databases such as Wiley, Springer Link and Science Direct. The search engine Google Scholar was also used. If possible, the data supplied by the RWA Rijnland was also utilized. Non-scientific articles and reports were sourced through the search engine Google. Local authorities and organisations such as Stichting VEEN have also been contacted in an attempt to acquire data on the intensity of recreation on the lakes during the year.

The search terms that were used and their relation to the sub-questions are noted in the table under Annex 3.

These terms were used in both Dutch and English. The terms were combined with each other using the Boolean operators AND, OR, NOT. Additional articles were also looked for in the reference list of relevant articles.

Articles were selected based on their relevancy and reliability. Most of the scientific articles were less than 30 years old, the more recent the research the greater its value. Most articles contained material relevant to shallow freshwater lakes and described situations that are comparable to those of the Reeuwijkse Plassen. The articles were of relevancy to the main question and side-questions. Peer reviewed published articles were used, and other articles and reports were sourced from trustworthy sources such as RWA's and ecological advice agencies with expertise in the subject matter. It is possible that some articles and reports contain a certain bias, these articles were only used if the information was of value and not related to the biased viewpoint of the author. These entail articles with an emphasis on the fishing industry or articles that put boating in a positive light.

To create an overview of the findings, the literature was compiled in a table. An example of this is shown in table 1.

Table 1: Example of literature table

Title	Type of study	Parameter	Purpose of study	Findings	Proposed measure
Flawed risk assessment of antifouling paints leads to exceedance of guideline values in Baltic Sea marinas	Study of seasonal variations of copper and zinc in two recreational marinas	Toxicity, concentrations of dissolved copper and zinc	Evaluation of Swedish risk assessment of Anti-Fouling paints	A link between a rise in Cu and Zn levels during boating season with antifouling being principal source	Refinement of environmental risk assessment within the EU

The chemicals that were found to be linked with boating will be listed in a table and compared with the chemicals that were found in the lakes during the last decade.

2.2 System analysis using Ecological Key Factors for standing waters

The key factors "Productivity Water" (EKF-1), "Lighting Conditions" (EKF-2) and "Habitat Suitability" (EKF-4) were analysed using the methods described by STOWA for the lakes due to the expected influence boating has on these factors.

These factors were analysed using the WFD progress reports from the RWA in conjunction with the monitoring data of the lakes from the last 6 years. The fish stock management plans of the National sportfishing organisation "Sportvisserij Nederland" were also analysed, these contained information on the condition of fish populations and reports on boating activity on the lakes.

Research area

The lakes that were analysed are Elfhoeven, Ravensberg, Gravekoop and Nieuwenbroek.

Elfhoeven is the lake found in the south-west corner of the lake system as shown in figure 3**.** It has a surface area of 109 hectares and an average depth of 2 metres. Together with the lake Gravenbroek above it, these lakes see the most recreational boating activity. Both due to the proximity with the canal the Breevaart, which connects the lakes with the cities Gouda and Reeuwijk, and the numerous harbours and boat sport organisations found around these lakes. Additionally, most boating competitions are held on these lakes. The north-eastern part of the lake has a sizable nature park often used for recreational activities. Elfhoeven has no boating restrictions except for the mandatory 6 km/h speed limit for motorized boats which applies to all the lakes. Satellite imagery, especially during the summer show a high level of activity on this lake.

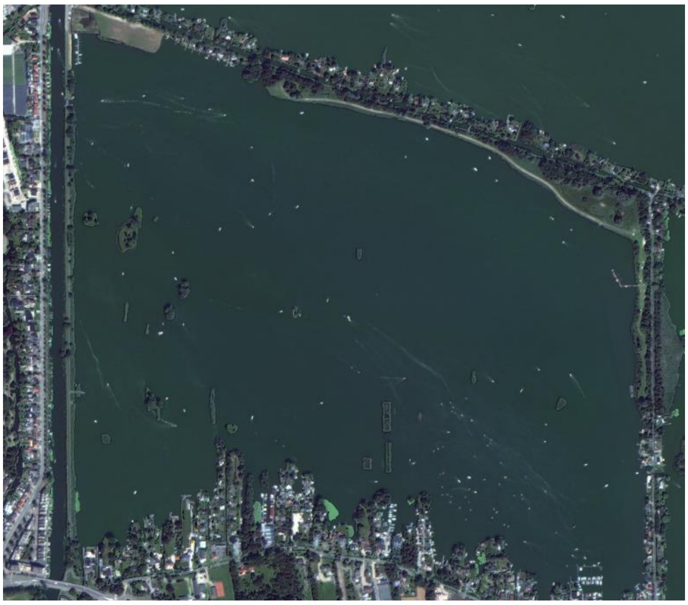

Figure 3: Lake Elfhoeven during June/July Source: Netherlands Space Office

Gravekoop is found on the eastern side of the lake system as shown in figure 4. It has a surface area of 86 hectares and an average depth of 1,7 metres. There is relatively little boating activity on this lake. Although there are no restrictions for motorized- and electric boats on this lake. Due to its distance from the cities and relatively sparse habitation, there is generally little boating activity on this lake. Satellite imagery shows only occasional boating activity on this lake. This lake also has no harbours and only has 3 or 4 privately owned mooring spots.

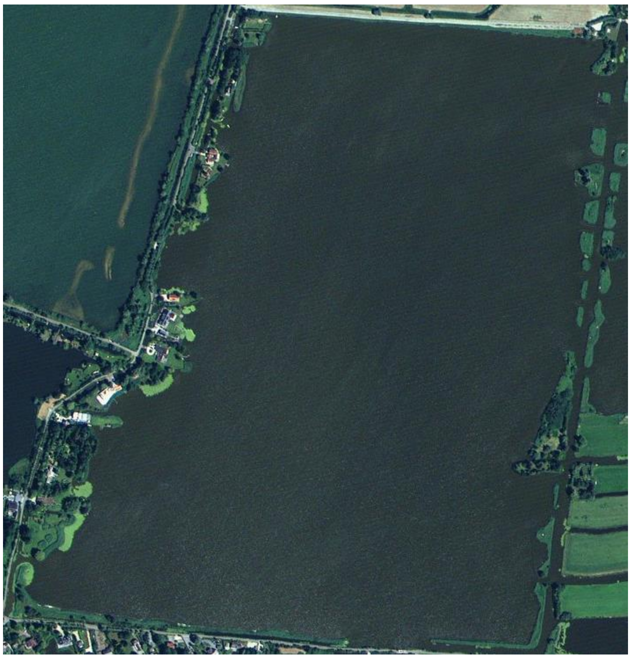

Figure 4: Lake Gravekoop during June/July Source: Netherlands Space Office

Ravensberg is the lake found above the lake S'Gravenbroek as shown in figure 5. It has a surface area of 111 hectares and has an average depth of 2,1 metres. There is even less activity on this lake than on Gravekoop even though it is in closer proximity of the cities. This is in part due to it being less easily accessible than Elfhoeven and due to the lake being restricted for motorized and electric boats. There are no harbours surrounding this lake. No harbours are found around this lake except for some small privately owned mooring spots. Satellite imagery shows little to no activity on this lake.

Figure 5: Lake Ravensberg during June/July Source: Netherlands Space Office

Lake Nieuwenbroek is found on the south-eastern side of the system as shown in figure 6. It is openly connected with lake Kalverbroek, meaning it shares similar conditions. It covers a surface area of about 104 hectares and has an average depth of about 1.8 meters. There is a reasonably high number of privately owned mooring spots and a harbour can be found in lake Kalverbroek. Based on satellite imagery the lake seems to have average boating activity during the summer. It seems to be more active than lake Ravensberg and Gravekoop respectively.

Figure 6: Lake Nieuwenbroek during June/July Source: Netherlands Space Office

Due to a lack of data EKF-3 Lakebed productivity, cannot be analysed and will be based on the last WFD report produced by RWA Rijnland. This key factor will still be mentioned in the results and discussion due to its connection with the effects of boating.

There is a close relation EKF 1,2 and 3. Together these decide the basic conditions for the occurrence of water vegetation (Schep et al., 2015).

Although the first three key factors describe desirable conditions for the system, they lack certain specifics for optimal conditions for the development of specific submerged macrophytes. EKF-4 describes additional conditions and parameters such as occurring species, effect of waves and lakebed structure. (Cussell et al., 2018) This creates an overview per habitat and helps put the first three key factors in perspective. This can give a view of physical damage that could be caused by boating activity.

Due to its complexity and scale EKF-8 Toxicity, will not be fully analysed and will also be based on the last WFD report of the RWA. The chemicals mentioned in the report will be compared to the substances found to be related to the occurrence of recreational boating in the comparative analysis.

EKF-1 Water productivity

An exceedance of the critical nitrogen or phosphorous load (Critical N-load or P-load) by the external nutrient load (N-load or P-load) causes excess productivity for overly dominant algae or duckweed growth which in turn impede the development of underwater vegetation.

The P-load exceeding the critical P-load results in a red colour for this key factor. However, to calculate this it would be required to calculate the entire water balance of the lake system, which due to time constraints and scope would be unrealistic.

Therefore, the suspended amount of phosphorous and nitrogen per lake were analysed. The monthly average for each lake was taken and compared alongside the other lakes to find any correlation with boating activity.

The most recent goal for the next WFD cycle set by the RWA for suspended phosphorous is 0,08 mg/l and for suspended nitrogen is 3 mg/l and exceedance of this level was regarded as a failing grade. This will be done based on the year average of the last recorded year.

EKF-2 Lighting

For development of aquatic vegetation, it is of importance that enough light reaches the lakebed.

First the transparency/depth ratio of each of 4 lakes was calculated during the summer. If this ratio is smaller than 0,6m it means that not enough light reaches the lakebed for plant growth.

If the transparency/depth ratio was smaller than 0,6, the absorption was calculated using the Underwater light calculation module on the Deltares site (2015). This is based on the model UITZICHT devised by H. Buiteveld (1995). The required data for this module is described in table 2. This data was also sourced from the databases supplied by RWA Rijnland.

Table 3: Required parameters and variables for the underwater light calculation module

Parameter	Variable
Depth	[m]
Suspended matter concentration	[mg/l]
Percentage ignition matter residue in Suspended matter	[%]
Chlorophyll-a concentration	[µg/l]
Dissolved Organic Carbon (DOC)	[mg/l]

The module gives the percentage of light reaching the lakebed. The module also calculates the percentage of absorption per type of suspended matter. These are, Chlorophyll-a, Detritus, Ignition residue and Humics.

If less than 4% of the light reaches the lakebed the key factor got a failing grade.

When the key factor failed, the absorption per type of suspended matter was analysed to determine the percentage of light being absorbed by algae and the other suspended substances.

The percentage of light absorbed chlorophyll-a should give a rough estimate of the amount of light being absorbed by algae. This gave an indication whether the light absorption is caused by algae blooms or due to the resuspension of lakebed soil due to other forces such as recreational boating.

In addition, the abundance of bottom dwelling fish was analysed. This also relate to EKF-3 Productivity lakebed and EKF-4 Habitat suitability.

EKF-4 Habitat

Habitat conditions were analysed using the reports and databases from the RWA, the fish stock management plans of the national sport fishing organisation, which gave descriptions of flora and fauna per lake, and the previously analysed EKFs 1,2 and the information available on EKF-3.

The EKF-4 report describes multiple zones with different environmental factors. The two zones occurring in the lakes to be analysed are shore and shallow waters. The current situation for multiple habitats were described based on elements specific to that habitat type. This description entails what effect each element has on this habitat type. The habitats and elements are as follows.

1. Habitat riparian plants

A description was made of the current water level regime, the level of intensity of waves, the embankment slope, and the estimated size of area suitable for riparian plant development.

2. Habitat submerged aquatic plants and floating leaf plants

A description was made of lighting conditions as mentioned in EKF-2, the embankment slope, type/abundance of fish species.

3. Habitat fish

A description was made of the structure and depth variation and the abundance of water vegetation on the embankment and underwater.

This factor got a failing grade when the habitat is described as unsuitable for the relevant species.

The RWA made a report on Nature Friendly Embankments (NFE) that have been implemented during the period of 2014 to 2018 in the lakes. This report entails the number of individual species recorded per plot along the shoreline. Using the Shannon's diversity index in Excel a number was calculated.

The Shannon's diversity index is defined as: $\mathbf{H = -\sum[(p_i) * \log(p_i)]}$

Where $\mathbf{\sum}$ Signifies the total number of samples and $\mathbf{p_i}$ signifies the number of samples of each individual species. Shannon's index is defined by **H,** the higher the number the high the relative species diversity of an area. (Cohen et al., 2013)

This was analysed in conjunction with the amount of boating activity on each lake, due to a possible correlation between macrophyte diversity and abundance and boating activity.

EKF-8 Toxicity

As mentioned prior this EKF was not fully analysed using STOWA tools. The chemical data and the WFD report of the RWA were analysed.

As shown in the report by Lagerstörm et al., (2020) the pollutants that could leach from the boats is found in higher concentrations near the harbour. As mentioned earlier only lake Elfhoeven has any real harbours, therefore by comparing the chemical data for each lake there could be a measurable change in the concentration of chemicals occurring in the water column.

The chemicals that were analysed were sourced from the literature research. These included metals such as copper and zinc which are found in anti-fouling and other boating products.

2.3 Comparative analysis

The anticipated effects from recreational boating attained during the literature research were compared with the RWA databases and the system analysis.

Boat traffic

Unfortunately, there is no concrete temporal data available of boating traffic on the lakes. Therefore, this was estimated based on the activity seen during the summer season and with available Superview satellite data.

The summer season for recreational boating is from April through to November. The summer season is split into three periods. The pre-season April through to mid-July, the high season mid-July though to the end of August and the post-season from September through to early November.

It is expected that the highest level of boat traffic will occur during the period of May through to August due to bank holidays such as Pentecost and the summer vacation and improved weather conditions.

Comparison lakes

The system analysis for each lake was compared side by side in a table.

Monthly averages were compiled of key factor parameters of EKF 1 and 2 during the summer period from the last 6 years sourced from the RWA database. Additional parameters were selected based on the literature research if available in the monitoring database. Possible correlations between the findings were researched using excel graphs.

For EKF-4 habitat conditions, the species diversity and descriptions of each lake were compared. A difference in species composition and abundance could indicate an influence cause by recreational boating.

For the EKF-8 toxicity, the concentrations of substances that have been linked with the occurrence of boats were compared. The distance between the lakes with less boats and the lake with high activity could show a difference in concentration. The monthly averages for the last 6 years were analysed. Some boats are stalled out of the water during autumn and put back in during spring, this could also cause a change in substance concentration, meaning that there should be an observable increase and decrease during the beginning and ending of the summer season.

3. Results

3.1 Literature research

The literary research resulted in twenty-three relevant articles relating to recreational boating and shallow lakes. The found articles have been listed under annex 4. A short summary for the results of each sub-question has been listed below. The findings will be further discussed in the following chapter.

Basic requirements EKF 1,2 and 3

Six articles were found with relations to the basic requirement EKFs and boating. Five articles report influence on resuspension by boating be it at differing degrees depending on the circumstances. One article reports no significant influence caused by boating.

In a case study comparing lakes with and without boating activity Nedohin & Elefsiniotis (1996) report that boating creates enough disturbance to release phosphorous stored in the lakebed. This boating activity might cause the lake the prematurely reach a state of eutrophication due to the increased level of phosphorous in the water.

The article reporting little influence by Ailstock et al. (2002) reports boating has little effect in shallow waters where the lakebed is mainly composed out of sand. The article reports most of the resuspension and turbidity occurring in the bottom layer of the water column. However, the article also suggests that lakes with a larger share of silt on the lakebed could be more susceptible to resuspension by boating. To add to this the article also mentions that the experiments were carried out while adhering to the speed limit and no wake zones. Conversely a study done by Alexander & Wigart (2013) in a near shore are with now restrictions shows a much stronger correlation with boating activity and turbidity. It also reports it being likely that this boating activity suspends sediments and releases nutrients into the lake system.

Anthony & Dowing (2003) suggest that wind is the main contributing factor to the resuspension with boating being a contributing factor. Indicating that boating might contribute an additional 50% increase in turbidity over 56% of the lake. In an article by Hoverson & McGinley (2007) also report wind as the main contributor with boating having a more subtle influence. They argue that while wind transports sediments to a certain part of the lake where it goes out of reach of the wind, boating mobilizes sediments and transports them to areas where they become available for wind driven resuspension. In addition, they found increases in turbidity and fine sediments coinciding with periods of boating in early summer.

In a study by Lenzi et al. (2013) a significant effect on sediments was reported. The article shows a correlation between resuspended nitrogen and phosphorous in relation to the distance of boats. It is also suggested that due to binding to finer particles of detritus, phosphorous can be redistributed over much larger distances.

Habitat conditions EKF 4

Six articles were found in relation to the effects of boating on habitat conditions. All articles show strong relation between the degradation of biodiversity and biomass of boating activity.

A study by Asplund & Cook (1996) reported a dramatic decrease of macrophyte biomass in areas with high levels of boating activity. They argued the main cause of this decrease was due to turbulence and direct cutting by propellers of passing boats. The turbulence caused by the boats would disturb the lakebed substrate, burying emerging shoots and decreasing the quality of the sediments preventing the settlement of plants. In addition, they also argued that high levels of boating activity during early summer was disrupting the germination of macrophytes as well.

Although they did not observe an influence on macrophyte development due to boat induced turbidity, it was suspected that the species currently found in the lake were hardier and more resistant to high turbidity with species more sensitive to poor lighting conditions being found in areas with little boating activity.

In a systemic review by Sagerman et al. (2020) also reported boating having a significant effect on macrophyte development and abundance. This article reports areas with poor vegetation conditions being much more susceptible to boating activity. The article also argues that boating could also influence the composition of species found in a waterbody.

An article by Hansen et al. (2019) also reports a decrease in vegetation cover and links this decrease to lower fish abundance. Reporting that lower vegetation cover removes areas suitable for juvenile fish species to thrive.

In an experimental study by Gabel et al. (2012) reported a high level of detachment of invertebrates in near shore vegetation due to boats passing close by. Reporting a decrease in invertebrate populations between 45% and 75% depending on the velocity and proximity of boat passages.

Overview articles by Asplund (2000) and Ter Heerdt (2012) report additional effects caused by recreational boating such as shoreline erosion, the harming of fish by waves and propeller damage and the disturbance of nesting birds.

Toxicity EKF 8

Ten articles were found relating to the effects of toxic chemicals related with recreational boating activity.

Table 4 shown below lists the relevant chemicals attributed to recreational boating, their use or source and their current legal status if necessary.

Table 4: Substances related to recreational boating found in literature research

Substance	Use/source
Benzo(a)-pyrene	Found in exhaust gasses of boats
Benzo(g,h,i)-perylene	Found in exhaust gasses of boats
Copper (Cu)	Widely used in anti-fouling paints (legal substance)
Diuron	Anti-fouling herbicide (banned in 2008)
Irgarol 1051	Anti-fouling herbicide (banned in 2016)
Indeno(1,2,3-cd) pyrene	Found in exhaust gasses on boats
Tributyltin (TBT)	Substance used in anti-fouling paints (Banned in 1989)
Zinc (Zn)	Widely used in anti-fouling paints (legal substance)

Multiple articles by Boyle et al. (2016), Lagerström et al. (2020) and Schröder et al. (2022) correlate the concentration of anti-fouling related substances with both the distance from harbours and the amount of boating activity. Especially copper and zinc concentrations were attributed to anti-fouling paints leeching from boats and from harbours, there was also a temporal correlation with an increase in concentration during boating season. Copper was consistently reported as being the most abundant

Although both TBT and Irgarol 1051 were banned in anti-fouling paints, Egardt et al. (2017) reported elevated concentrations found in sediments suggest that these are still being used, be it due to ignorance or unwillingness to comply with regulations. Two articles by Lambert et al. (2006) and Mohr et al. (2008) report long term effects on multiple groups such as phytoplankton and zooplankton communities.

One article by Machate et al. (2021) reports on lakes in Schleswig-Holstein reports that despite the reduction of nutrient input and eutrophication, the macrophyte communities in the lakes had not recovered. Arguing that the contamination of the lakebed with antifouling substances was preventing the return of macrophytes in the lake.

Stichting Waterpakt (1999) reported that pollution of water due to motor engine emissions of leisure boats also contributed to a decrease in water quality. Over 90% of polluting emissions were attributed to two-stroke engines. However in a report by Deltares and TNO (2016) these engines were shown to be in strong decline over the last two decades, being replaced by less polluting four-stroke engines.

3.2 System analysis

This section shows the results from the system analysis per ecological key factor.

EKF 1 Water productivity

The highest level of suspended phosphorous occurs in lake Gravekoop and the lowest levels are found in lake Elfhoeven. All lakes show an influx in suspended phosphorous during May, lake Elfhoeven also has a second influx and larger average influx during July. The average level of suspended phosporous in lake Gravekoop is almost double that of lake Elfhoeve during May.

The monthly average of dissolved phosphorous per litre for the lakes is shown in figure 7 below.

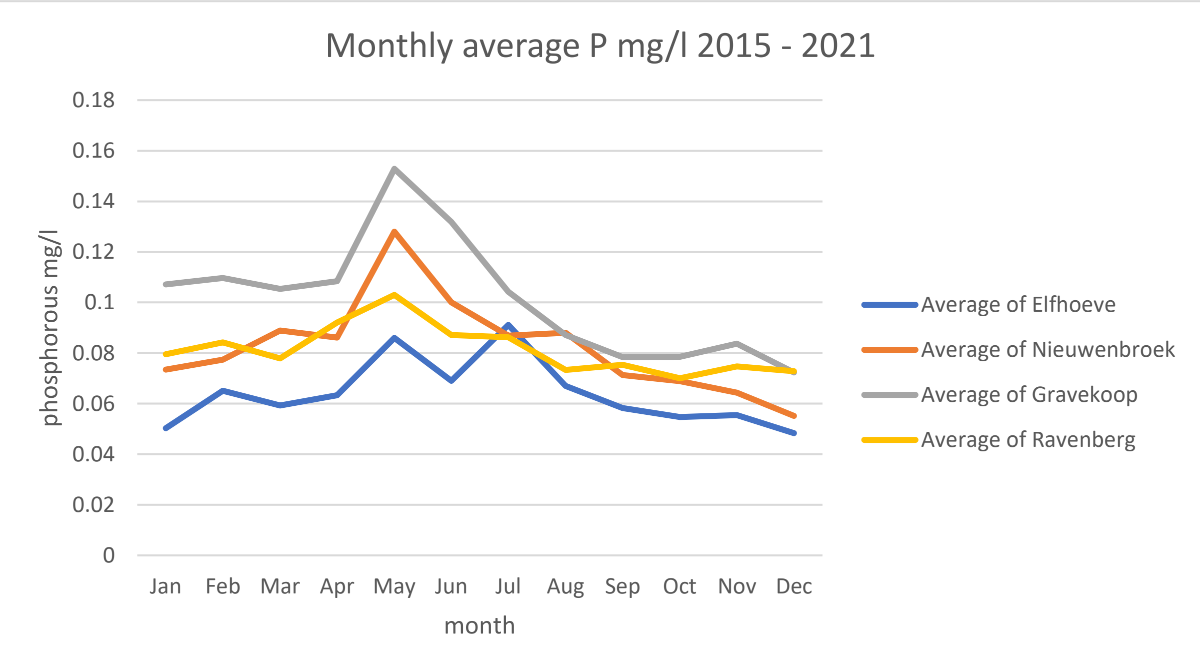

Figure 7: Monthly averages of dissolved phosphorous over 6 years. Note the peak occuring during May. Based on data sourced from RWA Rijnland, Leiden, 11 November 2021.

The following graph shows the fluctuation in phosphorous concentration over the last 6 years.

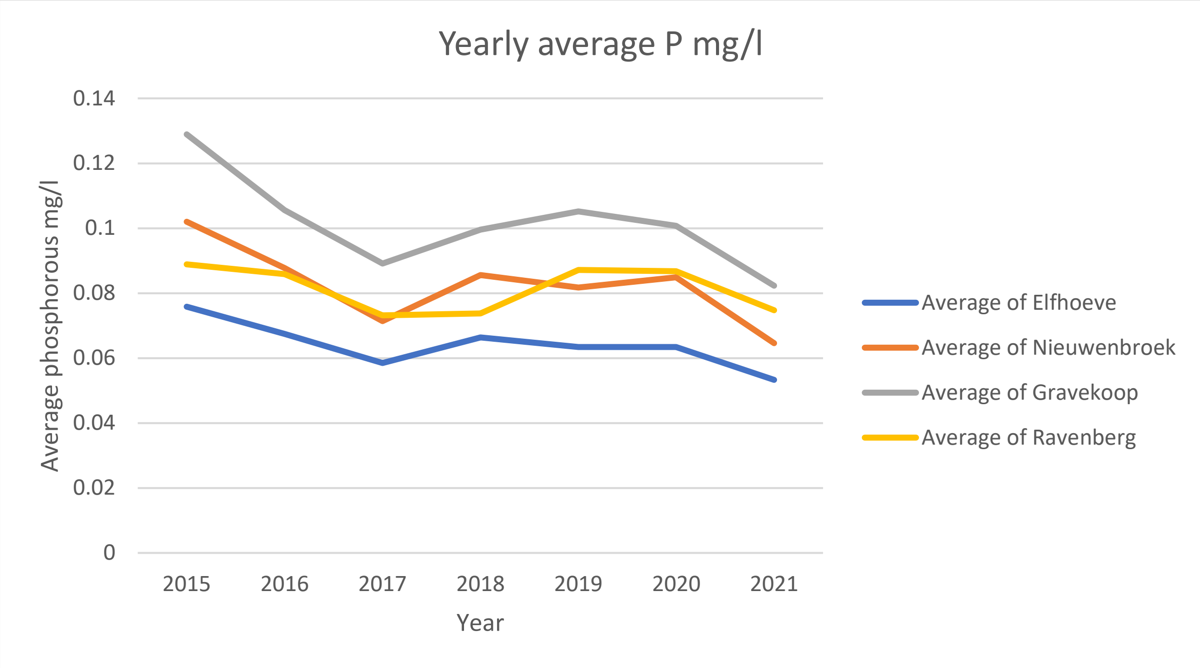

Figure 8: Fluctuation of yearly average of phosphorous concentrations. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

The average level of dissolved phosphorous in 2021 is shown in table 5 below. The current goal set by the RWA for the new WFD cycle is to reach levels below 0,08 mg/l.

Table 5: Average phosphorous mg/l in 2021. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

Lake	Average P mg/l 2021
Elfhoeve	0.05 mg/l
Nieuwenbroek	0.06 mg/l
Gravekoop	0.08 mg/l
Ravenberg	0.07 mg/l

Three of the lakes were below the 0,08 mg/l of phosphorous during 2021 there for getting passing grades. Lake Gravekoop only just exceeded the set dissolved phosphorous level with 0,082 mg/l therefore receiving a failing grade.

The average level of nitrogen suspended in the water does not entirely reflect the level of suspended phosphorous. In comparison the nitrogen concentration is relatively more constant with less pronounced spikes in concentration. Lake Gravekoop and Nieuwenbroek have relatively similar levels of suspended nitrogen. The influx during May is seen again with the nitrogen excluding with lake Ravenberg which has a relatively level average amount of nitrogen during the year. This influx is less pronounced than with the phosphorous concentrations. The second influx in lake Elfhoeven is not repeated with the nitrogen. The monthly average of dissolved nitrogen per litre is shown in the figure 8 below.

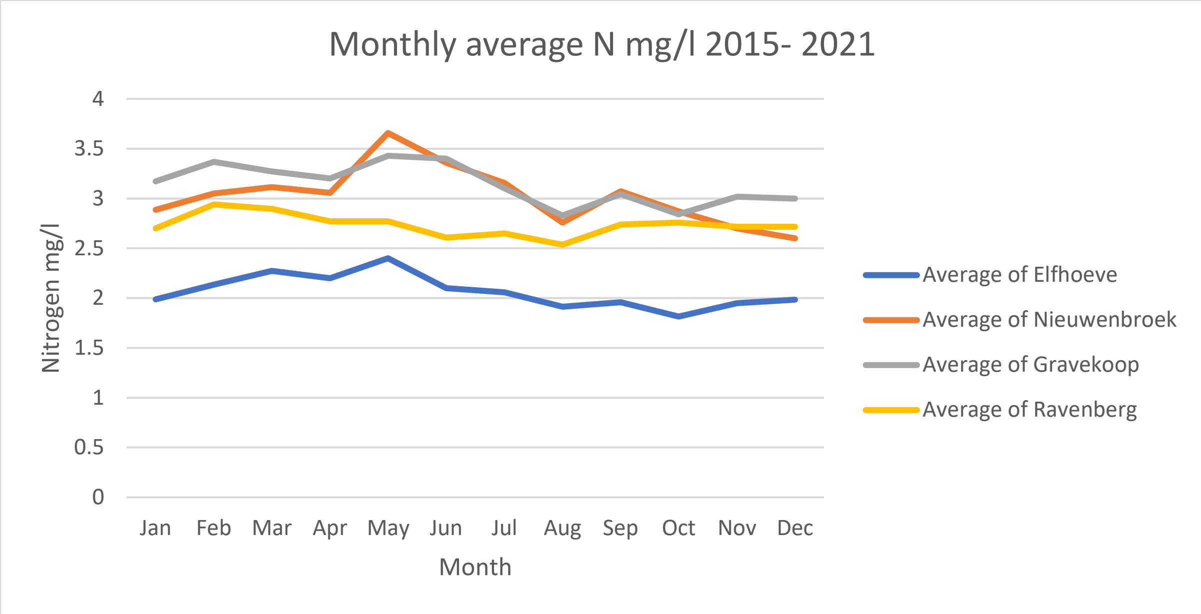

Figure 9: Monthly averages of dissolved nitrogen over 6 years. Again, a peak occurs during May. Based on data sourced from RWA Rijnland, Leiden, 11 November 2021.

The following graph shows the fluctuation in nitrogen concentration over the last 6 years.

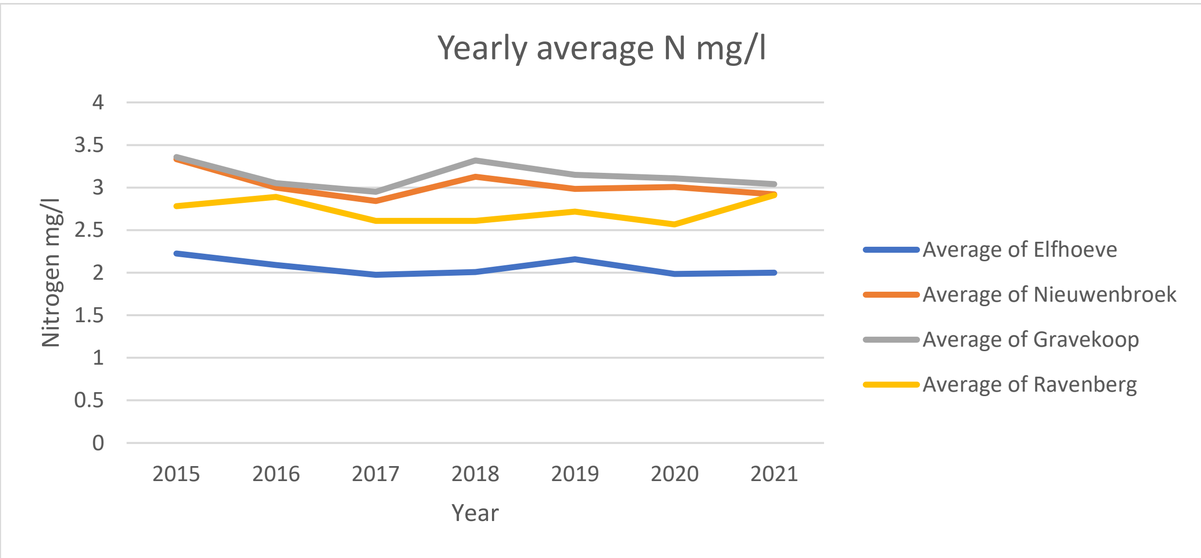

Figure 10: Fluctuation of yearly average of nitrogen concentrations. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

The average level of dissolved nitrogen in 2021 is shown in table 6 below. The current goal set by the RWA for the new WFD cycle is to reach levels below 3 mg/l.

Table 6: Average nitrogen mg/l in 2021. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

Lake	average N mg/l 2021
Elfhoeve	2.00 mg/l
Nieuwenbroek	2.92 mg/l
Gravekoop	3.04 mg/l
Ravenberg	2.91 mg/l

Three of the four lakes get a passing grade, with lake Gravekoop getting a failing grade due to exceeding the goal set by the RWA.

EKF 2 Lighting

The following graphs show the average monthly distribution of light absorption between 2015 and 2021.

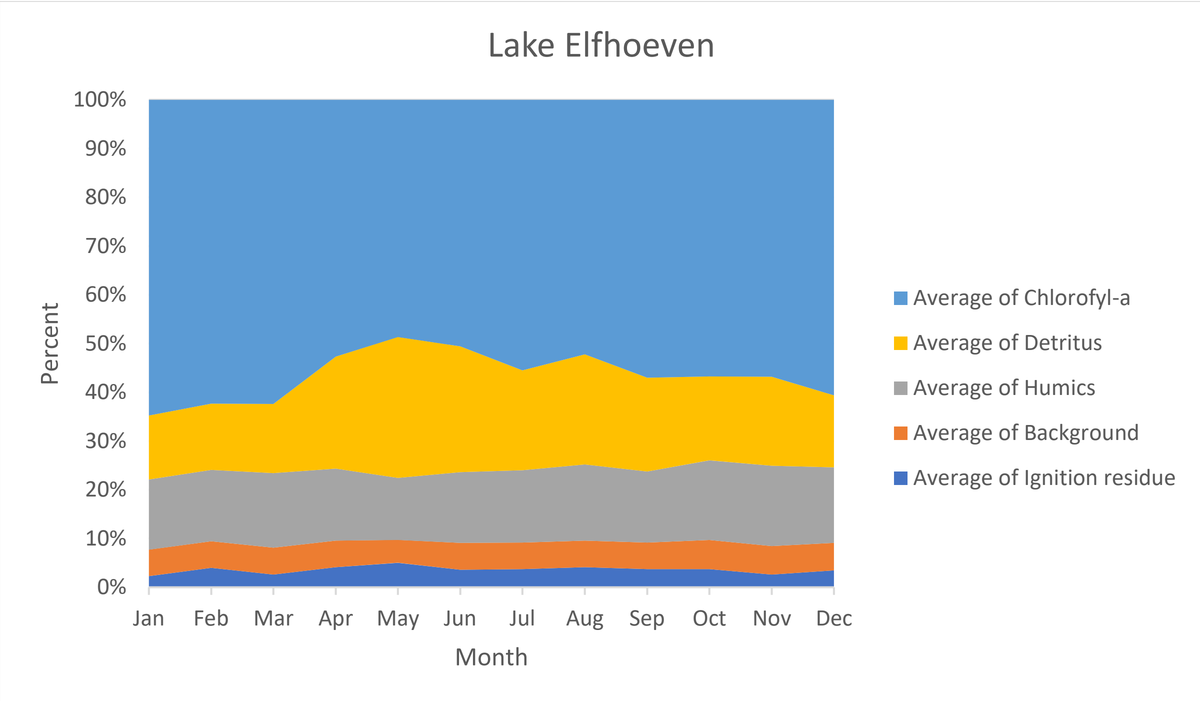

Figure 11: Distribution of light absorption lake Elfhoeven Note: Background is the absorption of light by the water itself. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

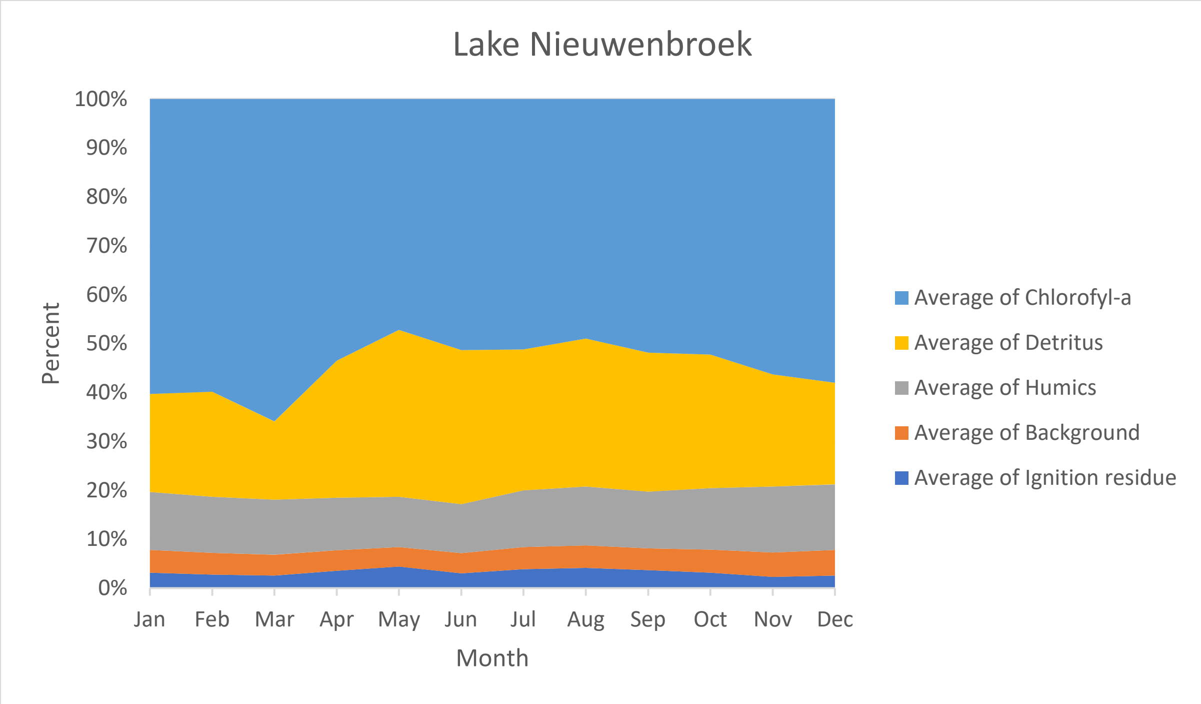

Figure 12: Distribution of light absorption lake Nieuwenbroek. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

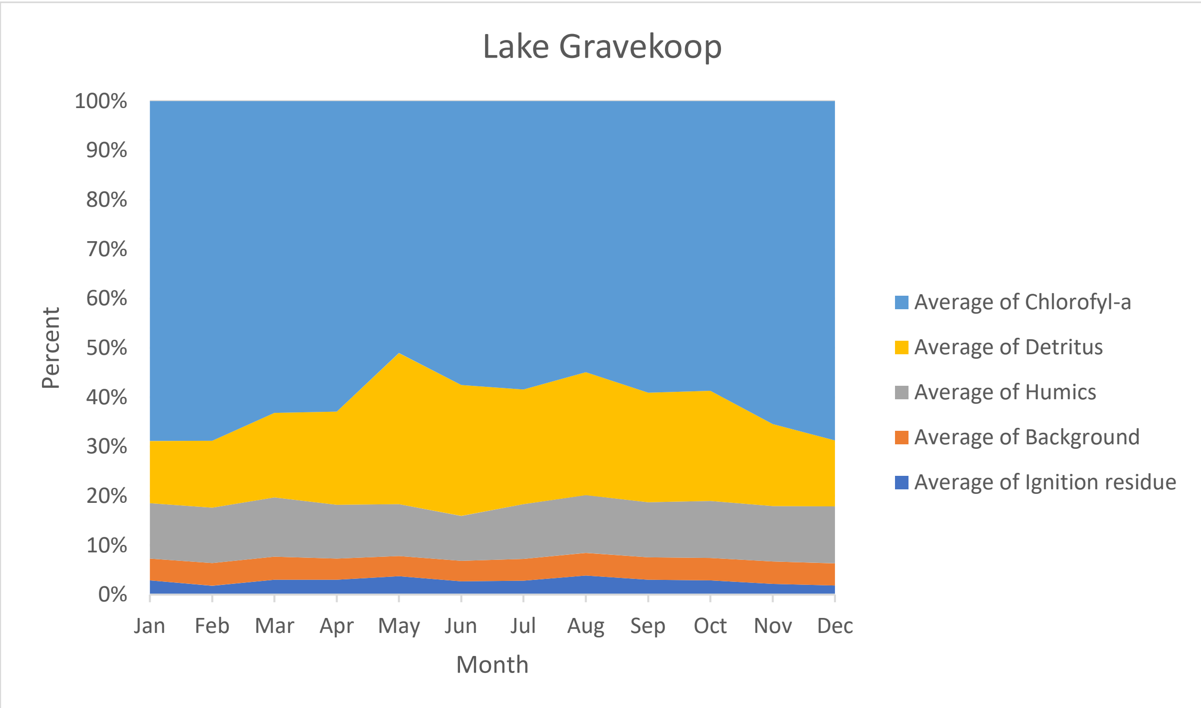

Figure 13: Distribution of light absorption lake Gravekoop. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

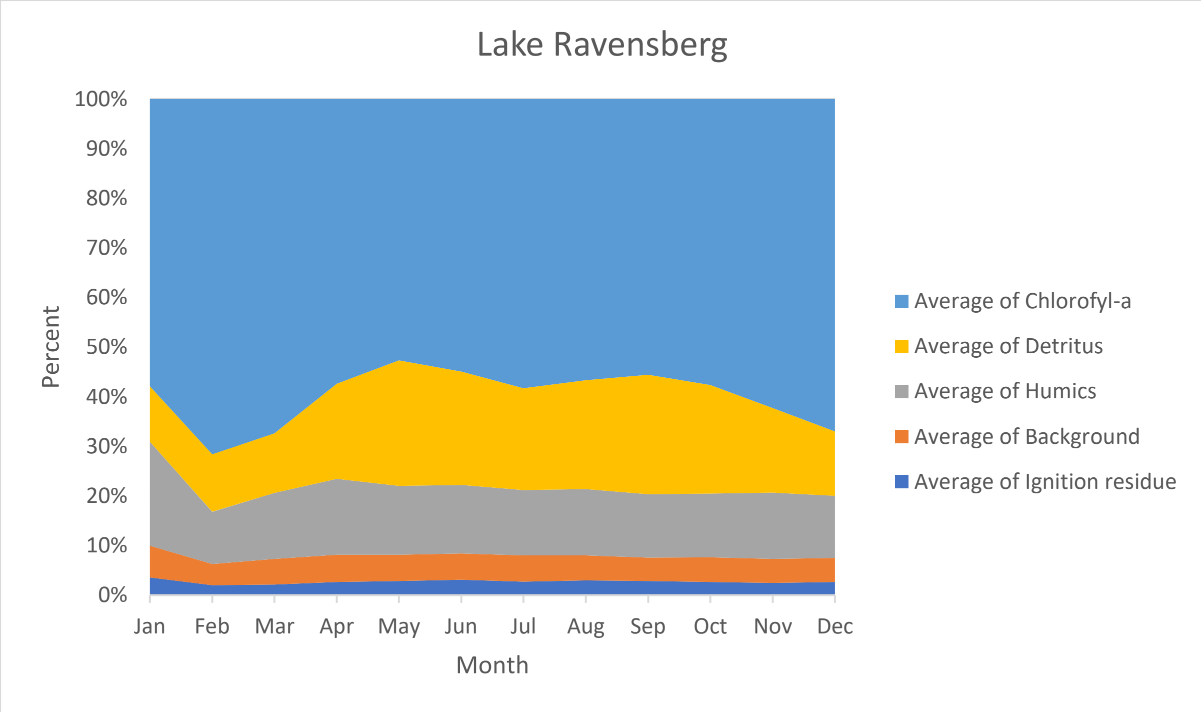

Figure 14: Distribution of light absorption lake Ravensberg. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

All lakes show an increase in suspended detritus from May until August coinciding with the period of increased recreational boating activity. There is also a small increase in ignition residue during these months. The highest peak in detritus occurs during May in all lakes. The main amount of light absorption is being caused by chlorophyl-a in the water column which can be attributed to algae and living organic matter.

The following graphs shows average monthly percentage of light reaching the lakebed.

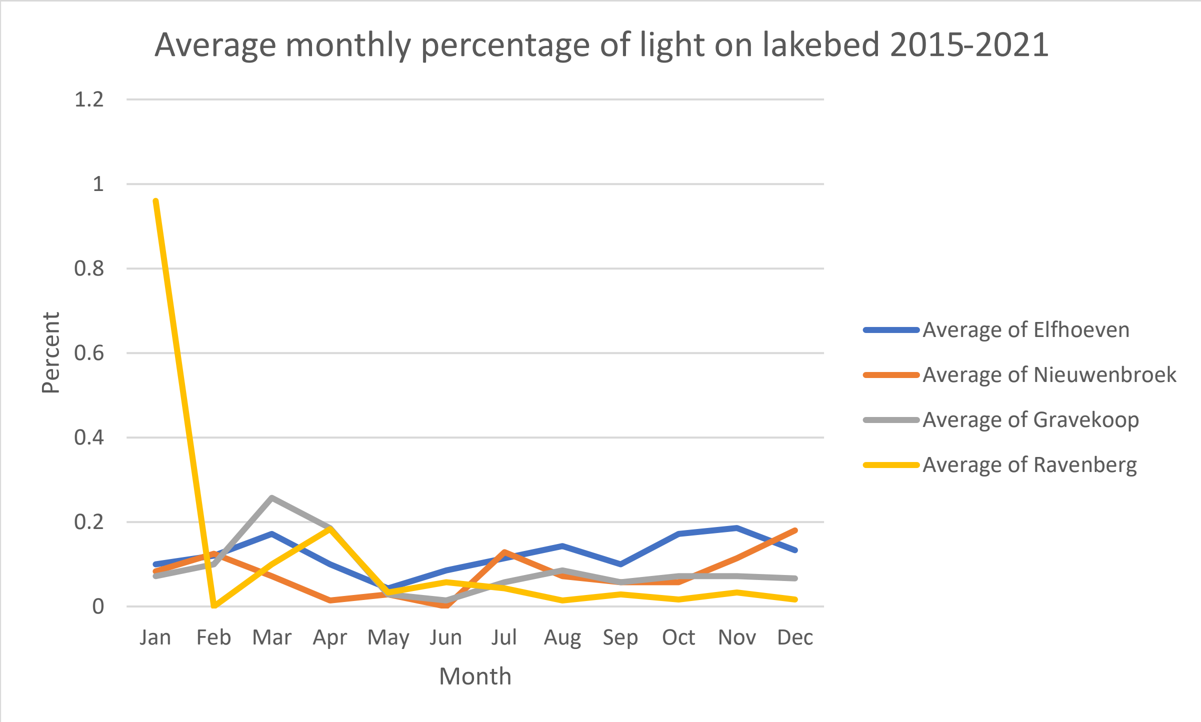

Figure 15: Average monthly percentage of light on lakebed 2015-2021. Peak in visibility in Lake Ravensberg only occurs for one year. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

During the 6 years of measurements only lake Ravenberg reaches more than 4% of light on the lakebed during the month of January 2015. Afterwards there is never a point where more than 1% of light reaches the lakebed. None of the other lakes have more than 1% of light on the lakebed either. Lake Elfhoeven on average has the most light reaching the lakebed varying between 0.1% and 0.2%.

The following graph shows the yearly fluctuation in the percentage of light reaching the lakebed.

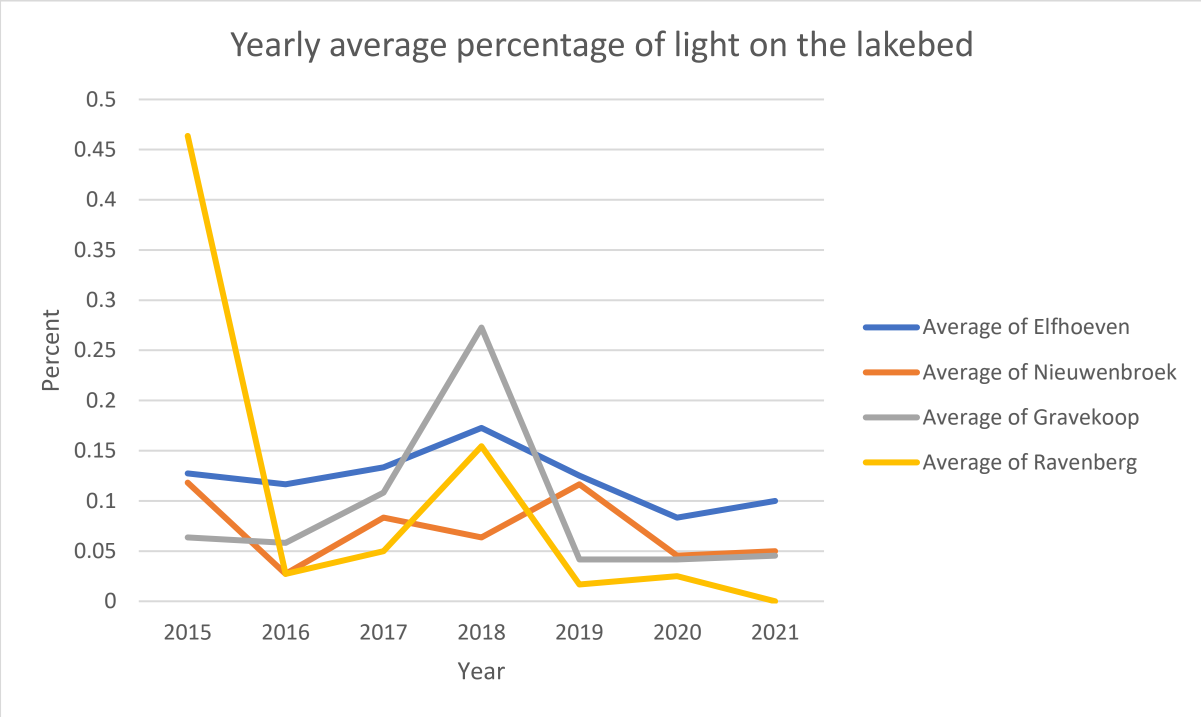

Figure 16: Average yearly percentage of light on the lakebed. As mentioned prior only lake Ravensberg has an acceptable amount of light reaching the lakebed for one year only to worsen over the years. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

The samples were taken at the same location on all lakes at a point with roughly the same lake depth.

All lakes get a failing grade for the WFD parameter lighting.

EKF 4 Habitat conditions

The following section will detail the habitat conditions based on the report of the RWA on the ecological situation of the implemented nature friendly banks and the fish stock management plan set up by the fishing organisations involved with the Reeuwijkse Plassen.

Habitat riparian plants

The lakes adhere to a natural water level that was implemented in 2018. Meaning the water level is allowed to fluctuate by about 8 centimetres during the summer fluctuating between -2.21 and -2.29 metres below sea-level. The winter level is set at a standard level of -2.24 metres below sea-level. Most implemented NFEs having a sloped talud extending by about 1 to 3 metres into the water. Most of the shorelines are shielded against wave by planks and poles installed along the length of the banks.

The table 7 show the amount and length of the implemented NFEs per lake.

Table 7: Plots and length of plots. Based on data sourced from RWA Rijnland 2018.

Lake	Number of Plots	Length (M)
Elfhoeven	9	2110
Nieuwenbroek	8	779
Ravensberg	9	1165
Gravekoop	26	4430

Habitat submerged aquatic plants and floating leaf plants

The lighting conditions for all the lakes is very poor for the development of aquatic plants. With less than 0.2% of light reaching the lakebed at any given time during the year.

The main type of fish found in all the lakes are the common bream (*Abramis brama*) and pikeperch (*Sander lucioperca*). With the common bream being very common and pikeperch being reasonably common. Three species of exotic American crayfish (*Faxonius limosus, Faxonius virilis* and *Procambarus clarkia)* and the exotic Chinese mitten crab (*Eriocheir sinensis)* are also reasonably to very common in all the lakes.

Habitat fish

Both the local fishing organisation and the RWA report little to no submerged vegetation. Reporting only small amounts of vegetation near the shoreline and no vegetation in the deeper parts of the lake.

Lake Nieuwenbroek, Ravensberg and Gravekoop have a reasonably level lakebed with little variation in depth. Lake Elfhoeve has a reasonably level lakebed on the southern half of the lake, the northern part of the lake has a deeper part descending an additional 3 metres to a depth of about -5.5 metres.

Species abundance Nature Friendly Embankments

The following table shows the number of individual macrophyte species found in the water along the shoreline in the lakes during the period of 2014 to 2018.

Table 8: Individual found species in the NFEs between 2014 and 2018. Based on data sourced from Hoogheemraadschap Rijnland 2018.

	2014	2015	2016	2017	2018
Elfhoeve	10	18	21	17	21
Nieuwenbroek	0	13	8	9	7
Ravensberg	7	7	19	15	17
Gravekoop	7	24	20	18	24

Using Shannon’s diversity index the following graph was devised showing the relative diversity per lake. A high number indicates a higher level of diversity.

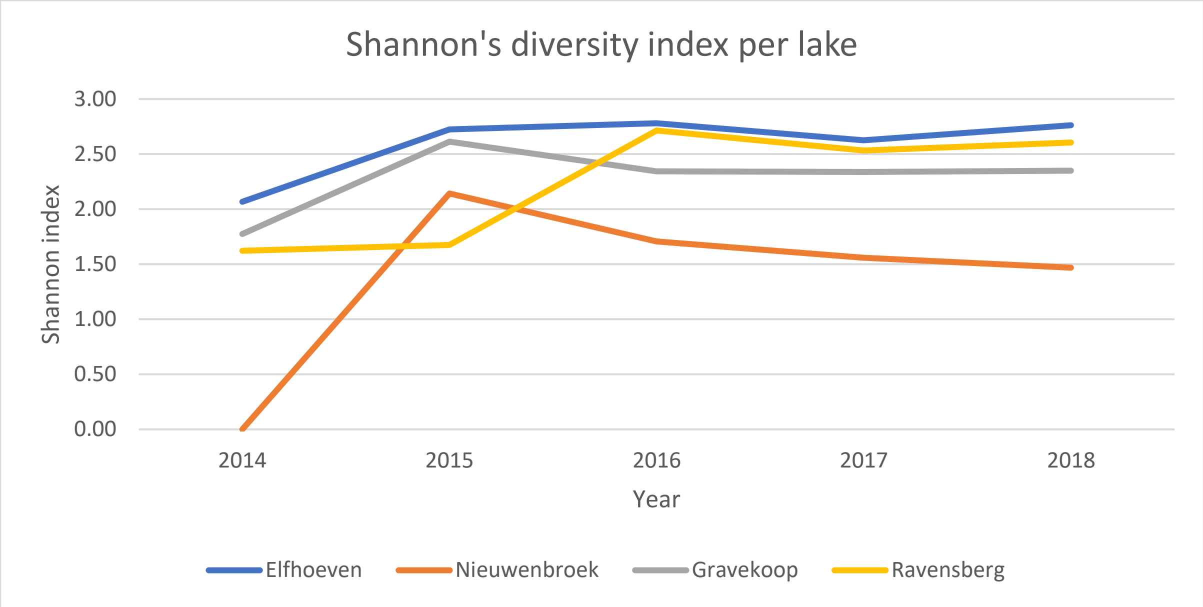

Figure 17: Yearly level of species diversity for each lake based on the Shannon index. With the vertical column being the index number. Based on data sourced from Hoogheemraadschap Rijnland 2018.

Excluding lake Nieuwenbroek, the other three lakes have a reasonably high level of diversity occurring in the NFE’s.

Lake Nieuwenbroek scores very poorly with only 7 individual species being found in 2018, this in part due to the lack of protected shoreline. While lake Ravensberg also has multiple plots without a protected shoreline, this lake supports a much higher level of diversity. Indicating that there is a higher level of shoreline erosion occurring in lake Nieuwenbroek.

Although the habitat conditions along the shoreline are quite good due to the NFE project enacted by the RWA, the submerged plant habitat and fish habitat conditions are very poor for all the lakes.

The poor visibility prevents the development of submerged vegetation which in turn prevents fish species such as the northern pike (*Esoc lucius*) or the common roach (*Rutilus rutilus*) of settling in this area.

The poor visibility conditions as reported under EKF 2 make the lakes an extremely poor habitat for plant species found in M27 type lakes which in turn makes the lakes unsuitable for fish found in these types of lakes. All the lakes therefore get a failing grade.

EKF 8 Toxicity

The following graphs show the yearly average concentrations of zinc and copper in the lakes. Lake Ravensberg is not included in this list due to not being monitored for these substances.

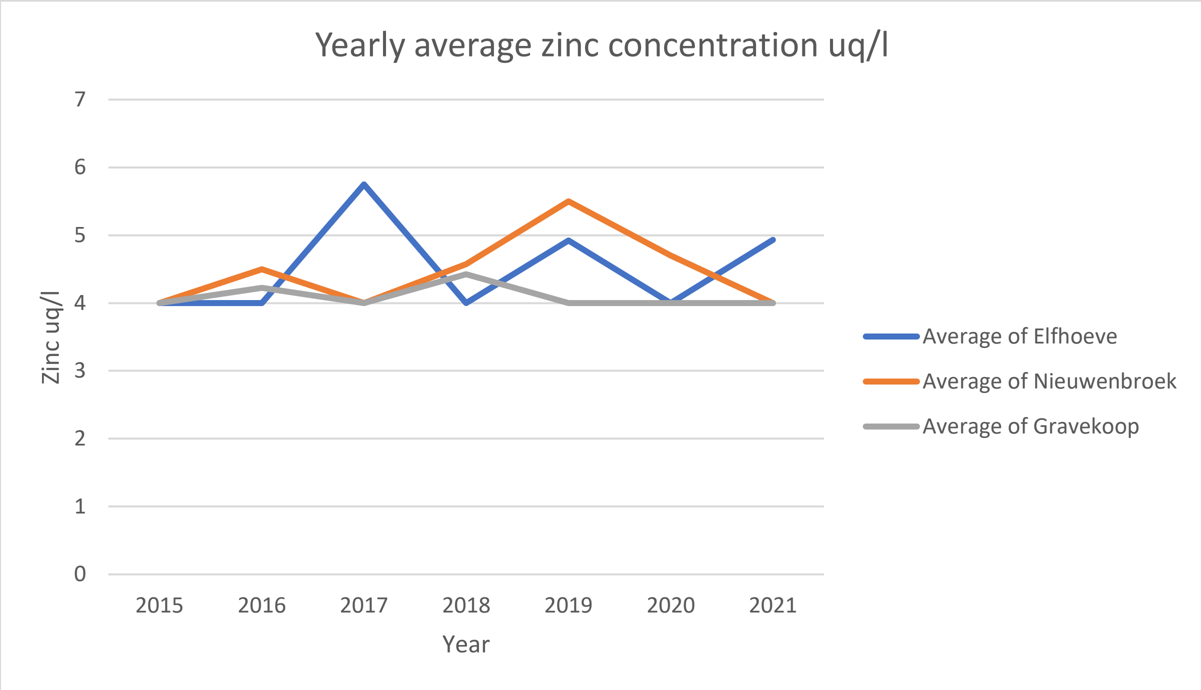

Figure 18: Average yearly zinc concentration uq/l. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

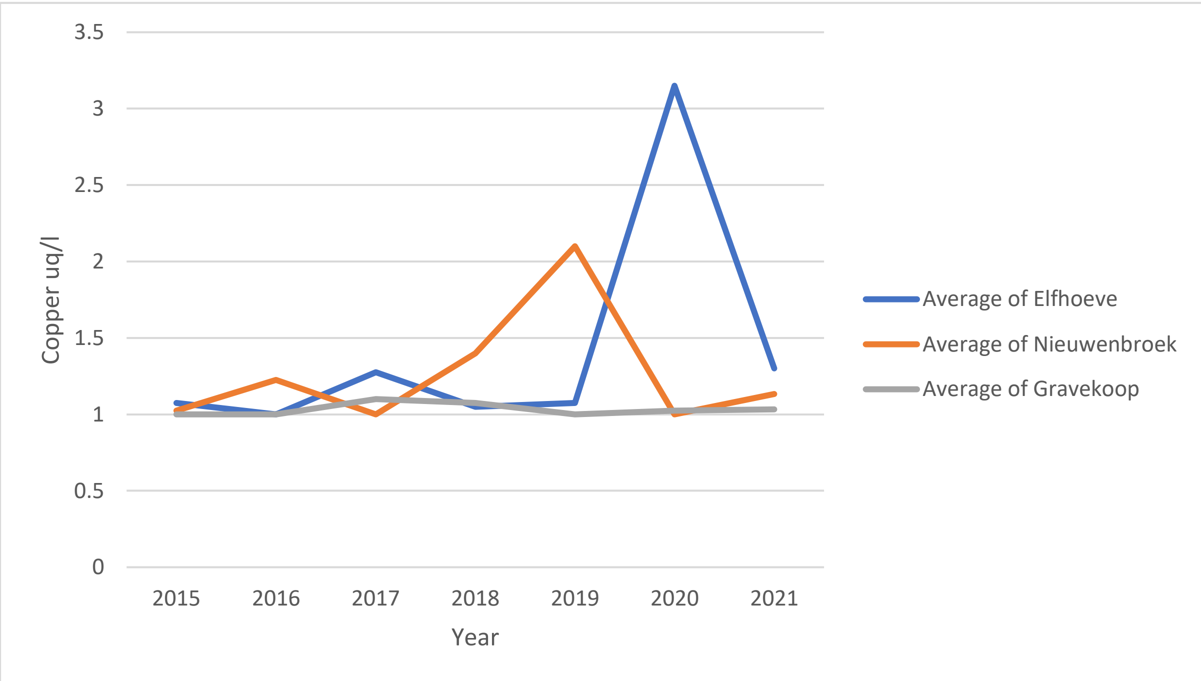

Figure 19: Average yearly copper concentration uq/l. Based on data sourced from Hoogheemraadschap Rijnland, Leiden, 11 November 2021.

On average lake Elfhoeven has the highest concentration for both Zinc and Copper followed by lake Nieuwenbroek and lake Gravekoop with the lowest concentrations. The zinc concentrations peak during March while the copper concentrations are stronger during the latter part of the year in both lake Elfhoeven and Nieuwenbroek.

For zinc the yearly average permissible amount is 7,8µg/l and a maximum permissible amount of 14µg/l. All the lakes are within the parameter with yearly averages around the 4,6 µg/l. (Bonten., et al. 2011)

The maximum amount of dissolved copper that can be found in a waterbody according to the WFD with a good ecological condition is 1,5µg/l. Lake Gravekoop always has concentrations below this parameter. Lake Elfhoeven exceeds this parameter twice during March of 2017 and December 2020 and lake Nieuwenbroek exceeds this parameter twice during September of 2018 and 2019.

Lake Elfhoeve and Nieuwenbroek receive a failing grade due two exceeding the permissible concentrations of dissolved copper multiple times over the last 6 years. Lake Gravekoop receives a passing grade due to never exceeding the permissible concentrations of both zinc and copper.

3.3 Comparison lakes

The table 8 shows the grades for all the analysed EKFs for each lake, with green indicating a passing grade and red indicating a failing grade.

Table 8: EKF grades for each lake

	EKF-1	EKF-2	EKF-4	EKF-8
Lake Elfhoeve				
Lake Nieuwenbroek				
Lake Gravekoop				
Lake Ravensberg				

4. Discussion

The goal of this report was to show that recreational boating was a potential factor in the poor WFD scores of the Reeuwijkse Plassen using data currently being monitored by the RWA and with the use of sources available on the internet.

4.1 Results

What additional influence does boating have on the basic requirement EKF group, EKF 1,2 and 3?

The nutrients suspended in the water are the opposite of what was expected. The lake with the most boating activity had the lowest concentration of both phosphorous and nitrogen while the lakes with the least expected activity scored significantly higher. Especially lake Gravekoop had a high level of suspended nutrients albeit only just exceeding the goals set by RWA Rijnland.

One of the possible explanations might be the proximity to agricultural fields. The area adjacent to the east of Gravenkoop consists of fields that are in use for intensive agriculture. The higher concentrations could be caused by the leaching fertilizers and manure of these fields. This would also explain the higher concentrations in both lake Ravenberg which has a several smaller agricultural field to the west and lake Nieuwenbroek which has agricultural fields to the east as well. A report from STOWA from 2007 on the leaching of fertilisers from grassland showed a correlation between the concentrations of nutrients in the water and the surrounding agricultural fields. Arguing the fertilizers were contributing to the exceedance of nutrient norms in surface waters. (Van de Weerd et al. 2007)

Another possible explanation might be the redistribution of nutrients through repeated resuspension due to boating activity in lake Elfhoeve and lake s’-Gravenbroek. The article by M. Lenzi et al. mentions that particles such as phosphorous be redistributed over larger distances due to being suspended in the water for a longer amount of time. It could be possible that the phosphorous found in lake Elfhoeve are being redistributed over the other lakes. The map of the lakes in annex 1 shows this interconnectivity from lake Elfhoeve through to Nieuwenbroek and Gravenkoop via lake Klein Elfhoeve and Vrijhoef. There is also a connection between lake ‘s-Gravenbroek and Ravensberg which could also in part explain the elevated levels of nutrients occurring in Ravensberg.

The influx of detritus as mentioned in the previous chapter does coincide with the increased boating activity. Especially the month May seems to be the most prevalent with the increase in detritus and the decrease in visibility on the lakebed. This coincides several holidays in late April and a school holiday in May. Which is one of the more active periods on the lake. The local fishing organisation reports regular exceedance of speeding limit and boats passing too close to the shoreline on regular basis which could be a cause for the resuspension of detritus as well. There is no clear difference in lighting conditions between lakes based on boating activity, the detritus and phosphorous could spread to the other lakes by way of a current flowing between the lakes.

This could also correlate with findings in the previously mentioned article by M. Lenzi et al. which suggest that the phosphorous might travel these distances due to binding to smaller fractions of detritus. The RWA rapport on the lakes from 2018 mentions under the analysis of EKF-3 that the amount of phosphorous found in the lakebed sediments was very high, the lakebed is regarded as a source of additional nutrient loading.

Cause of the poor lighting conditions

This despite the nutrient concentrations declining over the years and being mostly with the range set by RWA Rijnland. This indicates that phosphorous is probably not the cause of the high turbidity occurring in the lakes. Indicating resuspension of sediments being the main contributor to the poor visibility conditions

This resuspension could be caused by wind but as mentioned by multiple articles could also be caused by boating activity. (Nedohin, D. N., & Elefsiniotis, P. 1997; Anthony, J. L., & Downing, J. A. 2003; Alexander, M. T., & Wigart, R. C. 2013).

More importantly, an article by Penning et al. (2013) on the effects of wind driven resuspension on shallow Dutch lakes shows that wind might not be the main driving force of resuspension on the lakes of Reeuwijk. Using meteorological data, the article shows that due to the occurrence of the peat islands on the lake the wind does not have that much effect on resuspension. Insinuating other forces are causing resuspension. The article also reports the particle size of the lakebed sediments being very fine, making them more susceptible to forces and giving them quite a long time to settle as well.

This makes it quite possible that boating is a driving force behind the resuspension of sediments of the lakebed rather than wind.

The poor lighting conditions in lake Ravensberg could be explained by the reported decay of the many peat islands found in the lake, these have not been reinforced and shielded unlike the islands found in the other lakes which in turn could cause an increased amount of detritus in this lake. In addition, the decay could attribute an increase in the level of dissolved nutrients occurring in the lake as well. (Hoogheemraadschap Rijnland, 2018)

To what degree does boating in the lakes disrupt habitat conditions, EKF-4?

The level of species diversity found in the NFE's in all the lakes excluding lake Nieuwenbroek was quite high. However, almost all the embankments were shielded by shoring protecting the macrophytes from most waves generated by wind and boating activity.

The poor level of diviersity found in lake Nieuwenbroek could be partially explained by the placement of the NFE's most of which were along small peat islands which were already in quite poor condition due to erosion. Even though the RWA reported the NFE's in lake Ravenberg to also be decaying and in poor structural condition lake Ravenberg still supported a reasonably high level of species diversity. This could potentially relate to boating activity as well with lake Nieuwenbroek having more boating activity than lake Ravensberg. The overview article by Asplund T. (2000) mentions boating activity close along the shoreline causing the erosion. The lakes having shorelines consisting mostly of peat could be a cause of this. It is also noted that boating passages close to the shoreline might cause stronger wave induced sheer stress than wind induced waves.

The local fishing organisation reports species such as water soldiers (*Stratiotes aloides*) in areas with little boating activity. The fishing report and the RWA report both mention that the biomass and diversity of macrophytes within the lakes is little to none. This can almost entirely be attributed to turbidity and resuspension.

As mentioned prior in the article by Asplund & Cook (1997) boating could also be disturbing the lakebed sediments, preventing macrophytes from settling on the lakebed as well.

Unfortunately, the monitoring data on submerged and floating plant species was not available, giving only a fragmented view of species diversity and preventing a side-by-side analysis of the macrophyte abundance of all the lakes.

Do recreational boats increase the concentration of toxic chemicals in the lakes and to what extent?
The gradient in zinc and copper concentrations correlates with the finding in the literature research that the areas surrounding the harbours contain a higher level of metals due to the leaching of anti-fouling materials. Lake Elfhoeven has a peak in zinc concentration during March in 3 of the 7 years, which coincides with the period in which boats in the harbour are repainted and reintroduced into the lake.

Even though samples were only being taken about three to four times a year for each lake, the differences in concentrations still give a reasonable indication of the influence of the harbours found in the lakes. Unfortunately, no data on toxic substances was recorded for lake Ravensberg resulting in the selection of an additional lake, lake Nieuwenbroek, to analyse the chemical data.

Additionally multiple substances reported in the literature research such as Irgarol 1051, Diuron and Tribultyltin had very little monitoring data. Several of these substances were only monitored in lake Nieuwenbroek, while some of the substances suchs as Tribultyltin were only recorded up until 2001. Which in turn prevents a proper comparison of the concentration of these substances in conjunction with the other lakes. A study in 2017 reported that banned substances such as Diuron or Iragol could still be in use. (Egardt J. et al.). It is possible that these might still be in use at the harbours surrounding the lakes as well especially considering quite a few of these harbours have been there for considerable amount of time dating back to the 1980’s. If the gradient in metal concentrations such as copper and zinc was also observable in the lakes it could be possible that the is a detectible decay in banned antifouling paints as well especially from lake Elfhoeven and ‘s-Gravebroek.

Chemicals such as benzo(g,h,i)-perylene and indeno(1,2,3-cd) pyrene were also only monitored in lake Nieuwenbroek. Although it is expected that the emissions from the engines of recreational boats have significantly decreased due to the change to 4-stroke engines, it could be possible that lake Elfhoeve might still have higher concentrations due to the concentration of harbours and boats.

The literature research indicates that there is a correlation between boating activity and water quality, especially macrophytes and the leaching of toxic substances. Although the levels of antifouling substances found in the water column are mostly within safe levels, it could be possible that the lakebed has much higher concentrations, due to deposition.

The article on lake Schleswig-Holstein by Machate et al. (2021) mentioned in the prior chapter, reports that antifouling substances that have settled in the lake sediments could be preventing the development of macrophyte communities.

4.2 Literature research

A total of twenty-two articles were found relating to shallow lakes and the effects of recreational boating. This is arguably a relatively sparce.

There were no articles relating directly to shallow peat lakes. A reason for this is that these lakes do not exist almost anywhere else in the world, especially not in the artificial form found in the Netherlands. Therefore, although some information is available on the effects of boating on shallow lakes is available, almost nothing is known about the effects of boating on shallow peat lakes. This means there is a lot of potential research to be done on the lakes in the Netherlands.

What also became apparent during the literature research is that the emphasis of the studies was usually based on the effects of water quality on recreation instead. This reiterates the consensus stated by the article from Venhor et al., 2018 that the impacts of water recreation on water quality is often understated and the management of economic, environmental, and recreational aspects are poorly linked. Water quality and ecology habitats usually take the backseat when it comes to research to the perceived societal importance of economic conditions over that of nature.

4.3 Comparison of the lakes

Accurate reports on the level of boating activity occurring on the lakes was unfortunately unavailable, resulting in having to use satellite imagery and reports from the local fishing authority to give and rough estimate on the expected level of boats occurring on the lakes.

The peak in phosphorous concentration from EKF-1 and the increase in detritus from EKF-2 seems to coincide around the same time across all the lakes. The RWA report mentions high concentrations of phosphorous being found in the lakebed soil. This could in turn explain the peak of phosphorous as seen in EKF-1 and coincide with binding to detritus observed in EKF-2.

Except for toxicity lake Elfhoeven repeatedly seems to be the best scoring lake when it comes to the EKFs. Refuting the hypothesis of this report that this would be the worst scoring lake due to having the highest level of boating activity. It could be argued that that the low levels of nutrients reported in the lake could be due to the repeated resuspension and redistribution of these nutrients.

To what extent might boating activity influence the poor WFD scores of the Reeuwijkse Plassen?

The results of EKF-2, EKF-4 and EKF-8 show possible influence of boating activity. This indicates that boating may have some influence in the poor WFD scores especially if the wind is less of an influence on resuspension.

The currently available monitoring data from the RWA is arguably insufficient to analyze the full extent of the effect of boating due to the infrequent monitoring of parameters and more importantly no active monitoring on the amount of boating occurring on the lake at any given time. This kind of information would make the case for correlations between observed effects in the EKFs and boating activity much stronger.

5 Conclusion and recommendations

The goal of this report was to study to what extent boating might influence the poor WFD scores of the Reeuwijkse Plassen using monitoring data from the RWA and reports and data available on the internet.

Although the observed effects were subtle, boating might have enough of an effect to inhibit the improvement of the WFD scores of the lakes.

1. *What additional influence does boating have on the basic requirement EKF group, EKF 1,2 and 3?*

Lighting conditions in al the lakes were very poor. The repeated influx of detritus absorbing light during May coincides with the expected period of increased boating activity. This also coincides with a peak in phosphorous occurring during May as well.

As mentioned in the prior chapter wind does not seem to be the driving force behind resuspension of sediments, indicating that boating might be a more significant contributor to resuspension than expected.

2. *To what degree does boating in the lakes disrupt habitat conditions, EKF-4?*

Literature research indicates that boating can be very disruptive for habitat conditions by impeding macrophyte development and disturbing fish populations.

Macrophyte species diversity along the shoreline is quite high, excluding lake Nieuwenbroek. Even though lake Ravensberg has similar poor conditions in terms of erosion along the shoreline, like lake Nieuwenbroek it scores high in species diversity which might be due to experiencing little to no boating traffic.

All the lakes have little to no submerged vegetation which is for a large part due to poor lighting conditions which could be caused by boating. But the boating activity could also be the cause of the disturbance of sediments, preventing macrophytes from colonizing the lake bed.

3. *Do recreational boats increase the concentration of toxic chemicals in the lakes and to what extent?*

The concentration of both dissolved zinc and copper showed a correlation with the proximity of harbours and mooring spots in the lakes. These metals inhibit the development of macrophytes in the water. In addition, it is possible that antifouling substances still preside in the lakebed sediments preventing vegetation from developing as well.

To what extent might boating activity influence the poor WFD scores of the Reeuwijkse Plassen?

If wind is not the driving force behind the poor visibility conditions on the lake it is very likely boating might be a larger stressor than expected by both causing poor lighting conditions due to resuspension and by disrupting the settlement of macrophytes on the lake bed.

Boating activity seemed to have a noticeable effect in three of the four analysed EKFs. That being EKF-1 water productivity, EKF-2 lighting conditions and EKF-8 toxicity. In EKF-1 and EKF-2 there was a noticeable influx of detritus and phosphorous during the summer month which could correlate with boating activity.

In EKF-8 the levels of copper and zinc per uq/l seemed to reflect the proximity and number of harbours per lake. Additionally, there is a repeating peak occurring during multiple years coinciding with the period commonly used for painting and the reintroduction of boats into the lakes.

Recommendations

Data currently being acquired on the lakes is insufficient to observe full extent of the effect of boating. Raising the question if this might cause an oversight in the effects of boating. Additionally, no research has been done relating directly to shallow peat lakes such as those found in the Netherlands. A pilot observational study of a shallow peat lake would be advisable.

It would also be advisable to acquire additional monitoring data on boating activity on all lakes found within the Netherlands. Although boating activity is occasionally mentioned in reports as a potential cause of undesirable ecological conditions, it is usually only mentioned as a sidenote. Although some occasional reports were found on boat movements occurring on canals, actual information on boating activity on lakes was very sparce.

Additionally, it would be advisable to carry out additional sampling of lake sediments in multiple lakes. The RWA report mentions a lack of sampling of lakes sediments in the system for nutrients. To add to this the available data on banned anti-fouling substances is severely lacking and could be an additional negative influence in the lakes.

Although it would have been very time consuming to record such data efficiently and regularly several decades ago, with the advancement of remote sensing technology this could be done much more efficiently by using for example webcams and image recognition software.

There are multiple possible measures that could be implemented to negate the effects of recreational boating. Although the outright restriction of boating would be hard to enact on lakes such as those in Reeuwijk due to the financial income generated by boating. It might be possible implement a temporary restriction for motorized vehicles on the water.

It would be advisable to both improve the enforcement of speeding restrictions on the lakes and educating visitors of the lakes on the boating regulations. These regulations reportedly being regularly broken, and the authorities only have surveillance on the lakes about once a week excluding extremely busy days. The local yacht clubs could be addressed to make additional notice of the regulations on the lakes, and the local inhabitants could be reminded through local newspapers or advertisement campaigns.

Additionally, it might be advisable to implement additional restricted zones in the lakes to give a chance for lighting conditions to improve and for macrophytes to settle. This could be applied in a similar way as with lake Klein Elfhoeven which has a restricted passageway for boats to pass through.

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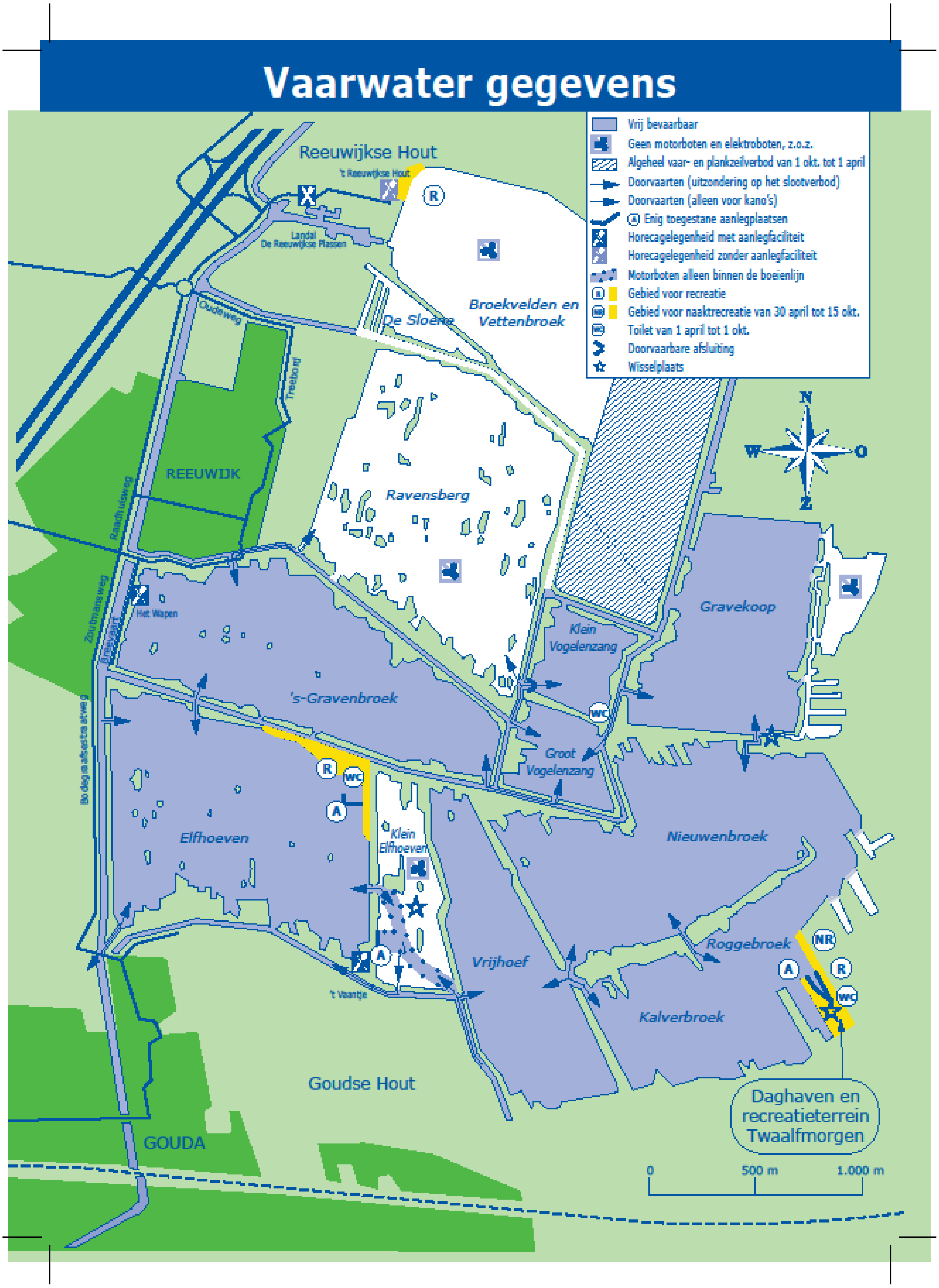
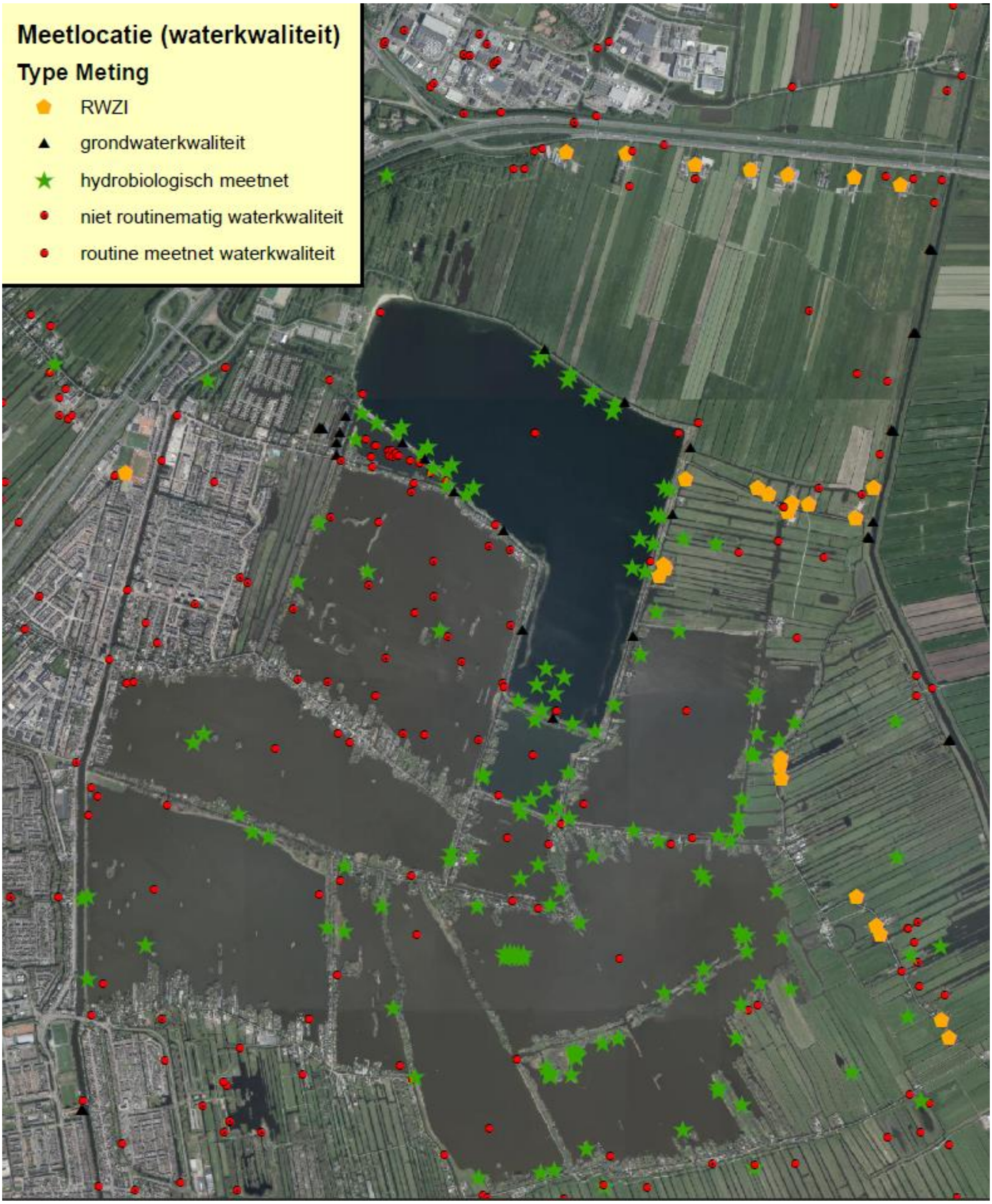
Annex 1. Map of Reeuwijkse plassen



Detailed map Reeuwijkse Plassen. Source: Stichting Veen

Annex 2. Monitoring points Reeuwijkse Plassen



Routine measuring points used in RWA database Source: RWA Rijnland

Annex 3. Literature research table

Sub-question	Search terms		Search engine used
All	Motorized boating, pleasure crafts, recreational boats, boat traffic, recreation, lakes, Shallow water, peat lakes, freshwater systems, environmental effects	The terms will be used in while searching for literature related to all sub-questions	G, GS, SP, SD,
Does boating have an additional influence on the basic requirement EKF group, EKF 1,2 and 3?	Sediments, eutrophication, lakebed composition, phosphorous, turbidity, lighting, resuspension, eutrophication	What kind of influence does boat activity have on the resuspension of nutrients and the lighting conditions in shallow freshwater lakes?	GS, SP, SD
Does boating in the lakes disrupt habitat conditions, EKF-4?	Submerged vegetation, macrophytes, mechanical damage, growth impediment, fish, disturbance, wave attenuation	What direct effects does boating have on the flora and fauna in shallow freshwater lakes?	GS, SP, SD
Do recreational boats increase the concentration of toxic chemicals in the lakes? EKF 8	Anti-fouling, exhaust fumes, heavy metals, copper, zinc, bioavailable, biocides, oil, seepage, leakage	What kind and how many pollutants leach of boats into the water?	GS, SP, SD

Annex 4. Literature research articles

Sub question 1 basic requirement EKF group, EKF 1,2 and 3

Title	Type of study	Parameter	Purpose of study	Findings	Proposed measure
Resuspension of Sediments by Watercraft Operated in Shallow Water Habitats of Anne Arundel County, Maryland (2002)	Experimental study	Secchi depth, turbidity, depth, boat size and speed	Study of the level of resuspension caused by boat traffic in shallow water in different creeks	There was no significant level of resuspension observed under restricted operating conditions	Enforcement of no wake zones provide a viable mechanism to reduce boating impacts on shallow environments
Physical Impacts of Wind and Boat Traffic on Clear Lake, Iowa, USA (2003)	Observational and analytical study	Boat traffic, turbidity, windspeed, nutrients	Study of the impact of wind and boating traffic on resuspension in a shallow lake	Wind is a major contributor to resuspension; boating seems to have an additional effect on turbidity. Over 50% of resuspension on the lake seems to be related to boating. Relationship between boating and turbidity difficult to characterize	Effects of resuspension and nutrient loading should be taken into account while setting restoration goals for time frames.
Waves, Wind, Watercraft, and Water Clarity A Study of Sediment Resuspension in Clark Lake (2007)	Experimental study	Sediment particle size, turbidity, wind speed, depth, boat power and velocity	Study of wind and watercraft generated waves on the resuspension of sediments.	Boating has a more subtle effect to resuspension; this depends on engine size and depth. Resuspension during summer	Precautions and limits to boating activity should be taken. Especially in more shallow areas. Stable plant communities could aid in resuspension.

				coincided with boating activity during early summer and more wind driven activity in late summer. Fine particles could be resuspended by boating activity and moved to areas more susceptible to wind. Effects of wind and waves decreased with interception of vegetation.	
Effect of motorized watercraft on summer nearshore turbidity at Lake Tahoe, California–Nevada (2013)	Observational study	Turbidity, boating activity, time of day	Study on the effect of motorized watercraft activity on resuspension in near shore shallow water on a large lake	Waves generated by boats near the shore are likely to resuspend sediments and release nutrients. A small area of intense resuspension could have an effect on the rest of the lake.	Additional research in near shore areas. A reduction of the hydrodynamic impacts of boating.
Assessment of resuspended matter and redistribution of	Experimental study	Boat passages, Sediment resuspension, nutrient load	Study of the effects of boat passages on sediment resuspensio	A significant amount of nutrients was resuspended by boat	Argues that sediment redistribution might increase species

macronutrient elements produced by boat disturbance in a eutrophic lagoon (2013)			n and redistribution in a shallow lagoon	passages. The redistribution of nutrients correlated with the distance of the boats. Additionally phosphorous was found to redistribute over further distance due to binding to small organic particles.	richness in the lagoon.
THE EFFECTS OF MOTOR BOATS ON WATER QUALITY IN SHALLOW LAKES (1997)	Comparative study	pH levels, turbidity, phosphorous	Water quality comparison of two lakes, on with motorboat activity and one without motorboat activity to see if motorboats act as a catalyst for poor water quality.	Motorboat activity has a significant effect on the water quality of the lake. Heavy boating activity during the summer caused an increase in phosphorous on the lake.	No measures proposed

Sub question-2 habitat conditions, EKF-4

Title	Type of study	Parameter	Purpose of study	Findings	Proposed measure
Effects of boat traffic and mooring infrastructure on aquatic vegetation: A systematic review and meta-analysis (2020)	Systematic review and meta-analysis of studies on boating and mooring effects on aquatic vegetation	Abundance of submerged aquatic vegetation, recreational boat traffic and mooring facilities	Quantify to what extent boat traffic and mooring facilities affect submerged vegetation	Boat traffic, docks and mooring buoys associated with a decrease in vegetation abundance	Informed management of boat traffic and improved design of docks and buoys

Effects of ship-induced waves on littoral benthic invertebrates (2012)	Experimental study	Number of detached invertebrate species, habitat complexity, wave height and length, boat velocity and distance from shoreline	Evaluation of the relationship between wave induced shear stress by different boat velocities, passing distances and habitat complexity on the number of detached species	Shear stress caused by boat waves cause a large number of benthic invertebrates to detach from habitat.	Implementation of shoreline protection, reduction of maximum boat speeds and passing distance, implementation of more complex shoreline structures such as dense reeds and submerged tree roots
Recreational boating degrades vegetation important for fish recruitment (2019)	Field study and statistical analysis	Vegetation cover and height, distance from marina, fish abundance	An examination of the effect of recreational boat marinas on the amount of coverage and height of submerged vegetation and the relation of vegetation and fish abundance.	A lower level off vegetation cover near moorings and a strong association between vegetation cover and fish abundance	Shoreline constructions and associated boating activity should be allocated to more disturbance tolerant environments.
Effects of Motorboats on Submerged Aquatic Macrophytes (1997)	Experimental study	Biomass percentage, macrophyte species composition, coverage and shoot heigh	A comparison of submerged macrophytes in enclosed plots and open control plots in a lake with high recreational boating activity	Dramatic decrease of plant biomass associated with motorboat activity	Implementation of no wake zones applied to areas with fragile macrophyte communities and areas more suitable for macrophyte development.
Effect gemotoriseerde recreatievaart op waterplanten: mechanismen,	Overview of scientific literature	Papers on the effects of motorized pleasure crafts on water plants	An overview of literature about motorized recreational crafts in	There is a strong association between vegetation damage and	Either the adaptation of the WFD goals or the implementation of mitigating

kwantificering en de relatie met de Europese Kaderrichtlijn Water (2012)			relation to water plants and the quantification of the expected effects	boating activity	measures and/or removal of boating.
The effects of motorized watercraft on aquatic ecosystems. (2000)	Overview report	Species abundance, shoreline erosion, fish populations	A summary effect on the effects of recreational boating on multiple aspects of ecological conditions of lakes.	Boating attributes to a multitude of negative impacts on water quality and habitat conditions. Such as disturbing aquatic wildlife, decreasing macrophyte biomass and eroding shorlines. Especially in shallow waters less than 3 metres deep and aling the shoreline.	Implementation of no-wake zones, restricted areas, increased enforcement and education.

Sub question 3 Toxicity

Title	Type of study	Parameter	Purpose of study	Findings	Proposed measure
Toxic metal enrichment and boating intensity: sediment records of antifoulant copper in shallow lakes of eastern England (2016)	Analytical study	Tributylin, Cu, Zn, Pb, boat activity	Study of sediment core samples for toxic metals leached from antifouling paints.	A correlation was found between an increase in toxic metals and an increase in recreational boating during the last half century.	Current regulations on copper in antifouling paints are still. Inadequate and should be reviewed

				With copper being the main source of contamination.	
Evidence for antifouling biocides as one of the limiting factors for the recovery of macrophyte communities in lakes of Schleswig-Holstein (2021)	Observational and analytical study	Biocides, pesticides, herbicides, PAHs, PCBs	Study of biocides found in	In a situation with multiple pressures, toxic pressure due to antifouling biocides could be a limiting factor for the recovery of aquatic vegetation.	Multiple stressors should be considered and analysed together while analysing areas with poor conditions.
Flawed risk assessment of antifouling paints leads to exceedance of guideline values in Baltic Sea marinas (2020)	Study of seasonal variations of copper and zinc in two recreational marinas	Toxicity, concentrations of dissolved copper and zinc	Evaluation of Swedish risk assessment of Anti-Fouling paints	A link between a rise in Cu and Zn levels during boating season with antifouling being principal source	Refinement of environmental risk assessment within the EU
Assessment of the risk posed by the antifouling booster biocides Irgarol 1051 and diuron to freshwater macrophytes (2006)	Obsevational and experimental study of biocides Irgarol 1051 and diuron	Igarol 1051, Diuron, growth rate, root growth	Risk assessment of effect of biocides Irgarol 1051 and diuron effect on macrophyte development and occurrence of biocides	Igarol 1051 and diuron impede growth rate and root growth of multiple macrophytes. The biocides were found in a large number of	No proposed measures

			in freshwater rivers and lakes.	lakes and rivers. These biocides pose a threat to macrophyte decelopment in multirple freshwater systems.	
Copper leaching from recreational vessel antifouling paints in freshwater: A Berlin case study (2022)	Observational field study and analytical study	Copper concentration, boating activity, presence of marinas, pH, DOC and salinity	Finding a correlation between boating activity and copper concentration in freshwater and sediment layer. Risk assessment of copper concentration on specific water parameters.	Copper leeching from antifouling paints was overestimated but third largest source anthropogenic source in German waters, Ch leaching depends on pH, salinity, and swell. Sediments near marinas tainted by copper.	Prohibition of antifouling paints with high copper content. Extra caution should be taken during boat maintenance at marinas.
Long-term effects of the antifouling booster biocide Irgarol 1051 on periphyton, plankton and ecosystem function in freshwater pond mesocosms (2008)	Freshwater mesocosm study of Irgarol 1051 effects on periphyton, plankton and ecosystem	Irgarol concentration, nutrients, pH, chlorophyll, periphyton abundance, plankton communities.	Studying the effects of Irgarol on ecosytems in an experimental setup.	Periphyton communities were strongly affected by Irgarol introduction, nutrient concentration increased due to lack of competition. The	Irgarol should be prevented from entering the freshwater system.

				effects shown in the study are expected to underestimate the effects of Irgarol in natural conditions.	
Sediments indicate the continued use of banned antifouling compounds (2017)	Field study and sediment analysis	Copper, zinc, Diuron, Irgarol 1051, Tributyltin	Study of sediments to ascertain if banned anti-fouling substances are still being used on recreational vehicles.	Banned paints found in sediments, significantly higher levels of copper compared to background levels, study suggest correlation with recreational boats, banned paints are potentially still in use.	Enforcement of regulations and information campaign on the banned anti-fouling paints that might still be in use due to ignorance or reluctance to adhere to legislation.
Motoremissies uit de recreatievaart (2016)	Factsheet	Indeno(1,2,3-c,d)pyrene, benzo(g,h,i)-perylene, benzo(a)-pyrene	Overview of substances found in engine emissions from recreational boats.	Only reports the chemicals found in engine emissions.	Introduction of emission factor for newly certified boats.
Watervervuiling door motoren van pleziervaartuigen (1999)	Scenario study and analytical study	Engine type, benzo(a)pyrene	A study on the extent of pollution from recreational boats and the effectivene	90% of emissions originate from two-stroke engines, due to strongly	The collection of missing data and additional research on the degree to which recreational

			ss of mitigation measures	localized recreational use of Dutch waters, ecological damage could be worse than national average figures might suggest.	boating contributes to pollution of waterbed sediments.
Ecologische risico's van koper en zink in het oppervlaktewater (2011)	Analytical study	Copper, zinc	Study on the concentrations of zinc and copper found in the surface waters of the Netherlands.	Repeated exceedance of standards found across the country of both zinc and copper concentration.	Argues for the use of the *Biotic Ligand model* to create a better overview of the ecological condition of Dutch surface water.