TRANSPARENCY BERENDONCK

The effect of coagulants on water quality and sediment stability

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ABSTRACT

This report describes the effectiveness of the coagulants aluminium sulphate (Alum), poly aluminium chloride (PAC), and chitosan on the water transparency and sediment stability in the divers pond located in the recreation area de Berendonck in Wijchen, the Netherlands. The pond, with a maximum depth of approximately 16 meters, is monitored for water quality from the period November 2023 to June 2024 and compared to data from November 2002 to June 2003.

The issue in the divers pond is that the water transparency is too low for proper diving activities. The pond is classified as mesotrophic/eutrophic system with turbidity levels ranging from 1 to 6 NTU in the top 14 meters which is primarily caused due to algae. At depths greater than 14 meters, turbidity is mainly caused by humic acids and detritus from resuspension events. The chlorophyll-α concentration from November 2023 until June 2024 is higher compared to the period November 2002 to June 2003, although turbidity levels remain similar between the two periods.

Experiments indicate that 2 mg Al/l of PAC combined with 50 mg/l of Phoslock$^{©}$ is the most effective dosage for removing algae (chlorophyll-α reduction up to 64%), which increased the water transparency. This treatment decreases the pH from an average of 7.97 (*SD* = 0.10) to 7.68 (*SD* = 0.18). However, no significant effect on the turbidity levels in pond water was observed from the coagulants and ballast compounds.

Phoslock$^{©}$ does not significantly impact sediment stability but accelerates the reduction of turbidity following a disturbance, which indicates faster settling of resuspended particles. A large dosage of PAC (68 g Al/m^2 sediment) also results in quicker particle settling, though it increases the sediment susceptibility to disturbances. While predicting the exact effects of PAC (and Phoslock$^{©}$) on the water quality in the divers pond is not possible. It is likely the application of PAC (and Phoslock$^{©}$) can enhance water transparency in the epilimnion. However, in deeper parts of the pond (>14 meters), the effects will be negligible, as turbidity issues from resuspension events remain unresolved by the PAC (and Phoslock$^{©}$) treatment.

CONTENTS

1. INTRODUCTION

Diving is a sport practiced globally across the whole world. There exist many diving associations where people can enrol as a member. The diving association 'Duikteam De Kaaiman' is located in Wijchen and was established in 1969 (Duikteam de Kaaiman, 2024). Adjacent to the building of De Kaaiman a pond is located where the members of the diving association could dive. The surface of the pond is approximately 5.84 hectares (which refers to the surface of the blue shape in Figure 1) and the pond is maximum 16 - 17 meters deep (Van Hall & Lürling, 2003) which an average depth of 6 meters (De Laak, 2010). This pond contains an underwater house that is located deeper than 15 meters (Duikteam de Kaaiman, 2024; Van Hall & Lürling, 2003). The pond is part of the recreation park the Berendonck. This recreation park contains mostly water recreation, however it includes also golf courses. These golf courses are located around the divers pond. Figure 1 gives an overview of the recreation park the Berendonck.

Problem description

To ensure optimal underwater visibility for diving, it is essential that the water in the pond maintains a relatively low turbidity. The current turbidity levels vary across depths of the pond. Data from Zaal (2022) and Van Hall and Lürling (2003) show that the pond is stratified between the months April and November. Stratification contributes to varying turbidity levels in distinct layers, as evidenced by differences in transparency and turbidity at various depths. Van Hall and Lürling (2003) reported that at the upper eight meters (epilimnion) the water has a vertically Secchi depth of 3 to 4 meters and a turbidity between 2 and 4 NTU (Nephelometric Turbidity unit). However, the horizontal Secchi depth at depths larger than 14 meters (hypolimnion) is often lower than 0.5 meters with a turbidity between 8 and 24.5 NTU (Van Hall and Lürling, 2003). This are too low transparencies for diving activities.

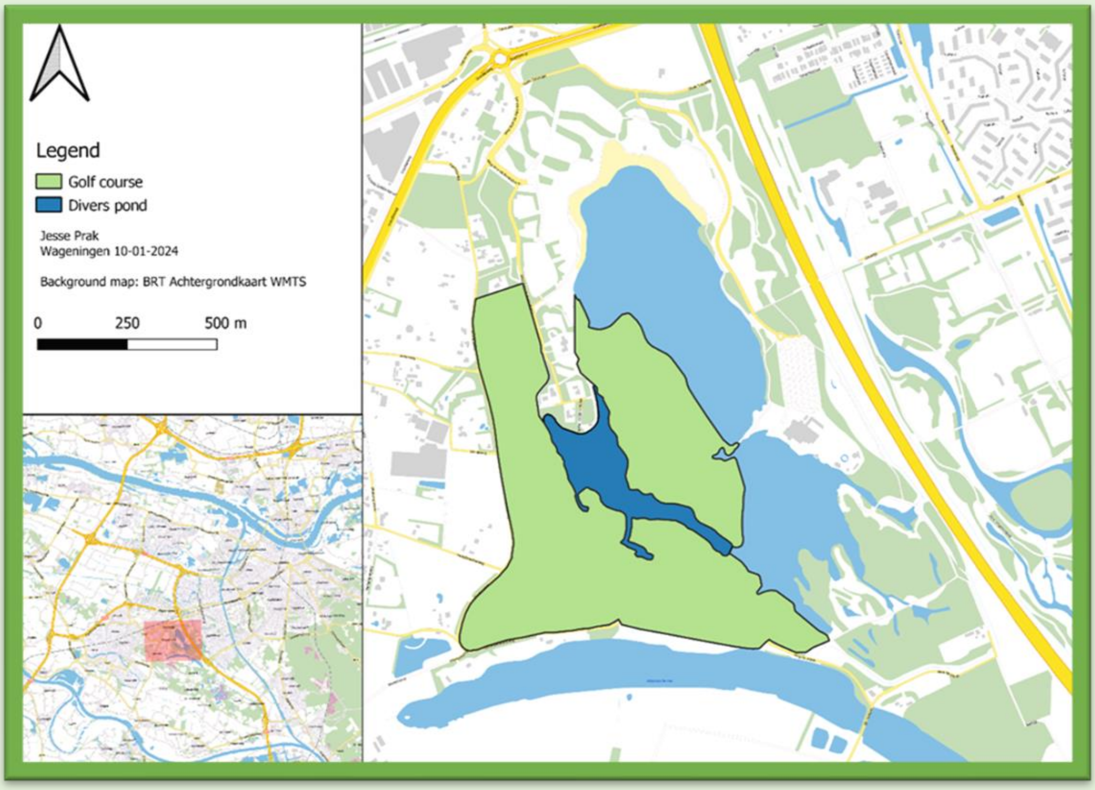

Figure 1 Recreation park the Berendonck

Van Hall & Lürling (2003) identified cyanobacteria as the main cause of turbidity in the epilimnion, while in the hypolimnion, insufficient sunlight limits algae growth. Here Van Hall and Lürling (2003) reported that resuspension and sediment focussing are the main causes of turbid water. Nutrient enrichment, potentially from sources like golf course drainage, could enhance algae blooms. Anthropogenic activities, such as diving movements and underwater house aeration, are reported to be major contributors to resuspension. Sediment focussing, transporting sediment to deeper parts like where the underwater house is located, could also increase turbidity (Hilton et al., 1986; Blais & Kalff, 1995). Various measures, including dredging and coagulant application, are general suggested measures to mitigate turbidity, though their efficacy in the divers pond is uncertain. Furthermore, it is not known if the current situation in the divers pond is similar to the situation in 2002/2003 on which Van Hall and Lürling (2003) data and conclusions are based.

Transparency

The transparency of the water is determined by both internal and external factors. The external factor is the irradiation of light that reach the water surface. The amount of light that reach the water surface depends on the cloudiness, shadows, waves and the angle of incidence. (Zaal, 2002; Van Hall & Lürling, 2003). When the light enters the water it could be either absorbed or scattered (Krik, 1994; Bohren & Hufmann, 2004). With adsorption the light disappeared where by scattering the light moves into an another direction. These mechanism are determined by the ‘’water itself, algae (phytoplankton), detritus, humic acids and inorganic suspended matter’’ (Van Hall & Lürling, 2003). The amount of the transparency of a fluid (water) could be expressed as the turbidity.

Coagulants

Coagulation is one of the major processes in (waste) water treatment (Jiang, 2015). In water treatment the process of coagulation is often combined with flocculation (Tzoupanos & Zouboulis, 2008; ChemReady, 2023). The objective of these two processes is the elimination of particulate impurities, particularly non-settleable solids or algae , from the water (Iwuozor, 2019) . Coagulating chemicals are designed to remove non-settleable particles in water. During the coagulation process, chemicals are introduced to induce initial destabilization of particles, causing them to clump together. Due to flocculation these particles form larger particles, which are called flocs (Santos et al., 2013; Jiang, 2015). These flocs are able to settle out of the water column. (Iwuozor, 2019). The coagulants/ flocculants that are discussed in this report (aluminium sulphate, poly aluminium chloride and chitosan) function of both as coagulant and flocculant (Renault et al., 2009; RX Marine international, n.d.). To give these one term these chemicals are described as coagulant in this report.

The application of coagulants proves to be an effective method for enhancing the water quality by reducing the turbidity, chlorophyll-α and the chemical oxygen demand of the water (Jiang & Graham, 1998; Miranda et al., 2017; Hoko et al., 2021; Shawal et al., 2023). Coagulants can be inorganic like aluminium sulphate (alum) & poly aluminium chloride (PAC), or organic like chitosan. (Jiang & Graham, 1998; Nozaic et al., 2001; Cheng et al., 2005; Gebbie, 2006). Inorganic coagulants can lower the pH of the water (Gebbie, 2006). The decrease in pH in the water depends on the alkalinity of the water, the type of coagulant and the dosage of the coagulant (Gebbie, 2006; Hoko et al., 2021; Shawal et al., 2023). The studies of Hoko et al. (2021) and Shawal et al. (2023) showed that alum has a stronger influence on the pH compared to PAC.

While coagulants can lower pH, it is important to note that the initial pH of the water also plays a crucial role on the effectiveness of coagulants. At lower pH levels (<6) aluminium based compounds can cause toxic effects for fish and macrofauna (Sarvala & Helminen, 2023). On the other hand, at a high pH (>8 – 8.5) aluminium could be mobilized from the sediment and release phosphate (Reitzel et al., 2013). Therefore, the most effective pH range for coagulation is for alum and PAC between 6 and 8 (Klute & Hahn, 1994; Ma et al., 2015). However, it should be noted that a rapid fluctuation in pH could harm the aquatic environment (EPA, 1986). To avoid a to large pH decrease a buffer compound like $Ca(OH)_2$ could be used in combination with a coagulant (Lürling & Van Oosterhout, 2013).

The advantage of chitosan in comparison with alum and PAC is that it is biodegradable (Bolto and Gregory., 2007; Renault et al., 2009; Lürling et al., 2017). However, chitosan is also not effective at higher pH- (>8) and alkalinity levels (Lürling et al., 2017). A disadvantage of chitosan is that it is multiple times more expensive than alum and PAC (Lürling et al., 2020). Furthermore, there is some discussion about the toxicity of chitosan. Some studies (e.g. Renault et al., 2009; Yang et al., 2016) claimed that chitosan is an environmental friendly, non-toxic coagulant. However, Mucci (2019) found that ‘’chitosan was able to cause cyanotoxins release’’. These cyanotoxins could be both toxic for the aquatic life and humans (Funari & Testai, 2008; Banerjee et al., 2021; EPA, 2023).

Application of ballasts

Positively buoyant cyanobacteria could accumulate at the surface of the water after the application of a coagulant (Lürling and Van Oosterhout 2013; Miranda et al., 2017; Lürling et al., 2020). To avoid this, a ballast could be added to water. The ballast should be added before the addition of the coagulant so once the flocs are formed due to the addition of the coagulants, the ballast will make the flocs heavier, causing the cyanobacteria to sink to the bottom (e.g. Waajen et al., 2016; De Lucena-Silva et al., 2022). Materials such as soils and clays (e.g. bentonite, zeolite) could be used as a ballast in water systems (Lürling et al., 2020). Another advantage of these ballasts is that they increase the sediment stability (Egemose et al.,2010, Yin et al.,2016) which (partially) avoid recolonization of cyanobacteria due to resuspension (Lürling et al., 2020). Therefore, a combination between the addition of a coagulant and ballast is an effective technique to enhance the water quality especially in deep (stratifying) waterbodies (e.g. Pan et al., 2006; Lürling et al., 2020).

Water system analysis

There are no lakes that have exactly the same characteristics (surface, depth profile etc.) (Van Liere & Gulati, 1992; Mucci, 2019). Before adding coagulants and/or ballast in a waterbody to restore the water quality it is important to conduct a proper system analysis (Lürling et al., 2020). Firstly, it is important to take the waterbody characteristics in consideration. For example, shallow waterbodies with a long fetch are susceptible for resuspension (Scheffer et al., 2003; Cavalcante et al., 2021). In this case a coagulant and ballast application will be not effective, because flocks can easily resuspended to the water column (Lürling et al., 2020). Also bottom feeding fish like carp and bream can increase this effect resulting in even more resuspension (Breukelaar et al., 1994; Scheffer et al., 2003).

Furthermore, it is important what the cause(s) are of the poor water quality (e.g. eutrophication). An important aspect is if the main nutrient load is coming from an internal or an external source (De Magalhães et al., 2018; Lürling et al., 2020). When the external nutrient load is large then the effect of a coagulant would be timewise not effective, therefore it is essential to control the external nutrient inflow first (Lürling et al., 2020). When the internal nutrient loading (i.e. nutrient release from the sediment) is the major part of the nutrient influx, the application of a coagulant and ballast method may be an effective solution (Cavalcante et al., 2021; De Magalhães et al. 2018). A proved effective strategy is the addition of both a coagulant and an absorbent like lanthanum-modified bentonite (LMB) which is also called as Phoslock© what inactivates phosphorus in the sediment by forming a barrier of absorbent material upon the sediment (Lürling et al., 2017 Lürling et al., 2020). This technique is also known as the Flock and Lock methodology.

Relevance

This project aims to assess the efficacy of different coagulants in enhancing the turbidity within the Berendoncks divers pond. Coagulants may possess the ability to bind nutrients and could settle the cyanobacteria, potentially leading to increased water transparency (e.g., Lürling et al., 2020). However, the specific effects of the applied coagulants on turbidity of the water of the divers pond in the Berendonck are not entirely predictable. This study focuses on evaluating the impact of three coagulants aluminium sulfate (alum), poly aluminium chloride (PAC), and chitosan on water turbidity in this pond. Resulting in the following main objective:

Investigating the effectiveness of coagulants and ballasts in decreasing water turbidity from the divers pond in the Berendonck.

Research questions:

- *What are the main causes of turbidity in the divers pond in the Berendonck?*
- *Is the current situation in the divers pond in the Berendonck comparable with the situation in 2002/2003?*
- *What are the effects of three coagulants and two ballast on the water turbidity in the divers pond in the Berendonck?*
- *What is the effect of these coagulants and ballasts on the resuspension of sediment from the divers pond in the Berendonck?*

Hypothesis

Multiple studies have demonstrated that the application of coagulants leads to a reduction in water turbidity and consequently improves transparency (Latha et al., 2022; Ma et al., 2015; Hoko et al., 2021). Findings from Zaal (2002) and Van Hall and Lürling (2003) indicate that the water in the upper eight meters of the divers pond in the Berendonck typically exhibits turbidity levels ranging from 1 to 4 NTU. Hoko et al. (2021) investigated the efficacy of alum and PAC in Lake Chivero, Zimbabwe, and found that their addition reduced water turbidity from 3.5 NTU to 1 NTU.

Furthermore, Daryabeigi Zand and Hoveidi (2015) and Hoko et al. (2021) demonstrated that PAC outperformed alum in turbidity removal. Additionally, Miranda et al. (2017) showed that PAC was more effective than chitosan in cyanobacteria removal. However, Noyma et al. (2016) found no significant difference between PAC and chitosan in cyanobacteria removal. Consequently, it is expected that all three coagulants tested (PAC, alum and chitosan) reduce turbidity in the water column and the expectation is that PAC and chitosan perform better than alum in turbidity reduction.

Moreover, studies by Lürling et al. (2020), Lürling and Van Oosterhout (2013), and Miranda et al. (2017) revealed that positively buoyant algae tend to accumulate at the water surface after the addition of coagulants. These studies utilized a ballast to facilitate algae sinking to the bottom. Consequently, a lower dosage of a coagulant is needed to let algae sink to the bottom. Therefore, it is expected that without a ballast compound, a larger dosage of a coagulant is required to let algae sink to the bottom.

Furthermore, Egemose et al. (2010) and Yin et al. (2016) showed that a ballast compound (Phoslock©) could enhance the sediment stability. In addition, Egemose et al. (2010) showed that the addition of aluminium flocs solely decreased the sediment stability. Consequently, the expectation is that when a ballast compound, which a higher density, atop the sediment will confer greater resistance to disturbances compared to the sediment from the Berendonck. Furthermore, the expectation is that application of a coagulant solely makes the sediment more susceptible to a disturbance, because flocs with a lower density resuspend easier (Egemose et al., 2010).

The expectation is that the possible causes of turbidity (nutrient enrichment, sediment focusing and diving activities) in the divers pond mentioned by Van Hall and Lürling (2003) still apply. However, due to sediment accumulation in those 20 years the sediment layer in the divers pond is possibly thicker than in 2002/2003. Therefore, the nutrient concentration could be higher in the divers pond. Furthermore, the resuspension of sediment at the bottom could be larger, due to the fact that the underwater house is closer to the water bottom. What could lead to an increased turbidity.

2. METHODOLOGY

This thesis contains out of three parts. The main part is to determine the effect of the coagulants on the water quality and sediment stability in the divers pond in the Berendonck. This part is conducted in different experiments. Secondly, a problem diagnosis about what the causes are of the turbidity in the divers pond is conducted. Third, developmental research is conducted where the water quality in the divers pond in 2023 and 2024 is be compared with the water quality in 2002 and 2003.

2.1 FIELD SAMPLING

Figure 2 illustrates the sampling points. Point A refers to the location where samples were taken from the divers pond (project area) at depth intervals of two meters. Sampling point B refers to the location where samples were taken on 23 April 2024 from the adjacent lake. The measurement locations A and B where entered with a boat. From this boat the water, seston and sediment were sampled. The points P1, P2, P3 and P4 refer to the ponds on the golf courses that were sampled on 12 June 2024.These samples were taken from the shore with an bottle attached to a stick where the top 30 centimetres of the water where sampled. After fieldwork, all the samples were transported the AEW laboratory at the Campus in Wageningen and stored in a dark fridge at 7 ˚C to be processed the following day.

Seston sampling

On 4 march 2024 the seston was collected with a phytoplankton net (mesh size 65 µm) at the upper 30 centimetres of the water column. These samples were used for the coagulant experiment. This was done to artificially create an extreme situation with higher turbidity what could occur in the divers pond. Before sampling the concentrated seston, the net was rinsed with pond water. This was done by filling and opening the tap at the end of the phytoplankton net. This was done three times before sampling. Subsequently, the tap was closed, and the seston was collected by horizontally moving the net deeper into the water column and bringing it to the surface, back and forth through the sampling point (Tuney & Maroulakis, 2013). After sampling, the concentrated water was stored in a 10 litre jerrycan and transported to the laboratory where the water was filtered again using a mesh size of 180 µm that filtered out most of the zooplankton and other larger particles.

Figure 2 Overview sampling points

Sediment sampling

The sediment was sampled at two different days. The first resuspension experiment took place on 4 March 2024. For this experiment samples for the coagulant-ballast resuspension experiment were collected. This sediment was sampled with a sediment grabber which grabs approximately the top 7 centimetres of the sediment. After sampling, the sediment was stored in three 10 litre buckets and transported to the laboratory. The samples for the second resuspension experiment where taken on 23 April 2024. For this experiment both samples from the top 7 centimetres sediment and original sediment where taken. The top sediment was collected with the sediment grabber. These samples where used for the control treatment and the treatment where PAC was injected into the sediment. In addition, the original sediment was sampled with the UWITEC sediment sampler. The original sediment that was sampled was sliced from the overlying sediment and putted in a separate bucket. These samples where used for a resuspension experiment with original sediment.

In-situ measurements

The water quality parameters pH, electronic conductivity (EC) and oxygen were measured on location. During fieldwork water measurements were conducted vertically in intervals of one meter below the water surface to the water bottom as outlined by Van Hall & Lürling (2003). The pH and conductivity were measured with the WTW-pH/cond 340i device and the oxygen and temperature measurements took place with the HACH HQ40d multimeter.

The light at different depth in the water was measured with two LI-250A light meters. During measuring, the light at the water surface was measured with one light meter. With the other light meter, the light was measured at depth intervals of one metre reaching from the water surface until 9 metres depth.

Water sampling

Water samples were taken on 4 March 2024, 23 April 2024 and 12 June 2024. The water that was sampled on 4 March and 23 April was used for the coagulant, ballast and resuspension experiments. Furthermore, the water samples were used for further analysis (see Section 2.2). For the experiments, water samples were taken from different stratification layers of the pond. On 4 March 2024 the pond was not completely stratified. Therefore, water from different depths ranging from 0 to 16 meter were collected for the experiments. Furthermore, an extra two litre bottle was filled with natural water in intervals of two meters to bring to the laboratory for turbidity, chlorophyl-α and humic acid analysis. On 23 April 2024 the pond was stratified. This time water samples for the experiment were taken from both the epilimnion as the hypolimnion, as well as water for other measurements (see Section 2.2).

2.2 LABORATORY MEASUREMENTS

The parameter turbidity, chlorophyll-α, nutrient, Dissolved Organic Carbon (DOC), Suspended solid and nutrient concentration were measured in the AEW laboratory. These measurements were taken from water samples collected from the water samples taken in two litre bottles in intervals of two meters, as outlined in the fieldwork section.

Chlorophyll-α

The chlorophyll-α was measured with the PHYTO-PAM ED in the laboratory as outlined by Miranda et al. (2017) and De Magalhães et al. (2018). This device measured the chlorophyll-α contribution of blue, green, and brown – algae (Maliaka et al., 2018). The total chlorophyll-α concentration was calculated with the sum of the chlorophyll-α concentrations of blue-, green- and brown algae.

Turbidity

The turbidity was measured with the HACH 2100P turbidity device in the lab from the 2 litre water samples taken in intervals of two meter in water depth.

Dissolved Organic Matter

The dissolved organic (DOM) was used as a proxy to estimate the humic acids in the water. Colored Dissolved Organic Matter (CDOM) is the colourful part of DOM that is measured with a spectrophotometer (STOWA, n.d.). The water sampled used for the analysis was filtered through a 0.45 µm Whatman GF/C glass fibre filter. A fixed wavelength of 380 nanometres was used to measure the light adsorption at 380 nanometres (A380). The amount of DOM (a380) was calculated according to the equation:

$A380 = 2.303 * A380/r$ (Lurling, n.d.)

Where r = The length of the cuvette (0.0125 m in the experiments)

Suspended solids

The suspended solids of both the organic and inorganic fractions were determined from pond water sampled in two meter depth intervals. Initially, two blank samples (bl) were prepared using demi-water. For filtration, Whatman GF/F filters were used. Before the filtration, the filters were placed in an aluminium dish and placed in an oven at 520°C for two hours. Subsequently, these filters were dipped in two glasses of demi-water. Afterwards, the dish containing the filter was placed in a stove overnight at a temperature of 105°C. Next, the aluminium dishes containing the filters were weighed on an analytical balance to measure initial weight (M_0). Subsequently, water from the pond was filtered through the filter. The volume of water filtered ranges from 0.4 to 2 litre, depending on the filtration ease. Additionally, two blank samples of demi-water (bl_0) were prepared.

Once filtration was complete, the aluminium dishes containing the filters were placed in the stove overnight at a temperature of 105°C. After this step, both the aluminium dishes and the filtered samples are weighed on an analytical balance to measure their combined weight (M_d/bl_d). Subsequently, the dishes with filters were placed in an oven at 520°C for three hours. Afterwards, the aluminium dishes were transferred to a desiccator for 30 minutes. After, the aluminium dishes containing the filters were weighed again on the analytical balance to obtain the final weight (M_a/bl_a).

The suspended solids are calculated as follows:

$$DW = \frac{(M_d - M_0) - (bl_d - bl_0)}{V} \quad \text{and} \quad AW = \frac{(M_a - M_0) - (bl_a - bl_0)}{V}$$

The ash free dry weight (AFWD) was calculated by subtracting the ash weight (AW) from the dry weight (DW).

2.3 EXPERIMENTS

The aim of these experiments were to investigate the effectiveness of the coagulants aluminium sulfate (alum), polyaluminum chloride (PAC) and chitosan on the water quality and sediment resuspension from the divers pond in the Berendonck.

Section 2.1 describes how the samples that were used in these experiments were collected. The coagulant and the ballast experiments were conducted four times in total. This involves using natural water samples collected on 4 March 2024 under non-stratified conditions, as well as samples obtained on 12 July 2024 from both the epilimnion and hypolimnion layers. Furthermore, the experiment were conducted with artificial water which contains a chlorophyll-α concentration that is approximately five time higher than the natural water samples.

Coagulant experiment

The aim of this experiment was to test the effect of the coagulants in decreasing chlorophyll-α and turbidity. The coagulant experiment was conducted with both natural water, and with seston concentrated water. The seston was sampled during the fieldwork at 4 March (see seston sampling in the section Fieldwork). The concentrated water contained a chlorophyll-α concentration that was five times higher than the chlorophyll-α concentration in the natural water. This was done to mimic an extreme condition in the divers pond.

The experiments took place in March and in May 2024. The experiment in March includes the application of alum (KEMIRA), PAC (Caldic - calflock P-14. 1.33 g/cm^3, 7.2% Al) and chitosan which is made from crab cells (SIGMA- ALDRIC). The coagulant experiment in May was conducted with natural water with water from both the epilimnion as the hypolimnion. In these experiments only the coagulant PAC was applied.

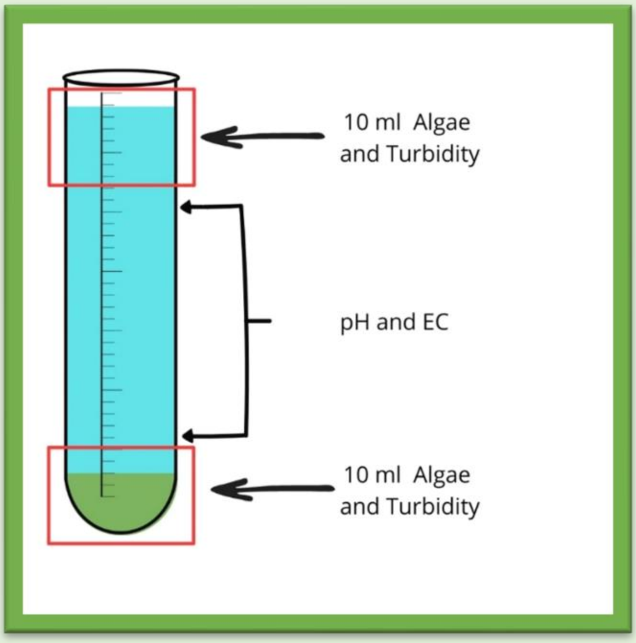

Figure 3 Sampling points in tube (illustration made in Canva)

The coagulant experiments are conducted with six different dosages (see Table 1) and with two different stagnation times namely 2- and 24 hours. Each dosage and time combination for both natural and concentrated water was conducted in triplicate.

After adding 100 ml of pond water in a glass tube, the coagulants were added to the tubes. The dosages of each coagulant is displayed in Table 1. Prior the application, the chitosan is acidified by 200 µl of 96% acetic acid to 200 mg chitosan in 40 ml of milli-Q water as reported in Mucci (2019).

Furthermore, three tubes served as a control group where no coagulant was applied. Intermediate after dosing the substance, the tubes were mixed using a spoon. After mixing, half of the tubes were kept stagnant for two hours the other half kept stagnant for one day. After this time, pH, turbidity, EC, and chlorophyll-α concentration were measured. Based on these measurements the chlorophyll-α and turbidity removal is calculated. This is done by dividing the chlorophyll-α concentration or turbidity level in the top of the tube after application of a coagulant by the chlorophyll-α concentration or turbidity level in the top of the tube of the control groups.

The algae (chlorophyll-α & yield) and the turbidity were measured from 10 ml samples from both the top as the bottom of the tube (Figure 3). The pH and EC were measured from the middle of the tube as illustrated in Figure 3.

Table 1 Dosages coagulants for the coagulant experiment in March

Coagulant	Dosages	Source(s)
Alum	1, 2, 4, 8, 16, and 32 mg Al/l	(Cruz et al., 2020; Dawah et al., 2015; Hoko et al., 2021; Hoko & Makado, 2011)
PAC	1, 2, 4, 8, 16, and 32 mg Al/l	(Hoko et al., 2021 ;Miranda et al., 2017 Noyma et al., 2016; Pan et al., 2011)
Chitosan	1, 2, 4, 8, 16, and 32 mg /l	(Li & Pan, 2013; Miranda et al., 2017; Noyma et al., 2016; Pan et al., 2012; Pan et al., 2011)

Ballast experiment

Lürling et al. (2020), Lürling and Van Oosterhout (2013) and Miranda et al. (2017) found that positively buoyant algae accumulate to the water surface after adding coagulants. To avoid this phenomenon different doses of Dutch Zeolite and Phoslock$^{©}$ (Lathanum modified bentonite) were used. The used dosages in this experiment were 50, 100, 200, and 400 mg/l Zeolite or Phoslock$^{©}$. These dosages were based on previous studies (De Magalhães et al. 2018; Lürling et al., 2020; Lürling & Van Oosterhout, 2013; Spears et al., 2013). In addition, in every sample 2 mg/l PAC was applied as a coagulant.

The methodology for this experiment closely follows the same methodology as the coagulant experiment, with the exception that the ballast was added to the tubes before the coagulant. Additionally, the water quality parameters measured include pH, turbidity, EC, and chlorophyll-α. The experiment in March was conducted with both Zeolite and Phoslock$^{©}$. The experiment in May was conducted with only Phoslock$^{©}$.

Resuspension experiment

In total two resuspension experiments were conducted. The first experiment was conducted with sediment that was collected during the fieldwork on 4 March. The purpose of this experiment was to determine the effect of the coagulants and ballast on sediment resuspension. The purpose of the second experiment was to determine the resuspension susceptibility at different sediment layers and the susceptibility of sediment injected with PAC. Both resuspension experiments were conducted in triplicates, except the treatment with original sediment in the second resuspension experiment. This treatment was only conducted singularly.

The experiments were conducted in transparent cylinders with a diameter of 150 mm and a height of 450 mm. Seven centimetres of the cylinder were filled with sediment. So, in total approximately 1.8 litre of wet sediment was added in each cylinder. After, two litre of natural water was added to the cylinder. Next, the sediment and water was kept untouched for eight days. After, the ballast was applied followed by the coagulant. In the cylinders with a ballast treatment, 40 grams of Phoslock$^{©}$ was added to the water surface in each tube. This dosage was based on multiple studies (Egemose et al., 2010; Rydin, 2000; Waajen et al., 2016; Yin et al., 2016). Furthermore, 2 mg/l PAC was added to the water surface in cylinders assigned to a coagulant treatment. This dosage was based on the coagulant experiments previously done. For the treatment where the coagulant was inject in the sediment 68 g Al/ m^2 was added with a needle in the sediment. This dosage was based on the study of Schütz et al. (2017). After these applications, the cylinders kept stable for three days. After these days, the treatments were exposed to a disturbance using a hydrocopter.

After this disturbance, the cylinders kept stable for an another 8 days. After, the treatments were exposed to a second (similar) disturbance. During these days the turbidity of the water surface was monitored.

During the experiment a hydrocopter was used to mimic a disturbance. In Figure 4, the setup hydrocopter is displayed. It contains a lamp *(1)* and light sensor *(2)* on both sides of the cylinder. The flow velocity was simulated with two rotatable blades placed approximately 5 cm above the sediment *(3)* driven by an electromotor *(4).* In the middle of the cylinder a smaller tube is placed (diameter 60mm) to create a laminar flow. The top point of the tube protrudes just above the water surface

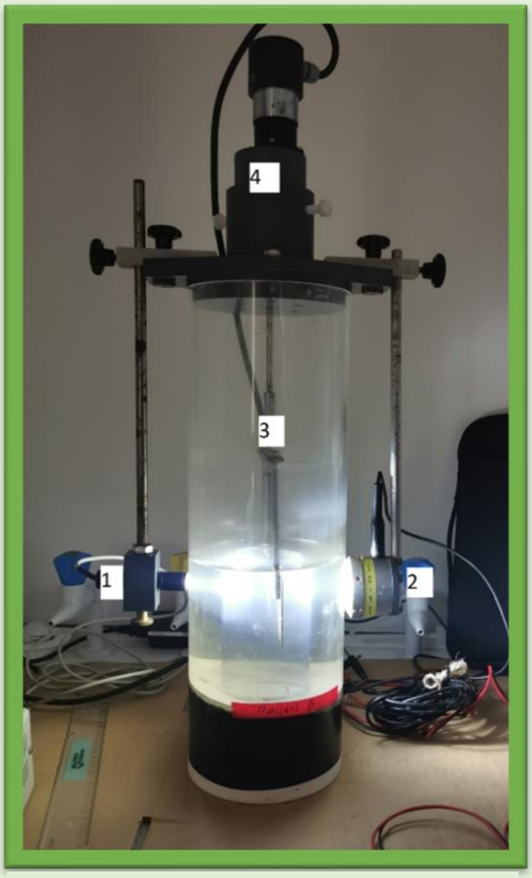

Figure 4 Setup hydrocopter

The electromotor is supplied by a power supplier which can supply power in a range between 1.5 and 12.5 voltage. The power was adjusted in steps of 0.5 V with time intervals of 2 minutes till the maximum speed was reached (12.5 V). During the experiment both the light intensity and the power was measured every second. For the light intensity, the maximum light value at every ten seconds was stored in the Squirrel data logger. For the power the average at every ten seconds is stored in this datalogger.

After the experiment, the collected data was displayed in a line graph where the light intensity index (compared with the light intensity at the start of the experiment) is displayed on the y-axis. On the x-axis the flow velocity is displayed. The flow velocity was determined by a calibration line (see Appendix I). In this calibration line the voltage were correlated with the rounds per minute (rpm) of the rotor.

To determine the rpm of the rotor blades, the amount of rounds were counted for a minute at intervals of 0.5 V. Subsequently, to calculate the velocity of the water the rpm was multiplied by 0.35 m which is equal to the average distance that the water flows around the 60 mm tube. Here, it was assumed that the velocity of the rotor blades is equal to the water velocity. Next, the calculated velocity (m/s) was correlated with power (V) the slope of the line was used to recalculate a measured power into a velocity.

Densities sediment and Phoslock$^{©}$

During the experiment, the wet densities of the sediment were measured at both the start and the end of the experiment. This is done by collecting a volume of 10 ml of wet sediment with a syringe. Subsequently, the wet weight of the sediment was measured on an analytical balance. The density was determined by dividing the weight of the sediment by the volume of the sediment (10 ml). The wet density of Phoslock$^{©}$ was determined by putting 10 g (dry weight) of Phoslock$^{©}$ in a beaker glass with 100 ml pond water. After 16 hours 10 ml of Phoslock$^{©}$ was collected and weighted on an analytical balance.

The samples taken from the sediment after the experiments were taken with a spoon from the top 3 centimetres of the sediment layer.

Statistical tests

Statistical tests were employed to assess potential differences in water quality parameters among different coagulant dosages, ballast groups, and the control group. Analysis of Variance (ANOVA) were conducted to determine these differences. Subsequently, post-hoc Tukey tests were employed to identify specific statistical differences in water quality parameters between individual coagulant dosages or ballast levels, as well as to compare each dosage or ballast level with the control group. To ensure the validity of the analysis, normality of the residuals are checked using QQ-plots, and the homogeneity of variances is verified using Levene's test.

When the data does not meet these assumptions Wilcoxon (signed) rank tests were applied. All tests were conducted with a significance level (α) of 0.05 and conducted in RStudio software.

To determine significant differences in turbidity levels after a resuspension event within and between treatments in the resuspension experiments the Friedman test (to test significant differences within treatments) and Dunn (1964) Kruskal-Wallis multiple comparison tests (to test significant differences between treatments) are conducted. The p values are adjusted following the Bonferroni method.

2.4 SYSTEM ANALYSIS AND PROBLEM DIAGNOSIS

Besides the experiment, a water system analysis in the divers pond was conducted. This analysis has two purposes. The first purpose was to compare the current state of the water quality with the situation in 2002/2003, reported by Van Hall and Lürling (2003). The second purpose was to conduct this analysis to determine the main sources that cause the turbidity and enhanced nutrient concentrations.

For the water system analysis, the water quality parameters that were measured during the field- and laboratory work (see Section 2.1) were analysed on their values at different depths and different time points. Furthermore, the water quality data from Vieira Neto de Rolan Teixeira (2024) was gathered from November 2023 to January 2024. This data was plotted in a time- and depth plot similar to the plots in Van Hall and Lürling (2003) where the x- axis represents the time of the year, the y-axis the depth of the pond and the colour the value of the water quality parameter (see Appendix IV).

Analysis of the main causes of turbidity

To analyse the main causes of turbidity in the Berendonck the results of the water quality parameters humic acids, detritus, ash weight, and chlorophyll-α were analysed to determine which parameter causes the turbidity. The results of these parameters were filled in the Onderwaterlicht Module which used the model UITZICHT (STOWA, 2015) to calculate the contribution of these parameters to the total turbidity (see Appendix III). During fieldwork the light intensity at different depths and the Secchi depth were measured on 23 April and 12 June to check if the practical situation was comparable with results from the model . Additionally, the extinction coefficients (Kd) were calculated by plotting the light intensities at different depths (see Appendix V) and compared with the modelled extinction coefficients.

3. RESULTS

3.1 RESULTS WATERSYSTEM

This subsection revealed the results (see Appendices III and IV) of diverse parameters in the divers pond in the Berendonck. The first subsection describes the results that were taken during fieldwork. For these results, data from my own fieldwork and fieldwork that was conducted by Vieira Neto de Rolan Teixeira (2024) on 23 November, 12 December and 25 January were used. In the second subsection, the causes of the turbidity are determined. The third subsection compares the data which is gathered in this research with the data of Van Hall & Lürling (2003) who gathered data of the divers pond in 2002 and 2003. Section 3.4 describes the results of the coagulant- and ballast experiment. Section 3.5 describes the results of the resuspension experiments.

Oxygen

The oxygen concentration over the depth and time in the divers pond ranges from 0.22 to 12.78 mg/l. During fieldwork in November and December 2023, the average oxygen concentration in the top 8 meters was 4.91 (*SD* = 0.31) mg/l. On 25 January 2024 , the concentration increased to an average of 8.05 (*SD* = 0.06) mg/l in the top 8 meters. In almost each month, oxygen concentrations were notably lower in the deeper parts of the pond compared to the shallower regions, with measurements below 1 mg/l near the bottom. An exception was observed on 25 January 2024, when the oxygen concentration was relatively uniform throughout the entire depth of the pond.

More detailed information is provided in Figure 25 in Appendix IV .

Temperature

The water temperature in the pond generally decreases over depth. On 12 December 2023, and 25 January 2024, the temperature drop from the surface to the bottom was approximately 0.5°C. On other dates, the temperature decrease was larger , with temperature decreases of 3.6°C at 11 November 2023 , 3.2°C at 4 March 2024, 5.8°C at 23 April 2024, and 11.1°C at 12 June 2024.

Based on this results we can identify that the divers pond was stratified in the period between the end of November 2023 and February 2024. More detailed information is provided in Figure 26 in Appendix IV.

Electronic conductivity (EC)

The EC of the pond was between 370 and 463 µS/cm with an mean of 395 (*SD*=20.8) µS/cm. The results in Appendix IV reveals that the EC is higher in the deeper parts of the pond compared to the shallower parts. Furthermore, the EC was higher on 23 April 2024 compared to the other sampling dates.

More detailed information is provided in Figure 24 in Appendix IV.

Chlorophyll-α

Figure 5 shows the chlorophyll-α concentrations in the pond at various depths and dates. On 4 March 2024, the chlorophyll-α concentration peaked at 26.83 µg/l near the surface and 10.02 µg/l near the bottom. Subsequently, the concentration declined to between 5.56 µg/l (bottom) and 9.41 µg/l (surface) on 23 April 2024. On 12 June 2024, the concentration increased to 14.03 µg/l at the surface. During the winter period (November to January), chlorophyll-α concentrations were lower, ranging from 0 to 2.5 µg/l. The data is provided in Appendix IV.

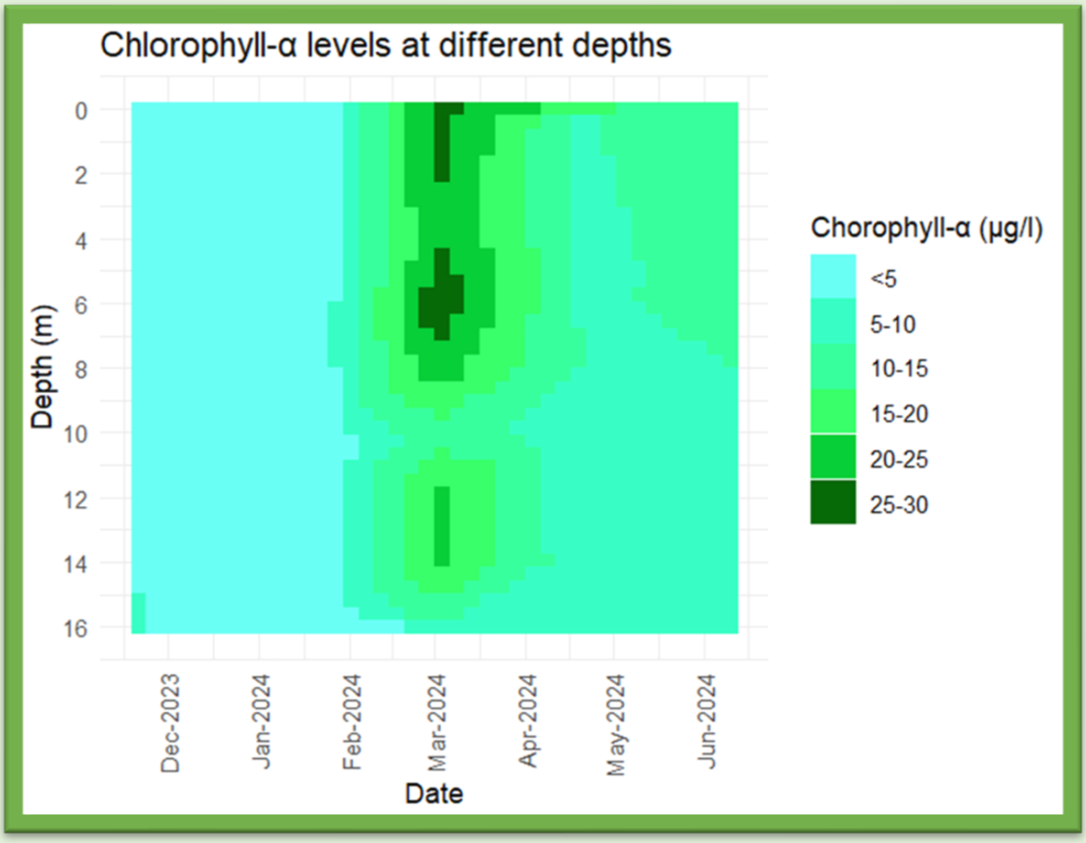

Figure 5 Chlorophyll-α concentration of the divers pond at different depths and dates.
Sampled at : 23-11-2023, 12-12-2023, 25-01-2024, 03-04-2024 , 23-04-2024 and 12-06-2024

pH

The pH of the divers pond varies between 6.6 and 8.16. On November 2023 the lowest pH was measured. At this date, the pH at the water surface was 6.6 and increases over depth until a pH of 7.22 was measured around the bottom of the divers pond at 16 meters depth.

In the period between 12 December 2023 and 4 March 2024 the pH was on average 7.55 (*SD*= 0.08). On 23 April the highest pH was measured. The pH measured at the water surface was 8.16. Over depth the pH decreases until 7.85 measured around the bottom of the divers pond. The pH measured on 12 June varies between 8.12 at the water surface, and 7.6 close to the water bottom.

More detailed information is provided in Figure 23 in Appendix IV.

Turbidity

Figure 6 shows the turbidity in the pond at different depths and dates. The turbidity in the top 12 meters of the water column varies between 1 and 10 NTU. The turbidity of the water column during the fieldwork in March, April and June (2-6 NTU) was higher compared to the turbidity in the water column during the winter period (1- 2.5 NTU). Additionally, the turbidity around the bottom of the pond (>14 m depth) were higher compared to the turbidity in the shallower regions of the pond. The turbidity levels around the bottom rose until turbidity levels of 36.3 NTU.

The data is shown in Appendix IV

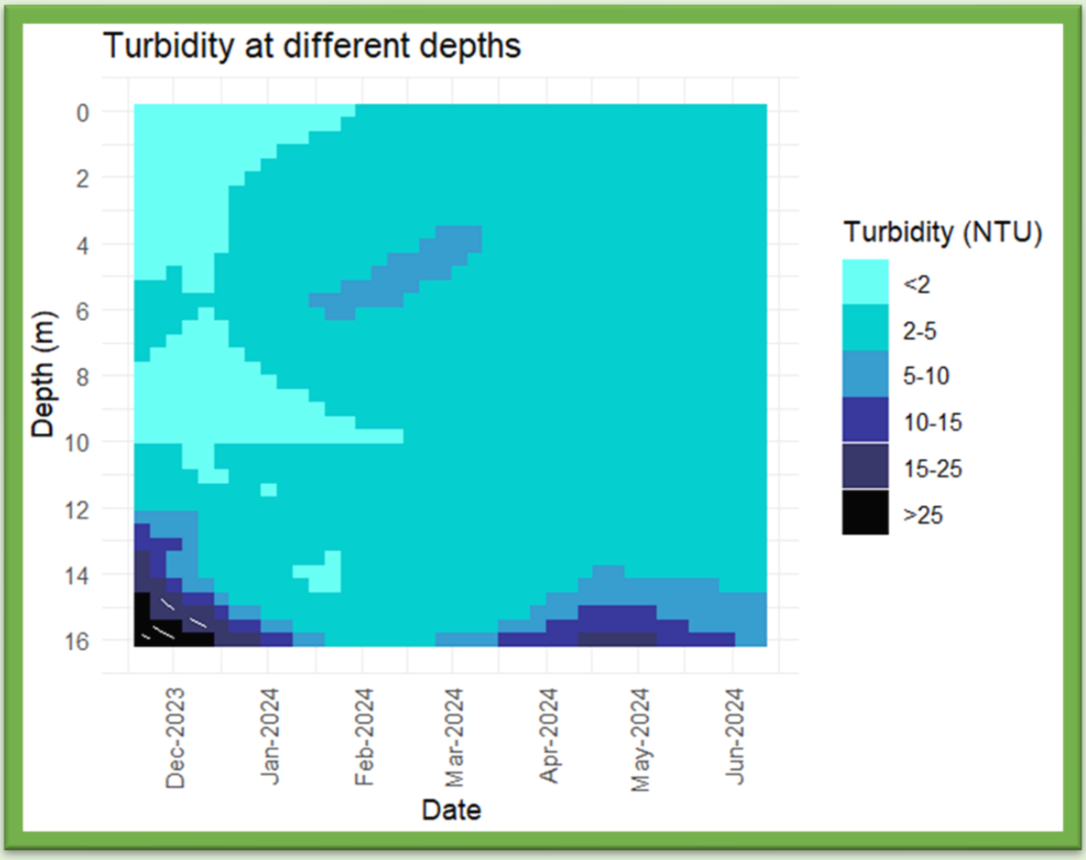

Figure 6 Turbidity of the divers pond at different depths and dates.
Sampled on : 23-11-2023, 12-12-2023, 25-01-2024, 03-04-2024 , 23-04-2024 and 12-06-2024

3.2 CONTRIBUTION TO TURBIDITY

Figure 7 shows the average contribution of the parameters chlorophyll-α, detritus, humic acids and ignition residue to the turbidity over the whole depth of the divers pond. These parameters were measured on 4 March 2024, 23 April 2024 and 12 June 2024. The module ‘Onderwaterlicht’(STOWA, 2015) was used to calculate the contributions displayed in Figure 7.

More detailed information is displayed in Appendix III.

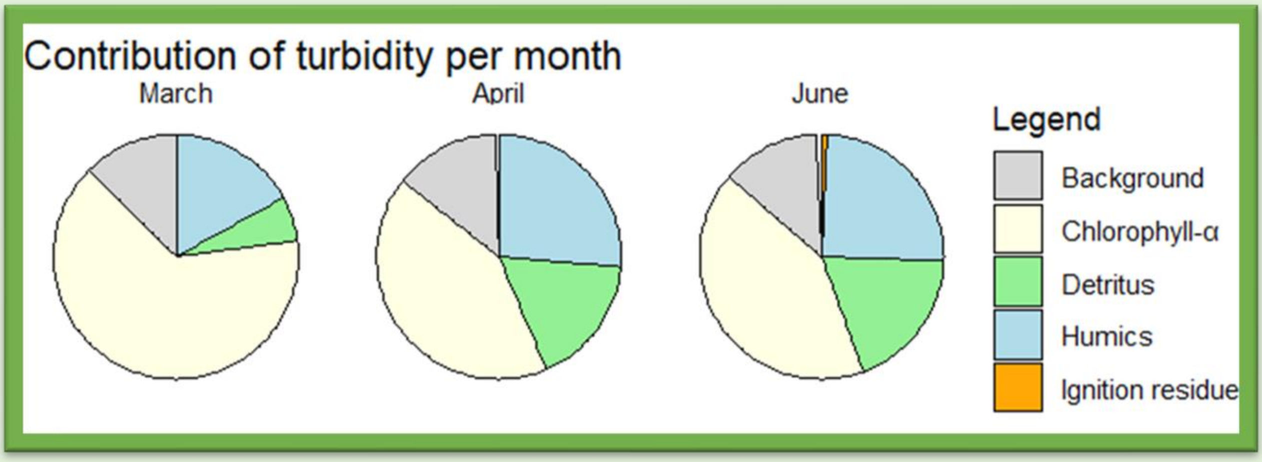

Figure 7 Contribution to turbidity at different dates (4 March 2024, 23 April 2024 and 12 June 2024). Contribution is calculated with the Onderwaterlicht Module (STOWA, 2015)

Figure 7 shows that chlorophyll-α contributes on average the most to turbidity. On 4 March 2024, chlorophyll-α was the largest contributor to turbidity throughout the entire depth of the pond (see Appendix III, page C). On 23 April 2024 (see Appendix III, page D), the contribution of detritus increased with depth, accounting for 10% of the turbidity at the surface and 31% near the bottom. This shift is due to both a decrease in chlorophyll-α concentrations and an increase in detritus at greater depths. On 12 June 2024, chlorophyll-α was the largest contributor to turbidity
(*M*= 42%) down to a depth of 14 meters (see Appendix III, page E). In deeper parts, humic acids and detritus were the primary contributors to turbidity.

Table 2 shows the measured light on 23 April 2024 and 12 June 2024 at various depths. The table also includes the vertical Secchi depths and the calculated extinction coefficients (Kd) for these dates (see Appendix V). Additionally, the results from the Onderwaterlicht module (STOWA, 2015) are presented for these parameters. The calculated extinction coefficients are based on the top eight meters of the water column. This table illustrates that the measured Secchi depth is higher than the modelled Secchi depth. Furthermore, the modelled Kd is higher than the calculated Kd (see Appendix V)

Table 2 Comparison modelled results from (STOWA, 2015) with the measured results

Parameter	23 April 2024		12 June 2024	
	Measured	Modelled	Measured	Modelled
Vertical Secchi depth (m)	3.4	2.49	2.3	1.93
Depth with 10% available light (m)	3.3	3.6	3	2.83
Depth with 4% available light (m)	4.6	4.1	4.2	3.33
Total Extinction coefficient (m^{-1})	0.70	0.78	0.76	0.97

Adjacent Lake

The turbidity in the adjacent lake (point B in Figure 2) ranges from 3.16 NTU at the surface to 1.38 NTU in deeper parts (>8 meters). The chlorophyll-α concentration varies between 4.58 µg/l at the surface and 3.07 µg/L at deeper depths (>8 meters). The average pH of the water is 8.05 (*SD* = 0.05), and the electrical conductivity (EC) averages 387 µS/cm (*SD* = 12.5).

Using the Onderwaterlicht module, the calculated average Secchi depth for this lake is 3.86 meters. During fieldwork, the vertical Secchi depth exceeded 4 meters, which is greater than that of the divers pond. The calculated extinction coefficient (Kd) averages 0.54 m^{-1}, resulting in light availability of 10% at 5.7 meters and 4% at 5.83 meters. Chlorophyll-α is the major factor contributing to turbidity (*M* = 42%, *SD* = 3.7%).

Ponds on the Golf Course

Turbidity in the golf course ponds (points P1 to P4 in Figure 2) ranges from 2.26 NTU (Pond 3) to 11.7 NTU (Pond 1). Chlorophyll-α concentrations vary between 6.74 µg/l (Pond 4) and 53.2 µg/l (Pond 1). The pH varies from 7.63 (Pond 4) to 7.94 (Pond 1), and the average EC is 368 µS/cm (*SD* = 15.7). The average measured dissolved organic carbon (DOC) in these ponds is 6.54 m^{-1} (*SD* = 1.1), while DOC from a drainage pipe releasing water from the golf course into the divers pond is 11.61 m^{-1}.

Using the Onderwaterlicht module, the calculated Secchi depth for these ponds ranges from 0.6 to 1 meter (*M* = 0.92, *SD* = 0.16), which is lower than the Secchi depth of the divers pond. Chlorophyll-α is the main contributor to turbidity in Ponds 1 and 2, whereas humic acids are the main contributors in Ponds 3 and 4.

3.3 COMPARISON DATA 2023/2024 WITH 2002/2003

In this section the fieldwork data from 2023/2024 is compared with the data of Van Hall & Lürling (2003).

Chlorophyll-α

Table 3 shows the average and standard deviation (*SD*) of the chlorophyll-α concentrations measured in different seasons of the year for both 2002/2003 and 2023/2024.

Table 3 Comparison chlorophyll-α concentration in the divers pond data 2002/2003 (Van Hall & Lürling.,2003)
****: Not measured in October 2023, based on results November and December***

Period	2002/2003		2023/2024	
	Average (µg/l)	*SD* (µg/l)	Average (µg/l)	*SD* (µg/l)
January- March	10.2	1.4	11.3	10.96
April - June	6.3	2.8	8.86	3.09
July - September	2.8	0.7	x	x
October - December	5.0	1.0	*2.1	*1.1

Table 3 shows that the chlorophyll-α concentrations in the period from January to June 2024 were on average 1.83 µg/l higher compared to the same period in 2003. Conversely, the concentrations from October to December 2024 are lower compared to October to December 2002. However, it should be noted that no measurements were taken in October 2024, while Van Hall & Lürling (2003) recorded the highest chlorophyll-α concentrations in October 2002 for the autumn period.

Turbidity

The turbidity of the divers pond in 2023/2024 is roughly similar compared to the situation in 2002/2003. In the winter period of 2003, the turbidity was below 2 NTU in the top 10 meters of the divers pond. During the spring in 2003 the turbidity raises up to 4 NTU at this depth. In the deepest parts of the pond, especially deeper than 16 meters the turbidity increases up to levels largen than 25 NTU (Van Hall & Lürling ,2003).

Stratification (oxygen and temperature)

During 2002/2003 the lake was stratified in the period from June 2002 until the end of October 2002. During November, the lake was completely mixed (oxygen concentration and temperature became similar over depth). This situation remained stable until April 2003 when the divers pond starts stratifying. Here the epilimnion got a higher temperature and oxygen concentration compared to the hypolimnion. The non-stratification period in 2023/2024 was shorter. The lake seems only completely mixed in December and January. In November 2023 and March 2024 the epilimnion got a higher temperature and oxygen concentration compared to the hypolimnion. When looking at the temperature, the water in 2002/2003 had in the winter period (November – January) a temperature between 2 and 4 ^{o}C. These are lower temperatures compared to the situation in the winter period in 2023/2024 where the water temperature was between 4.6 and 7.1 ^{o}C

3.4 EFFECTS OF COAGULANTS AND BALLAST ON THE WATER QUALITY

This subsection describes the effects of 2 mg Al/l poly aluminium chloride (PAC) in combination with 50 mg/l Phoslock© on the water quality in the divers pond in the Berendonck. These concentrations are the most efficient in chlorophyll-α removal in the divers pond in the Berendonck while keeping pH and EC values in a safe range. Appendix VI gives an elaborate description of why these concentrations were determined as 'most efficient' for the water in the divers pond in the Berendonck.

Algae

The chlorophyll-α removal in the top of the tube after application of 2 mg Al/l solely varies between 2% and 46% compared to the control group. Generally, the higher the initial chlorophyll-α concentration the higher the (relatively) chlorophyll-α removal in the top of the tube. Figure 8 shows the chlorophyll-α removal in the top of the tube when also 50 mg/l Phoslock© was applied. After this treatment, the chlorophyll-α removal in the top of the tube varies between 3% and 64% compared to the control (*M*=37%, *SD*=17%). Besides the start concentration also the duration of experiment has an influence. A One tailed Paired T-test revealed that the chlorophyll-α removal is greater when sampling after 2 hours (*M*= 50%, *SD*=10%) compared to sampling after 24 hours (*M*=27%, *SD*=14%), *t*(9)=4.48, *p*=<.001

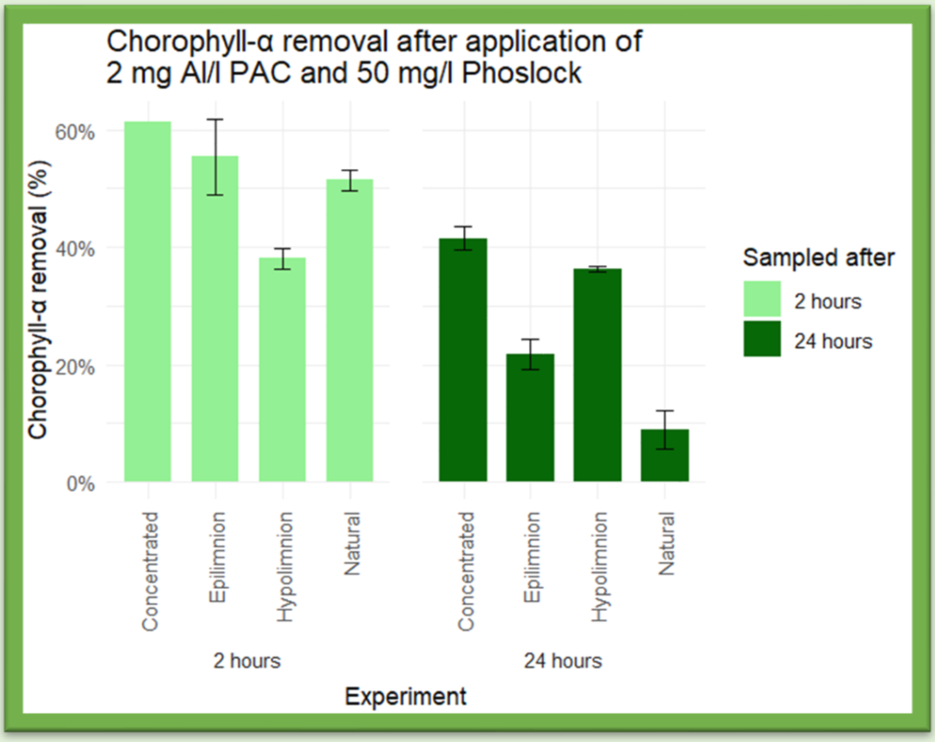

Figure 8 Chlorophyll-α in the top of the tube after application of 2 mg Al/l and 50 mg/l Phoslock© for different experiments in comparison with the control group. The error bars indicate the standard deviation (n=3)

Turbidity

A two-tailed One sided Wilcoxon signed rank test did not reveal significant differences in turbidity levels in the top of the tube between the control treatment (*M*= 2.62, *SD*= 1.29 NTU) and the treatment where PAC and Phoslock© are applied (*M*= 3.95, *SD* = 2.44 NTU), *V*=176, *p*= .113. When testing the turbidity levels in the top of the tube at the two different time periods a One-tailed Wilcoxon Signed rank test revealed significant higher turbidity levels for water treated with Phoslock© and PAC sampled after 2 hours (*M*= 6.36, *SD*= 1.35 NTU) compared to the experiments sampled after 24 hours (*M*= 1.94, *SD*= 0.46 NTU), *V*=55, *p* <.001.

pH

Figure 9 reveals the pH values after applications of the treatments with 2 mg Al/l PAC and Phoslock©, PAC solely and the control treatment. The average pH in the control treatment was 7.97 (*SD*= 0.10). After application of PAC the pH dropped to an average of 7.68 (*SD*= 0.18). A One-tailed paired T-test revealed significant lower pH values for water that was treated with PAC, *t*(21)= -12.9, *p*= <.001. However, a Two tailed paired T-test did not reveal significant differences between the treatment with Phoslock© and PAC and the treatment with solely PAC, *t*(21)= -0.59, *p*= .565.

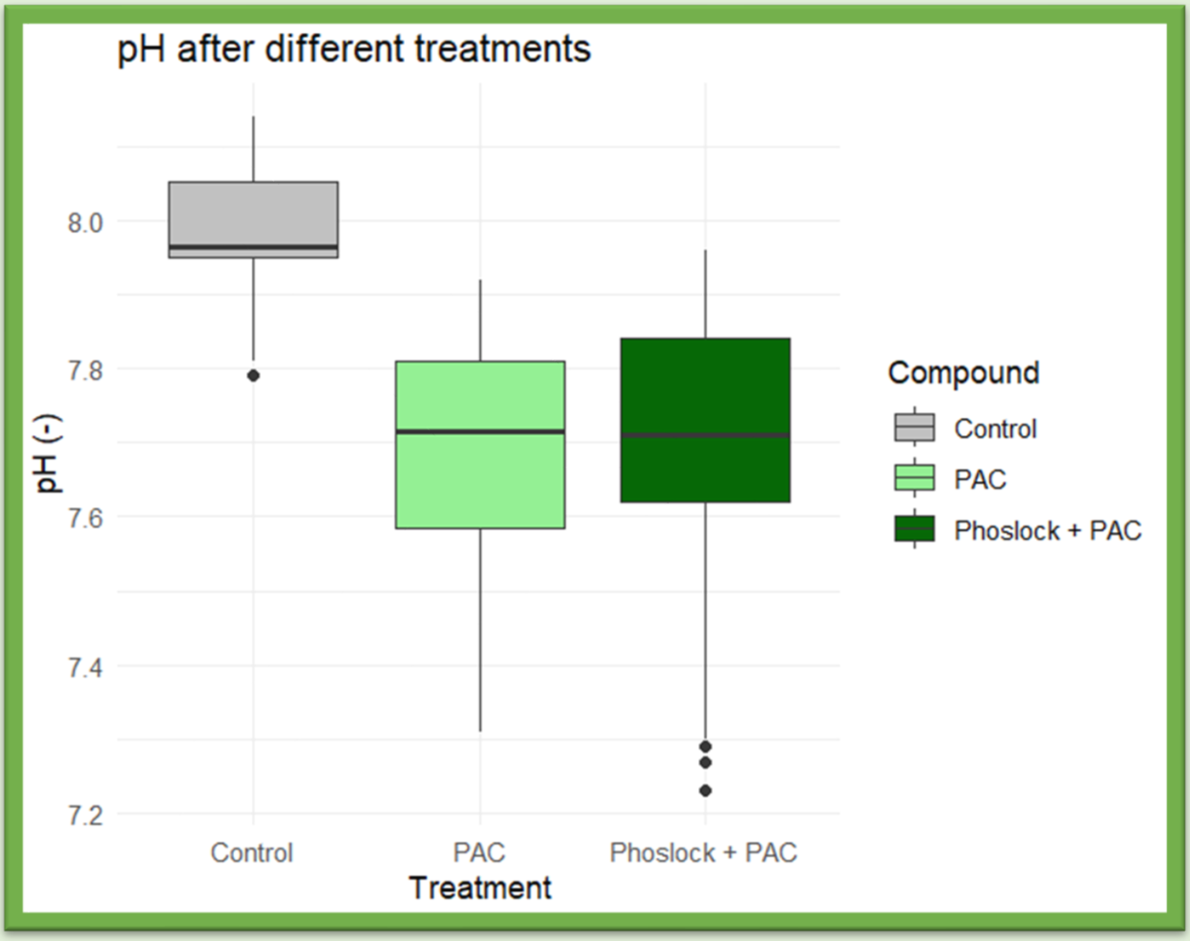

Figure 9 pH after different treatments, Control group, 2 mg Al/l PAC, and 50 mg/l Phoslock© + 2 mg Al/l PAC.

Electronic conductivity (EC)

A One-tailed Wilcoxon Signed rank test revealed significantly higher EC values in water treated with solely PAC (*M*= 433, *SD*= 38.6 µS/cm) compared to the control treatment (*M*= 426, *SD*= 50.6 µS/cm) , *V*= 210, *p*= <.001. However, a two Tailed Wilcoxon Signed rank test revealed no significant differences in EC levels between PAC treatment and the treatment where both 50 mg/l Phoslock© and 2 mg Al/ l PAC were applied (*M*= 431, *SD*= 32.1 µS/cm), *V*= 87, *p*= .330.

3.5 SEDIMENT STABILITY

This section describes the results of the resuspension experiments separately. the first resuspension experiment (Resuspension experiment 1) was conducted with a control treatment, a treatment with 2 mg Al /l PAC , a treatment with 2264 g Phoslock©/ m^2 and a treatment with both PAC and Phoslock©. The second resuspension experiment (Resuspension experiment 2) was conducted with a control treatment, a treatment where 68 g Al/m^2 PAC was injected in the sediment and a treatment with the original sediment of the lake.

Resuspension experiment 1

Figure 10 illustrates how turbid the water was three days after the application of PAC and/ or Phoslock©. This is the situation just before the start of the resuspension experiment. The turbidity of the control (*M*= 13.9, *SD*= 1.41 NTU) and the treatment only applied with Phoslock© (*M*= 11.7, *SD*= 1.84 NTU) is higher than the PAC treatments. The turbidity in the water where only PAC (*M*= 1.8, *SD*= 0.12 NTU) was applied is on average 0.2 NTU higher compared to the water treated with both Phoslock© and PAC (*M*= 1.6, *SD*=0.17 NTU).

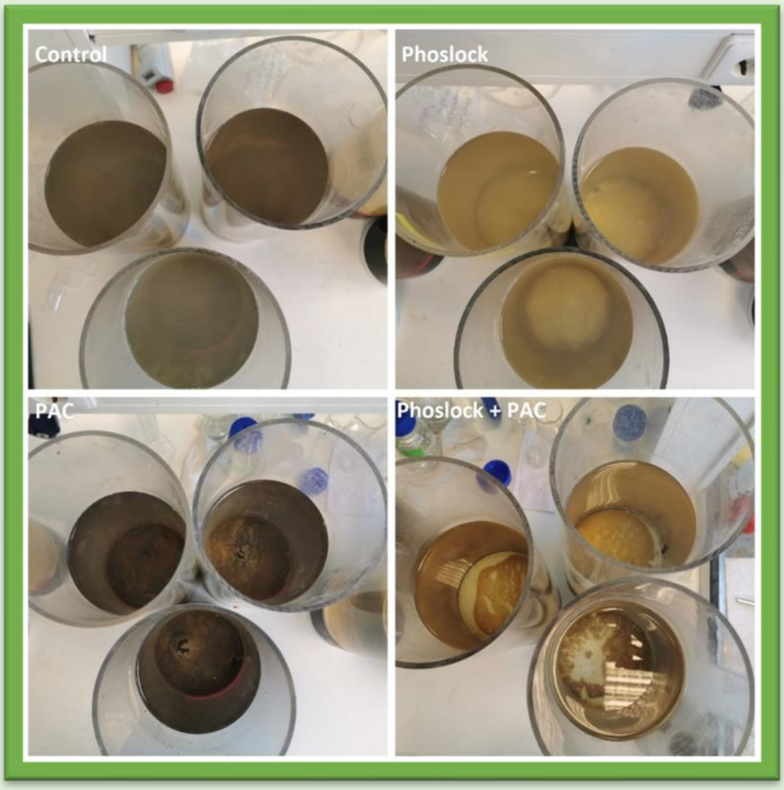

Figure 10 Water transparency three days after application of Phoslock© and/or PAC.

Figure 11 shows the light transmittance of the water after a certain disturbance. The x-axis represents the light intensity index on the sensor. The lines in the graph represent the percentage of remaining light measured through the sensor compared to when no disturbance took place. The intensity of the disturbance is shown at the x-axis which represents the laminar flow of the water. The vertical lines are error bars (*n*= 3) representing the standard deviation (*SD*). The left side of the figure shows the results of the first disturbance. The plot on the right shows the results of the second disturbance conducted eight days after the first disturbance.

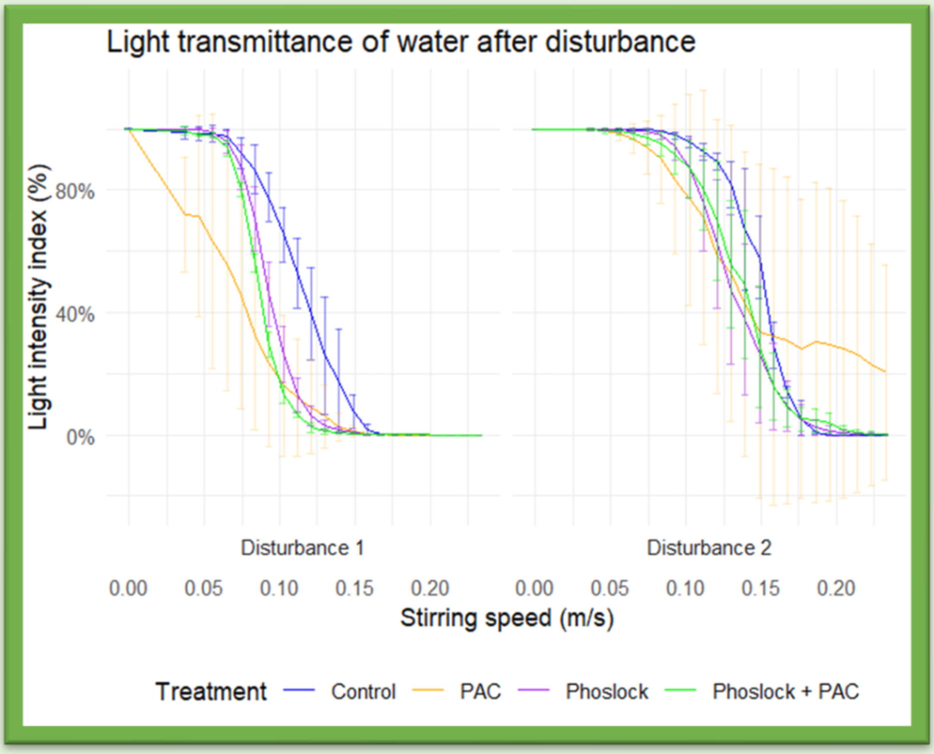

Figure 11 Measured light intensity after a certain disturbance (Resuspension experiment 1) More detailed information is shown in Appendix VII

During the first disturbance, the disturbance was strong enough for all treatments to cause resuspension of sediments, which absorbed all the light. Across all treatments, 0% light transmittance was achieved at a stirring speed between 0.149 and 0.167 m/s. The steepest decrease in light transmittance, indicated by the steepest slope of the line, occurred at a stirring speed of approximately 0.093 m/s for both treatments where Phoslock© was applied. In the control treatment, the steepest slope was observed between 0.102 and 0.149 m/s, while for the treatment where only PAC was applied, it occurred between 0.047 and 0.084 m/s.

Figure 11 illustrates that the sediment was more stable during the second disturbance. In one of the treatments where only PAC was applied, 0% light transmittance was not reached. For the other treatments, 0% light transmittance was achieved at higher disturbance levels compared to the first disturbance. In the control treatment, 0% light transmittance was reached at stirring speeds between 0.140 and 0.158 m/s. For the water treated with both Phoslock© and PAC, as well as Phoslock© alone, 0% light transmittance was reached at stirring speeds between 0.186 and 0.214 m/s, and 0.177 and 0.223 m/s, respectively. Additional statistics are presented in Appendix VII.

Figure 12 shows the turbidity at approximately 20 cm above the sediment after the disturbance. The y-axis represents the measured turbidity. The x-axis represents how many days after the disturbance the turbidity was sampled. The “T” on the x-axis stands for treatment which refers to the second disturbance that took place on day 8. Measurements are conducted at points including error bars (*n*=3), the other points are created with interpolation.

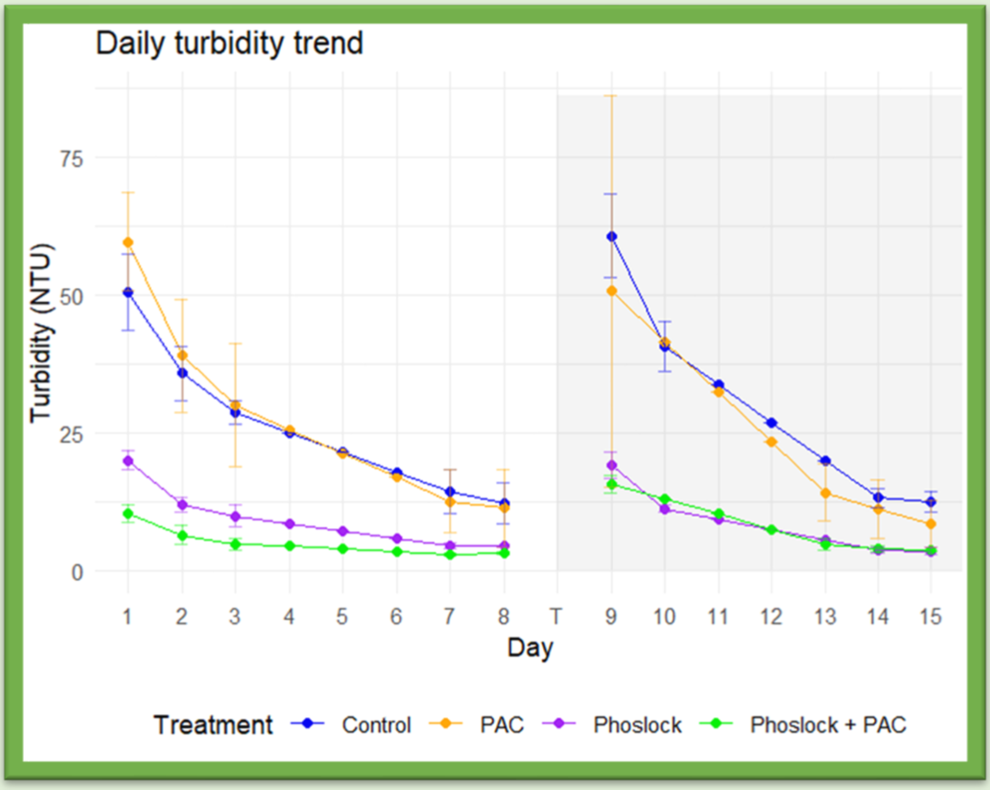

Figure 12 Turbidity levels in the top of the cylinder after certain amount of days (measured at day 1, 2, 3 ,6, 7, 8, 9, 10, 14 and 15).

Figure 12 shows that the turbidity in treatments of the water treated with Phoslock$^{©}$ and PAC and solely Phoslock$^{©}$ are noticeably lower than both the control treatment and the treatment where PAC is applied. A Friedman test revealed a significant effect of time after the resuspension event on the turbidity levels χ^2(3, *n*=32)= 19.95, *p* <.001. The medians (*Md*) indicated that the turbidity levels where highest one day after the disturbance (*Md*= 35.4 NTU). The Dunn (1964) Kruskal-Wallis multiple comparison test revealed significant differences between treatment where both PAC and Phoslock$^{©}$ (*Md*= 4.27 NTU) is applied and control treatment (*Md*= 22.3 NTU*;* p_{adj}= .007) and the treatment where only PAC is applied (*Md*= 19.8 NTU ;p_{adj}= 0.026). The median of the treatment where Phoslock$^{©}$ solely was applied is 6.41 NTU. The Dunn (1964) Kruskal-Wallis multiple comparison test did not reveal significant differences among other treatments.

The PAC treatments that had a turbidity below 2 NTU before the disturbance did not reach those turbidity levels again after the disturbances. The turbidity a week after the second disturbance was on average 8.51 (*SD*= 4.16) NTU for the PAC treatment. The turbidity a week after the second disturbance was lower for the Phoslock$^{©}$ and PAC and Phoslock$^{©}$ treatments (*M*= 3.69, *SD*= 0.10 NTU). Figure 13 gives an indication of the different water transparencies at the end of the experiment.

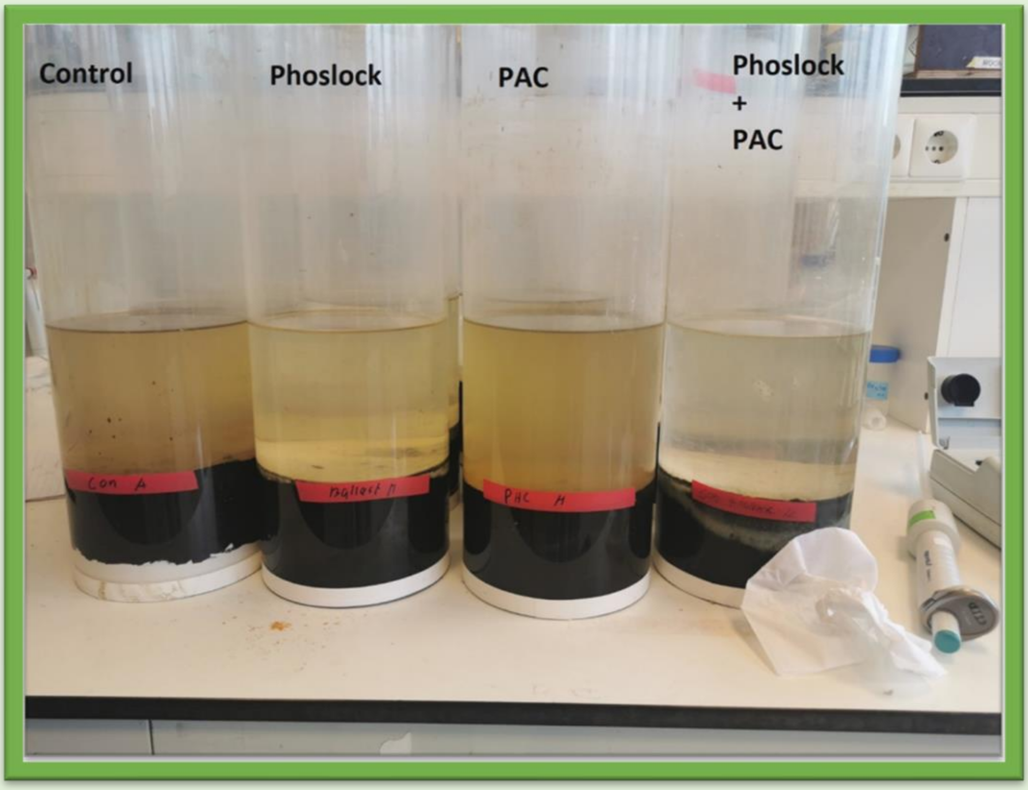

Figure 13 Transparency end of the first resuspension experiment (picture is made a week after the second disturbance)

Second resuspension experiment

Figure 14 illustrates the transparency of the water three days after the PAC injection. The average turbidity of the water in the control group (top 7 cm of the sediment) was 6.13 (*SD* = 0.82) NTU, which is higher than the turbidity in the cylinder with the original sediment of the divers pond, which had a turbidity of 5.28 NTU. In the treatment where PAC was injected into the sediment, the water had an average turbidity of 6.50 NTU (*SD*= 1.76). After the injection of PAC, a thin layer formed on top of the sediment that resuspended very easily (see bottom picture in Figure 14). However, the resuspended particles settled back to the bottom within a few minutes.

Figure 15 displays the light transmittance of the water from the second resuspension experiment which is conducted with the treatments described above.

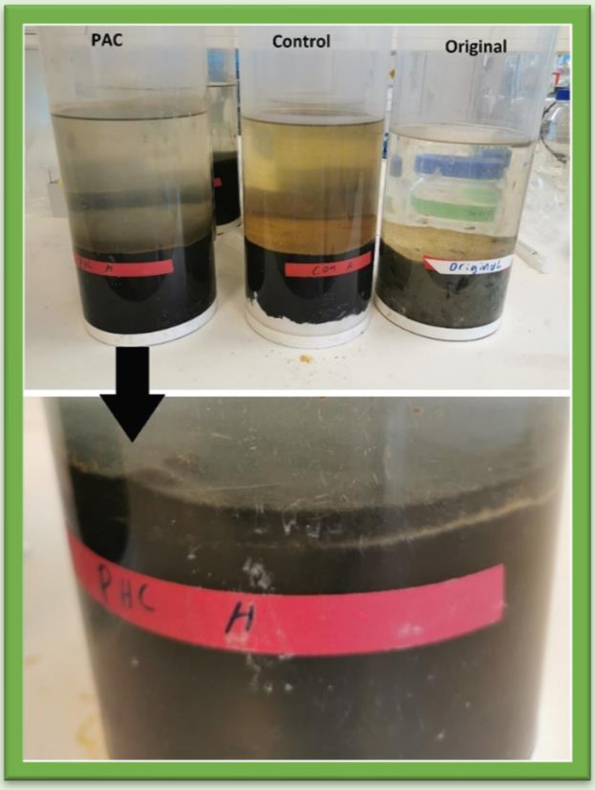

Figure 14 Transparency water at the start of the experiment, below the thin layer on top of the sediment after the PAC treatment.

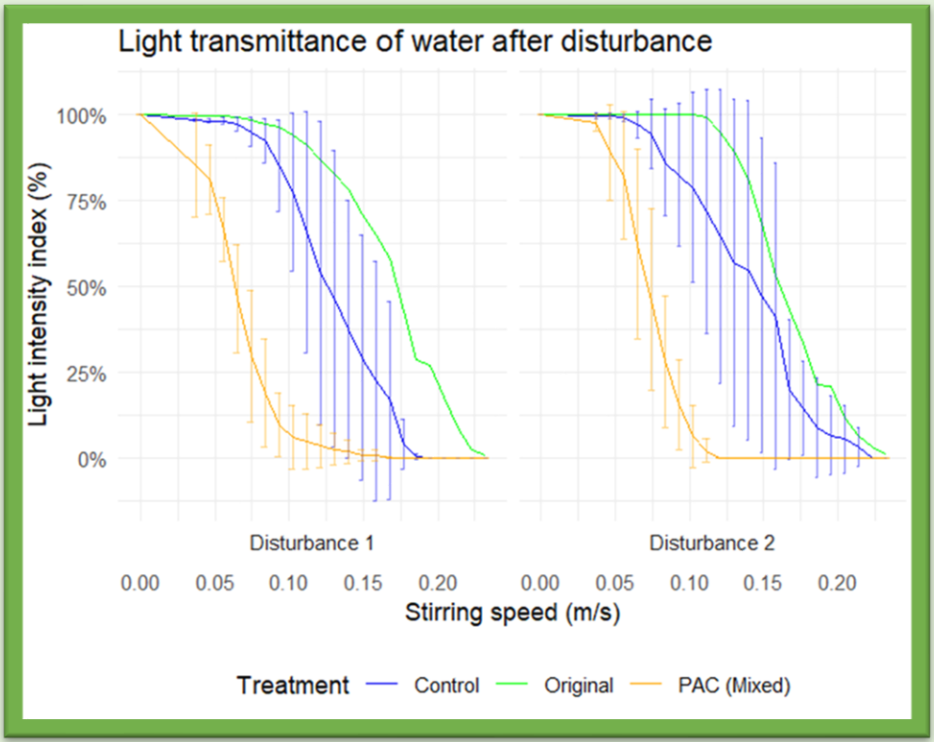

Figure 15 Measured light intensity after a certain disturbance (Resuspension experiment 2), more detailed information is shown in Appendix VIII

Figure 15 illustrates that the light intensity at the sensor decreases most rapidly in both experiments when PAC is applied to the sediment. In the first disturbance, 0% light transmittance was reached at a stirring speed between 0.093 and 0.167 m/s. During the second disturbance, a stirring speed of 0.121 m/s caused a resuspension event that absorbed all the light. The fastest decrease in light intensity for this treatment occurred at a stirring speed between 0.059 and 0.084 m/s.

In comparison, the top sediment without treatment was less (i.e. the control) sensitive than the PAC treatment but exhibited more variation. During the first disturbance, 0% light transmittance was reached at a stirring speed between 0.140 and 0.195 m/s. In the second experiment, all light was absorbed at a stirring speed between 0.149 and 0.223 m/s. The fastest decrease in light intensity for the control treatment occurred at a stirring speed between 0.065 and 0.177 m/s.

The original sediment seems to be the most stable. After both disturbances, 0% light transmittance was not reached. The fastest decrease in light intensity in the water occurred at a stirring speed of 0.177 m/s during the first disturbance and at 0.158 m/s during the second disturbance.

The daily turbidity trend between- and after these disturbances is displayed in Figure 16

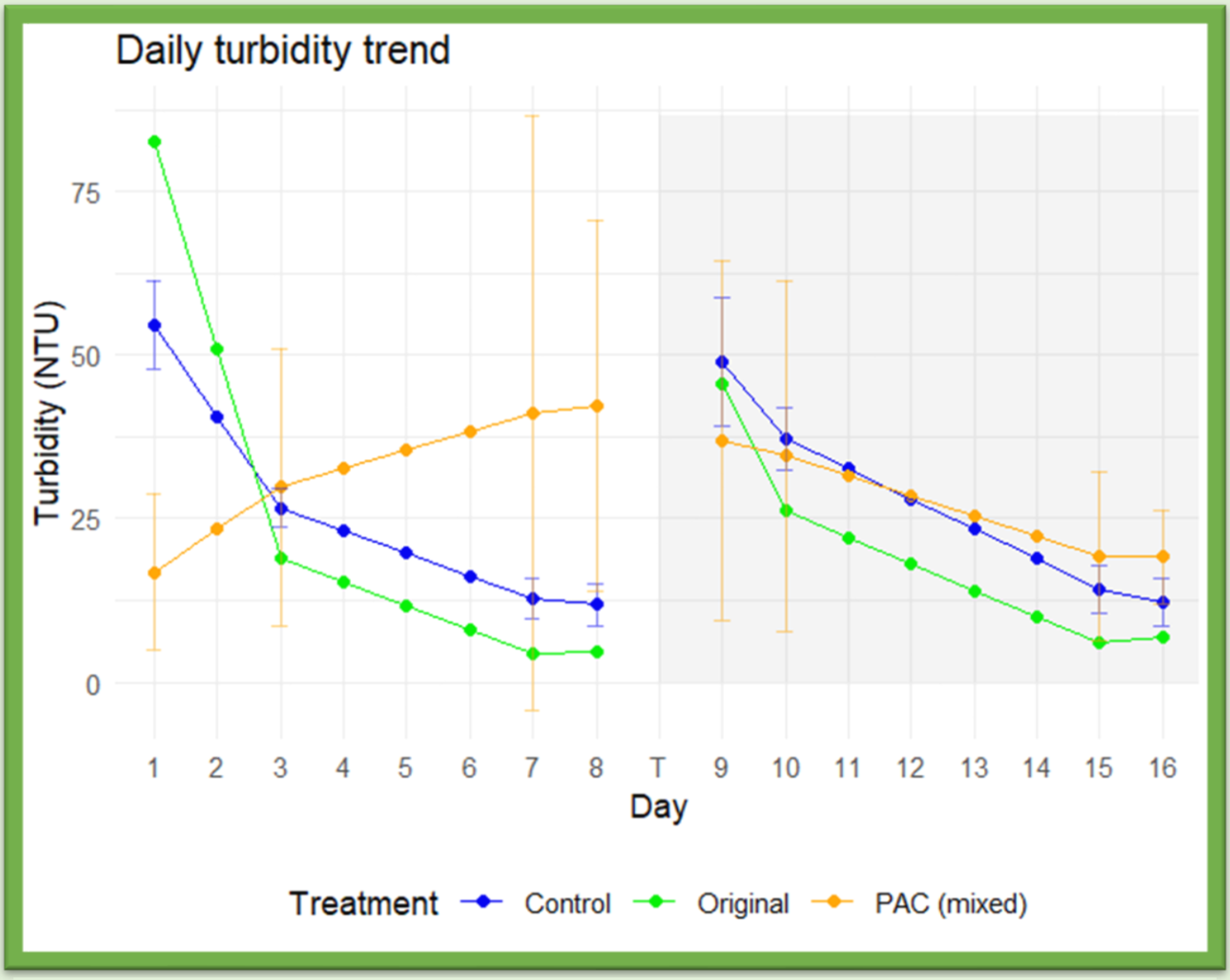

Figure 16 Turbidity levels in the top of the cylinder after certain amount of days (measured at day 1, 3 , 7, 8, 9, 10, 15 and 16).

A Friedman test did not revealed significant effect(s) of time after the resuspension event on the turbidity levels χ^2 (2, *n*=24) = 4.75, *p*= .093. Additionally, The Dunn (1964) Kruskal-Wallis multiple comparison test did not reveal significant differences between different treatments.

However, Figure 16 shows that the treatment where PAC is injected into the sediment has the lowest turbidity levels one day after the first disturbance. Unlike the other treatments, the turbidity levels in the water of the PAC- injected sediment treatment increase over time. By Day 8, the average turbidity was 42.3 (*SD*= 28.2) NTU. Following the first disturbance, the water developed an orange colour (see Figure 17), and the thin layer on top of the sediment expanded by approximately 5 centimetres (as shown in the left picture of Figure 17). To make sure that the rotor did not hit the bottom during the second disturbance, 800 ml of pond water was added to the cylinder on day 3 of the experiment.

During the second disturbance, the turbidity in the water of the PAC injection treatment decreased. This treatment exhibited lower turbidity levels than the treatments without PAC one day after the second disturbance. However, by the end of the experiment, the turbidity of the water in the PAC injection treatment was higher compared to the other treatments.

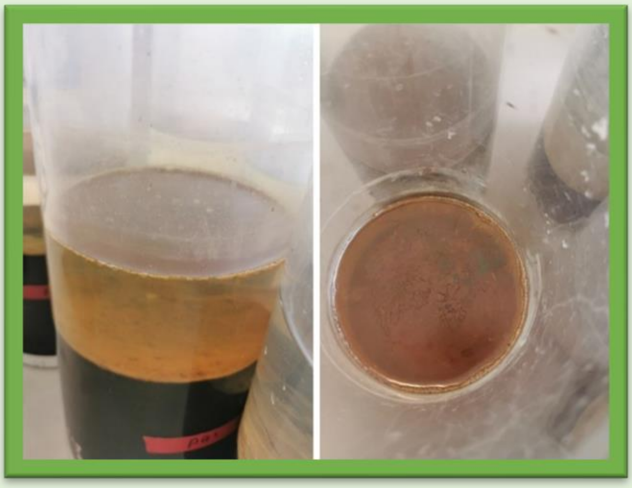

Figure 17 Orange water colour and expansion of the sediment (left) in the injected PAC treatment. Photo made three days after the first disturbance.

Except for Day 1 and 2 the turbidity in de water in the treatment with the original sediment was lower compared to the control group. It seems that the turbidity levels in the water for the treatments with the original sediment became stable a week after a disturbance.

Densities

Table 4 displays the densities of the different sediment types. The original sediment in the column “sediment type in Table 4” refers to the treatment “original” in the second resuspension experiment. The Phoslock$^{©}$ treatments refer to the treatments “Phoslock$^{©}$” and “Phoslock$^{©}$ + PAC” of the first resuspension experiment. The top sediment refers to the control treatments in the second resuspension experiment. The data on the left side of Table 4 is gathered from sediment measurements that were conducted before the experiment. The data on the right side of Table 4 is gathered from measurements taken from the top three centimetres of the sediment in the cylinder after the two disturbances.

Table 4 Sediment statistics before- and after the experiment (data in Appendix VIII)

Sediment type	**Wet density - before experiment**			**Density top sediment after experiment**		
	Average (kg/l)	*SD* (kg/l)	*n*	Average (kg/l)	*SD* (kg/l)	*n*
Original sediment	1.78	0.037	5	1.69	0.03	3
PAC injection	Based on control			1.08	0.03	9
Phoslock$^{©}$ treatments	1.19	0.011	5	1.04	0.10	6
Control	1.08	0.027	9	1.09	0.03	9

Table 4 shows that the density of the original sediment is higher compared to the other sediment types. A One-Tailed Wilcoxon rank test revealed significantly higher densities for the original sediment compared to the top sediment, *W*= 50, *p*= <.001. Furthermore, an One-tailed T-tests revealed significantly lower sediment densities after the experiment compared to the start for the original sediment, *t*(4.04)= -4.27, p= .006. Additionally, an One-tailed Wilcoxon-Signed rank test revealed significantly higher Phoslock$^{©}$ densities at the start of the experiment compared to the densities measured after the resuspension experiments, *W*= 0, *p*= .002.

4. DISCUSSION

In this section the research questions (see Section 1) are discussed. The first subsection discusses the water quality in the Berendonck and compares it to the situation in 2023/2024 with 2002/2003. The second and third sections discuss the results of the experiments and the expected effect is of coagulants on the water quality. The last section discusses the efficiency of the use of coagulants in the divers pond in the Berendonck.

4.1 WATER QUALITY

Chlorophyll-α

The chlorophyll-α concentration on 4 March 2024 was notably higher compared to other dates, this is caused by a spring algae bloom. On 23 April 2024, the chlorophyll-α concentration decreased, likely due to high grazing pressure from zooplankton (Van Hall & Lürling, 2003). During fieldwork on 23 April, a lot of zooplankton was observed in the pond. In the winter of 2023/2024, chlorophyll-α concentrations were lower compared to the winter of 2002/2003. However, the peak concentrations during the spring bloom were higher in 2023/2024. Indicating that algae got more fuel for their growth. Higher chlorophyll-α concentrations were also measured in some of the golf course ponds, indicating potential nutrient runoff from the golf courses, which could enhance algae growth.

Using Carlson and Simpson's (1996) trophic classification based on chlorophyll-α concentrations, the divers pond is classified as mesotrophic in the winter (November to February) and eutrophic in March and June. It is expected that chlorophyll-α concentrations will rise during the summer due to higher water temperatures, which enhance algae growth (Butterwick et al., 2004).

Nutrient Concentrations

The study by Vieira Neto de Rolan Teixeira (2024) found that phosphorus (P-PO_4^{3-}) concentrations in the divers pond were more than three times higher than those found by Van Hall & Lürling (2003). The release of P-PO_4^{3-} from the sediment into the water column was also higher in 2023/2024 compared to 2002/2003. Additionally, Vieira Neto de Rolan Teixeira (2024) reported higher total nitrogen concentrations in the winter of 2023/2024 compared to 2002/2003, although the reported ammonium and nitrate concentrations were not higher.

Indications for algae growth

The increase in phosphorus and nitrogen concentrations is likely the cause of the increased chlorophyll-α concentrations in the divers pond. Both nutrients are essential for algae growth, and the nutrient that is least available typically limits algae growth. While phosphorus often limits freshwater algae growth (Elser et al., 1990), Van Hall & Lürling (2003) concluded that nitrogen was the limiting nutrient in the divers pond in the Berendonck.

Further research on nutrient levels is needed to fully understand the algae patterns in the divers pond. During the fieldwork done for this thesis nutrient samples were also taken but due to a technical issue, it was not possible to measure them.

Turbidity/transparency

The turbidity of the water of the divers pond in 2023/2024 is roughly similar compared to the situation in 2002/2003. In both periods the turbidity is higher in the hypolimnion compared to the epilimnion. In the epilimnion the turbidity is rather low. The main factor that caused the existing turbidity in the water column is the algae (discussed in the previous subsection). The turbidity in the hypolimnion is higher compared to the epilimnion. This is probably caused by processes like sediment focussing, natural sedimentation and mainly swimming movements close to the water bottom (Hilton et al., 1986; Blais & Kalff, 1995; Van Hall & Lürling, 2003). During the resuspension experiment, it became clear that the top sediment is fluffy and did not settle easily. This probably caused low transparency in the hypolimnion.

Also the results of the Onderwaterlicht module supported this claim. In the deeper parts of the pond (>14 meters) factors like humic acids and detritus play a larger role in contributing to turbidity. This is partly caused by lower chlorophyll-α concentrations in the deeper parts of the pond which are caused by insufficient light availability for algae growth. Additionally, a higher concentration of humic acids and detritus are measured in these deeper parts. These particles are more abundant in the deeper parts because these parts are in closer contact with the sediment.

4.2 EFFECT OF COAGULANTS AND BALLASTS ON THE WATER QUALITY

This section discusses the effects of a coagulant dosage of 2 mg Al/l in combination with 50 mg/l Phoslock©. This was considered as the most optimal coagulant – and ballast dosages to enhance the transparency in the divers pond in the Berendonck. Appendix VI gives an elaborated description of the effect of other coagulant- and ballast dosages on the water quality.

Justification optimal dosages

Based on the coagulant experiment PAC was considered to be the most efficient coagulant. PAC has the highest chlorophyll-α and turbidity removal at the top of the tube compared to both alum and chitosan. Although chitosan has the least effect on the pH, the application of a low concentration of PAC (<16 mg Al/l) does not drop the pH levels below 6.5. Therefore the coagulant is still effective and is not toxic for macrofauna and fish (Sarvala & Helminen, 2023). Additionally, PAC is a cheaper alternative than chitosan.

A dosage of 2 mg Al/l PAC in combination with 50 mg/l Phoslock© is chosen to be suitable to apply in the divers pond in the Berendonck. The reason for choosing a dosage of 2 mg Al/l PAC is that these dosages showed a significant decrease in chlorophyll-α at the top of the tube. And is considered as a safe dosage concerning the pH stability and the EC. Additionally, a lower dosage of PAC is needed in combination with a ballast to let algae settle (De Magalhães et al., 2018; Miranda et al., 2017; Noyma et al., 2016). Therefore, it will not be needed to apply a higher dosage of PAC when also a ballast compound is applied.

Application of 50 mg/l Phoslock© seems to be enough to let the algae sink to the bottom. For most treatments application of more than 50 mg/l Phoslock© does not remove significantly more algae from the water column. Only for the concentrated water, more algae are removed from the water column after the application of more than 50 mg/l Phoslock©. The effective concentration of 50 mg/l Phoslock© is lower compared to other studies (De Magalhães et al., 2018; Li & Pan, 2013; Miranda et al., 2017; Noyma et al., 2016; Pan et al., 2012). This is probably due to the lower initial chlorophyll-α concentrations. At lower algae biomass, less ballast is needed to achieve sufficient algae removal (Noyma et al., 2016). Because the lowest used concentration is 50 mg/l possibly a lower Phoslock© concentration is also sufficient for a similar algae removal. However, this has not been tested in this study.

Also, an application of 4 mg/Al PAC solely could also be an option. In Appendix VI is described why a treatment of 2 mg Al/l PAC with 50 mg/l Phoslock© is preferred above this treatment.

Chlorophyll-α

The results revealed that application of 2 mg Al/l PAC in combination with 50 mg/l removes on average half of the chlorophyll-α concentration when sampled after 2 hours. The 24 hour experiments perform worse in chlorophyll-α removal. An explanation for this is that already most of the algae were settled at their selves. The control treatments supported this by having lower chlorophyll-α concentrations for the 24 hour experiments compared to the 2 hour experiments. It should be noted that during the experiments there was a completely stable situation, which does not correspond to the real situation in the divers pond where disturbances took place due to for example wind. Therefore, the results of the 2 hour experiments provide a more realistic picture.

Turbidity

The turbidity of the water does not decrease after the application of PAC and Phoslock©. This is because Phoslock© imparts a red colour to the water, increasing turbidity. This colour was particularly noticeable after 2 hours but diminished after 24 hours, although turbidity remained slightly higher in treatments where Phoslock© was applied. Consequently, turbidity measurements taken after 2 and 24 hours are not meaningful for drawing conclusions about water transparency post-ballast application. It is expected that turbidity will decrease over time to values lower than the starting point once all the Phoslock© has settled. This expectation is supported by the resuspension experiment (discussed in Section 4.3), which showed significantly lower turbidity levels three days after the application of Phoslock© and PAC compared to the pre- treatment situation.

pH and EC

When applying 2 mg Al/l PAC in combination with 50 mg/l Phoslock© no negative impacts on both the pH and EC was expected. The expected pH drop was around 0.3 units and the EC increased approximately 1.6% which are both fluctuations that are present in the divers pond. When the pH drop is considered to be too large a buffer like $Ca(OH)_2$ could be used in combination with PAC to keep the pH stable (Lürling & Van Oosterhout, 2013).

4.3 EFFECT COAGULANT (AND BALLAST) ON SEDIMENT STABILITY

Resuspension

In the first resuspension experiment, no clear differences in light intensities after disturbances were observed between the control, PAC, and Phoslock© treatments, indicating no proven differences in sediment stability .The results from the first resuspension experiment suggested that the top 7 centimetres of the sediment in the Berendonck are more stable than other treatments, but this could not be conclusively proved due to large variations. Similarly, while the 2 mg Al/l PAC treatment seems to be more sensitive to disturbances, this was not clearly different . The Phoslock© and Phoslock© + PAC treatments showed comparable results.

The findings of the first resuspension experiment do not support the hypothesis based on Egemose et al. (2010) and Yin et al. (2016) that PAC decreases sediment stability. One reason may be that the PAC concentration used (2 mg Al/l) was too low to reveal significant differences. In the second resuspension experiment, a higher dosage of PAC (68 g Al/m²) was injected with the sediment and did show a decrease in sediment stability, likely due to floc formation that decreases sediment density (Egemose et al., 2010). So, a large dosage of PAC could decrease the sediment stability.

It is estimated that, on average, each square meter of sediment is covered by 6,000 litres of water (assuming an average depth of 6 meters). When applying 2 mg Al/l of PAC in the Berendonck, results in an average PAC application of 12 g Al/m² in the Berendonck. However, the amount of PAC settling on the sediment will be higher in deeper areas. For instance, at a depth of 16.5 meters, the amount of PAC settling on the sediment would be 33 g Al/m² (2 mg/l Al PAC * 16.5 m water). If the PAC dosage is increased to 4 mg Al/l PAC, these values double. Thus, an average of 24 g Al/m² PAC would be applied, and in the deepest areas, the amount would be 66 g Al/m² PAC. Consequently, the first resuspension experiment, using 0.23 g Al/m² PAC, underestimates the amount compared to the second resuspension experiment, where 68 g Al/m² was applied. This value represents approximately the highest PAC application considered in this report.

Phoslock© did not enhance sediment stability, contrary to the findings of Egemose et al. (2010) and Yin et al. (2016). Egemose et al. (2010) reported a 265% increase in sediment stability with Phoslock©, but this was based on sediment from a single lake with a much lower in-situ density (reported 0.0645 kg/l, which is unrealistic because this density is lower than water) than the sediment in the Berendonck (1.09 kg/l). They also studied two other lakes with higher densities and found more comparable sediment stabilities to Phoslock© treatments. Yin et al. (2016) also concluded that Phoslock© increases sediment stability, but did not report control group sediment densities, complicating comparisons.

Yin et al. (2016) reported the granular density of Phoslock© as 3.82 kg/l, which varies with bentonite quality. However, the density of Phoslock© decreases when it absorbs water. The bulk density of Phoslock© is between 0.85 and 1.2 kg/l (Finsterle, 2014; Groves, 2010). The average measured bulk density of Phoslock© used in this study was 1.19 kg/l, which is slightly higher compared to the control group sediment densities. This possibly explains the lack of observed sediment stability increase. Egemose et al.'s (2010) findings of increased stability could be due to the lower control group sediment densities. The measured wet sediment densities in the Berendonck were higher compared to the densities reported in Egemose et al. (2010). Density is a crucial factor in sediment stability, as demonstrated by the original sediment treatment, which had a significantly higher density and a higher stability compared to the top 7 centimetres of the control group sediment.

Another explanation for the lack of increased sediment stability with Phoslock© is its vertical translocation over time within the sediment layer. Figure 18 shows that not all the Phoslock© (white) remains on top of the sediment. This may be due to previous resuspension events or the slightly higher density of Phoslock© compared to the original sediment. Consequently, vertical translocation occurs, burying Phoslock© deeper in the sediment. As a result, the sediment can come into direct contact with the water again, leading to potential resuspension. Thus, resuspension could cause the Phoslock© capping layer to disappear, keeping further sediment resuspension similar to the control group (Egemose et al., 2012; Meis et al., 2013).

Figure 18 Vertical translocation of Phoslock©

Precipitation

Before the first resuspension event, turbidity in the treatments with PAC was, on average, ten times lower than in the treatment without PAC. This indicates that the sole addition of PAC can remove 90% of turbidity within three days. However, it's important to note that the cylinders remained completely stable during this period, which does not reflect the real conditions in the divers pond, where disturbances such as wind occur.

Phoslock© did not seem to affect turbidity before the resuspension event. However, after both resuspension events, turbidity in the Phoslock© treatments was lower compared to the PAC and control treatments. The Kruskal-Wallis multiple comparison test did not reveal significant differences between the treatment with only Phoslock© and the control and PAC treatments. However, Figure 12 shows that the turbidity levels in the control and PAC treatments are noticeably lower compared to the treatment with only Phoslock©. The lack of significant differences is likely due to the low power of the test.

This suggests that Phoslock© included the sediment to settle faster after resuspension, likely due to the different shape, size, roundness, and surface texture of its particles (Dietrich, 1982). Turbidity levels one week after the first and second resuspension events were comparable. However, over a longer period, Phoslock© may translocate deeper into the sediment, reducing its influence over time (Figure 18).

Application of 2 mg Al/l of PAC affects turbidity before resuspension but has no effect after a resuspension event. When a larger dosage of PAC was injected with the sediment, turbidity increases after the first disturbance due to the possibly solubility of aluminium hydroxide, which gave the water an orange colour at a low pH (5.5) (Bensadok et al., 2008). After the second disturbance, turbidity decreased over time as the aluminium hydroxide was possibly already soluble and did not further increase turbidity. Although aluminium hydroxide initially increased turbidity, the sediment settled faster with PAC than in the control. One day after the disturbances, despite the presence of aluminium hydroxide, turbidity was lower in the PAC treatment due to flocculation, which increases particle size and, consequently, the particle settling speed (Kuenen, 1968).

The injection of PAC in the sediment reduced the pH of the water to levels that are lower than 6.5, which is not optimum for binding P neither to organisms. We might not expected this in the field as there will be more water to buffer the Al, but before injecting such a high amount of PAC, it would be important to check the buffer capacity of the lake and if needed add a buffer

Lastly, the original sediment (deep layer of the sediment, down to 30cm) had slightly lower turbidity values compared to the top 7 centimetres of sediment. This is likely caused by its higher density which enhances settling. After the first day, turbidity in the original sediment was higher than in the control, probably due to manual resuspension initiation, creating higher turbidity and an unfair comparison.

4.4 EFFICIENCY USE OF COAGULANTS (AND BALLAST) IN THE DIVERS POND

Short-term effects

The experiments demonstrated that water transparency increases when coagulants are applied. However, predicting the exact effect of coagulants on transparency in the divers pond, including the duration of these effects is impossible. Despite this, some estimations were made. Assuming a 50% reduction in chlorophyll-α concentration, the Secchi depth, as modelled with the Onderwaterlicht Module, increases by an average of 0.41 meters (*SD* = 0.58). This is likely an underestimation because it only accounts for chlorophyll-α removal, whereas PAC and Phoslock© can also remove humic acids and suspended particles (e.g., Lürling et al., 2020). In Appendix II details about these calculations are shown.

In Resuspension experiment 1, turbidity levels decreased to an average of 1.6 NTU after the application of 2 mg Al/l PAC (and Phoslock©). Using Zaal's (2002) relation, the predicted Secchi depth for this turbidity is 3.56 meters, which is 1.36 meters (SD = 0.32) higher than the measured Secchi depths. This is also likely an underestimation because modelled Secchi depths were lower than measured ones. In Appendix II details about this calculations are shown.

The turbidity levels after applying PAC and Phoslock© in the resuspension experiments were comparable to those in the adjacent lake (*M* = 2.04, *SD* = 0.98 NTU) at point B in Figure 2. This suggests that a similar transparency (> 4 meters) could occur in the divers pond after applying both PAC and Phoslock© in the top 14 meters of the pond. However, the resuspension experiment indicated that neither PAC nor Phoslock© increases sediment stability. Therefore, adding PAC and/or Phoslock© will not effectively reduce turbidity caused by resuspension events, such as those during diving activities. Which probably does not resulting in lower turbidity levels in the bottom 2-4 meters of the divers pond.

Long term effects

Predicting the exact long-term effects of applying PAC and Phoslock© to the divers pond is impossible. Several studies have reported that the impact of coagulant and ballast applications can last for multiple years, with a maximum duration up to 10 years (Huser et al., 2011; Reitzel et al., 2013; Van Oosterhout et al., 2021; Waajen et al., 2016). The most comparable lake to the divers pond where such a treatment has taken place is Lake Rauwbraken (Van Oosterhout et al., 2021). In Lake Rauwbraken, 9.6 mg of PAC per litre combined with 77 mg/l Phoslock© was applied to improve water quality. Following the treatment, the Secchi depth increased from an average of 3.5 meters (*SD* = 1.6) to an average of 4 meters (*SD* = 1.9) over a period of 10 years after treatment. Notably, the Secchi depth was higher for the first four years post-application before gradually declining to pre-treatment levels. This suggests that repeated interventions may be necessary.

However, it's important to note that these results only provide an indication of what might happen in the divers pond. There is no single water body identical to the divers pond. Therefore, the divers pond can respond differently to treatments. An essential factor to consider is the external nutrient influx, which remains unknown for the divers pond. A possible source of external nutrients could be the adjacent golf course. If the external nutrient influx is high, it should be controlled before application of a treatment with coagulants and/or ballast (Lürling et al., 2020).

Costs

In Appendix IX the material costs of the treatments are calculated. For the calculations an area of 58437 m^2 and an average depth of 6 m was used. The prices of one ton of Phoslock was defined as €2093/ ton and costs of PAC was estimated at €279/ tonnes. In total 9.7 tonnes of PAC and 17.5 tonnes of Phoslock© is needed to reach concentrations of 2 mg/l PAC and 50 mg/l Phoslock© in the divers pond. The total cost of this material is €39401 which consist of € 2717 of PAC and € 36684 of Phoslock© (assuming that no buffer is needed). When 4 mg/l PAC is added solely the costs will be much lower. 19.5 tonnes of PAC costs approximately € 5435. Additionally, a buffer is needed to avoid that the pH drops to much. For example, 8.4 tonnes of $Ca(OH)_2$ costs € 2364 (Lürling & Van Oosterhout, 2013) which makes the total price of € 7799 for the material. Application of 4 mg Al/l PAC could be seem as a cheaper (less effective) option to improve the water transparency of the divers pond.

5. CONCLUSION

Higher nutrient and chlorophyll-α concentrations are measured in the period November 2023 until June 2024 compared to the period November 2002 until June 2003. The measured turbidity in both periods is roughly the same. Chlorophyll-α contributes the most to the turbidity in the top 14 meters of the pond where humic acids and detritus are main contributors in depths larger than 14 meters which is mainly caused by resuspension of particles from the sediment from the water bottom.

It is proved that application of PAC in combination with Phoslock$^©$ can reduce the chlorophyll-α concentration up to 60% in the water column which increases the transparency of the water in the divers pond in the upper 12-14 meters of the water column. Side effects of the application of PAC is a reduction in pH and an increase in the electronic conductivity (EC) . However, no negative effects on the aquatic life are expected when the recommended dosages of 2 mg Al/l PAC in combination with 50 mg/l Phoslock$^©$ are applied.

It is also proved that both PAC and Phoslock$^©$ enhanced settling of particles resulting in a faster turbidity decrease after a resuspension event. However, it is shown a high dosage of only PAC improved the susceptibility of sediment for a disturbance which improved the chance of resuspension. No effects are shown of Phoslock$^©$ on the sediment stability. Therefore, application of PAC and/or Phoslock$^©$ do not result in an increasing transparency during or straight after diving activities in the bottom two to four meters of the divers pond.

It is up to the divers and/or water managers to decide if the costs (estimated on €39,401 for recommend dosage of PAC and Phoslock$^©$) are worth it. Also additional research can be considered to make a better prediction about the amount of increased transparency after the recommended treatment and/or the duration of this transparency increase.

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APPENDICES

APPENDIX I CALIBRATION CURVE RESUSPENSION EXPERIMENT

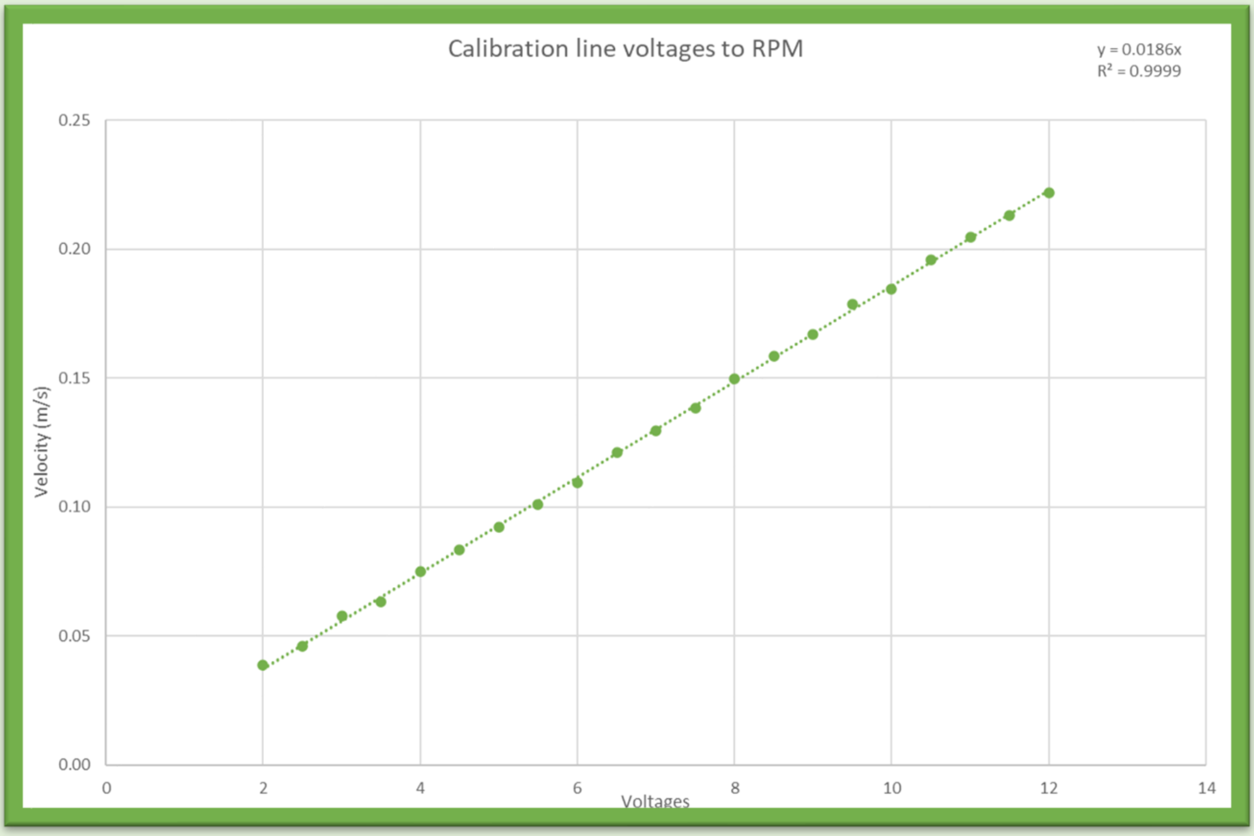

Figure 19 Calibration curve resuspension experiment

APPENDIX II PREDICTION EFFECT COAGULANT

Modelling with Onderwaterlicht module

In this section the Onderwaterlicht Module is used to predict the Secchi depth after application of a coagulant . The results in Appendix II.A show the measured chlorophyll-α -Humic acids and suspended solids concentrations in the divers pond at different dates. This data is used to estimate the Secchi depth With the Onderwaterlicht Module.

The results of the ballast and PAC experiment showed that the chlorophyll- α is decreased with 50% after application of 2 mg Al/l PAC and 50 mg/l. Based on this result the average half chlorophyll- α concentration (over depth) of each date is used as input in de Onderwaterlicht module together with the averages of the other parameters of each date. The model calculated a Secchi depth that is on average 41 (*SD*= 5.8) cm higher when only the chlorophyll-α concentration is adjusted. Table 5 gives a summary of the results.

Table 5 Output Onderwaterlicht Module based on original measurements compared to a situation where 50% of the Chlorophyll-α is removed

Month	Based on measurments				Assuming 50% CHLF reduction			
	Ex coef (1/m)	Secchie (m)	4% light (m)	10% light (m)	Ex coef (1/m)	Secchie (m)	4% light (m)	10% light (m)
March	1.03	2.0	2.8	3.2	0.82	2.4	3.9	3.4
April	0.76	2.6	4.2	3.9	0.66	3.0	4.8	4.3
June	0.89	2.1	3.6	3.1	0.78	2.4	4.1	3.6

Modelling based on turbidity level

In appendix II.B, C,D and E four different relations are used to calculate the Secchi depth based on the turbidity levels . (Baughman et al., 2015; U.S. Department of the Interior, 2016; Xu et al., 2019; Zaal, 2002). With these relation the Secchi depth could be calculated based on the turbidity value. To ensure that the model fits the situation in the divers pond in the Berendonck the Secchi depth is calculated with these models based on the turbidity of the first 4 meters of the divers pond. The calculated Secchi depth is compared with the measured Secchi depth during fieldwork. All of the models predicted in general lower Secchi depths than measured. The calculated Secchi depths with the model of Zaal (2002) fits the best with the measured Secchi depths. Therefore, this model is used to predict the Secchi depth after application of 2 mg Al /l PAC and 50 mg/l Phoslock$^{©}$.

In the resuspension experiment it is shown that that turbidity levels of the water decrease to an average of 1.6 NTU after application of both 2 mg Al/l PAC and 50 mg/l Phoslock$^{©}$. So, an turbidity of 1.6 NTU is used as input in the relation of Zaal (2002) which calculates a Secchi depth of 3.56 meters.

APPENDIX III FIELDWORK RESULTS; CONTRIBUTION TO TURBIDITY

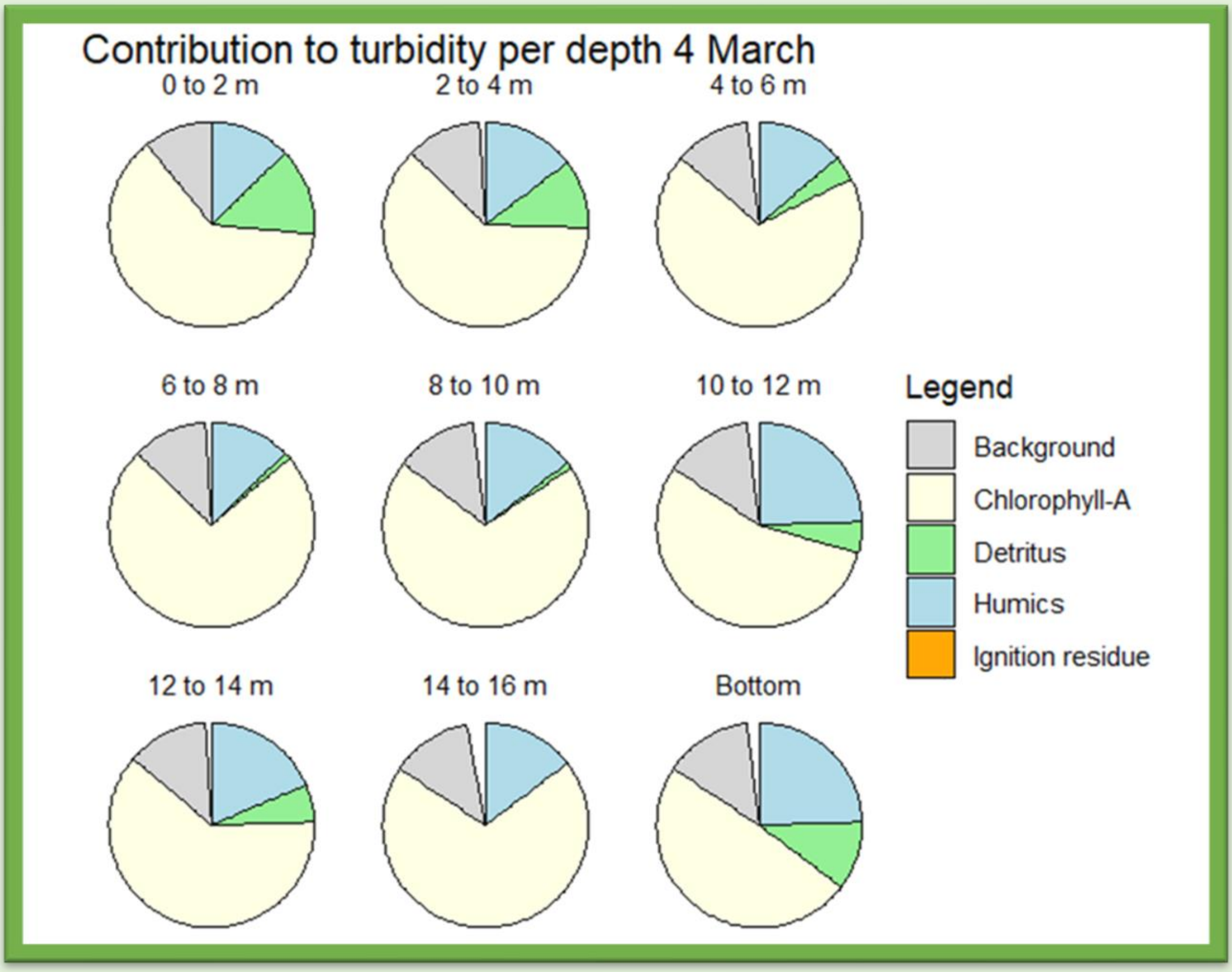

Figure 20 Contribution to turbidity at different depths on 4 March 2024

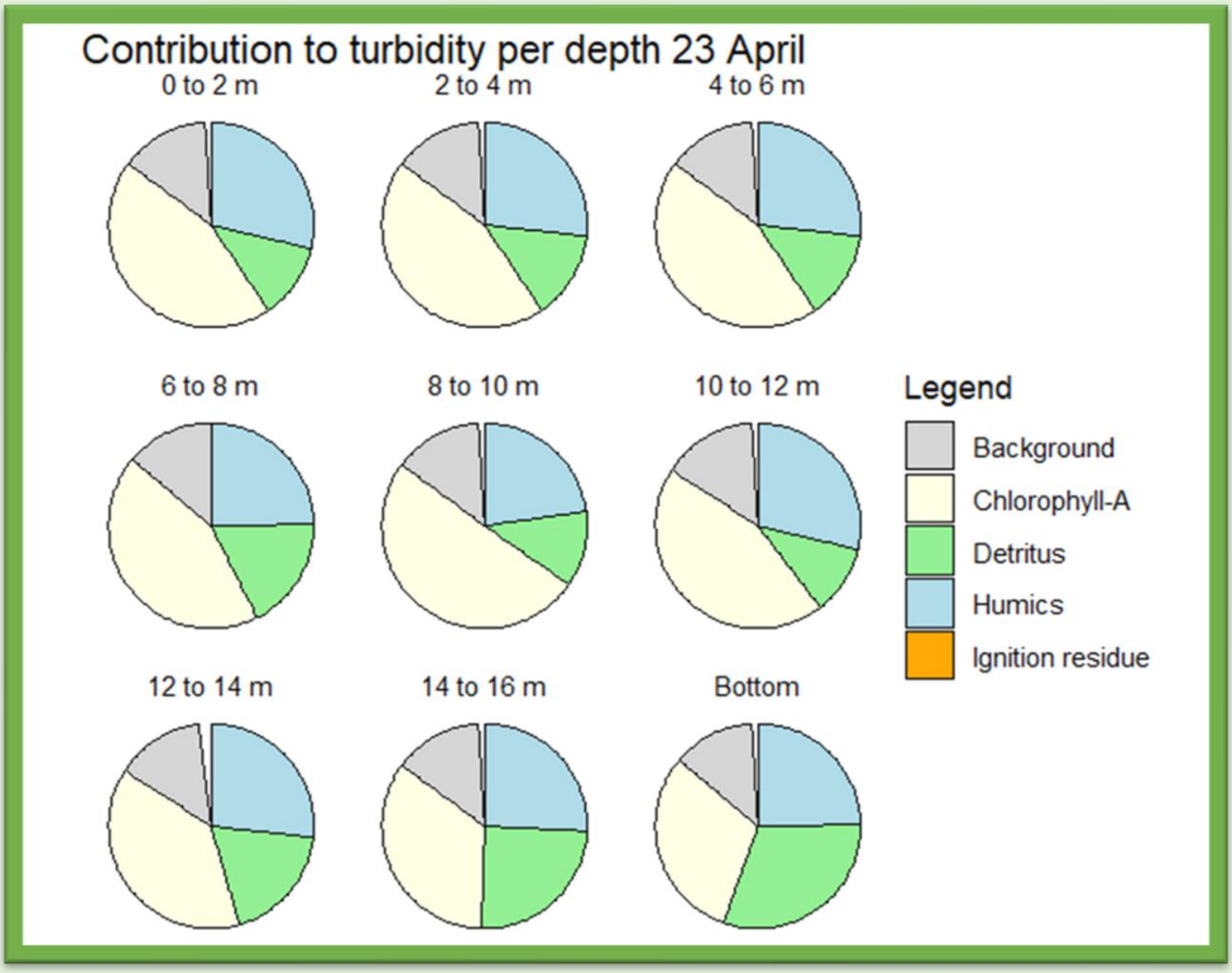

Figure 21 Contribution to turbidity at different depths on 23 April 2024

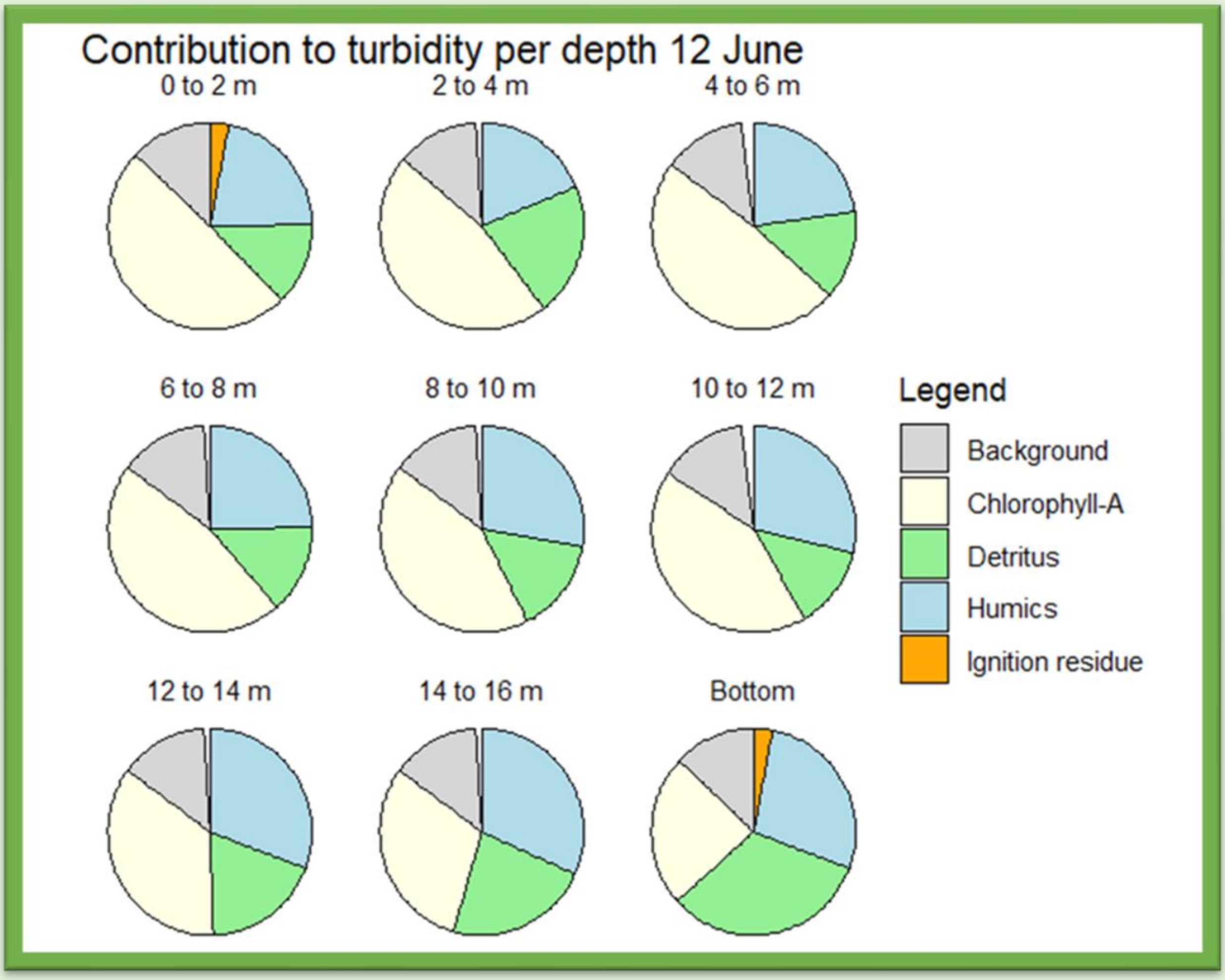

Figure 22 Contribution to turbidity at different depths on 12 June 2024

APPENDIX IV PARAMETER TRENDS

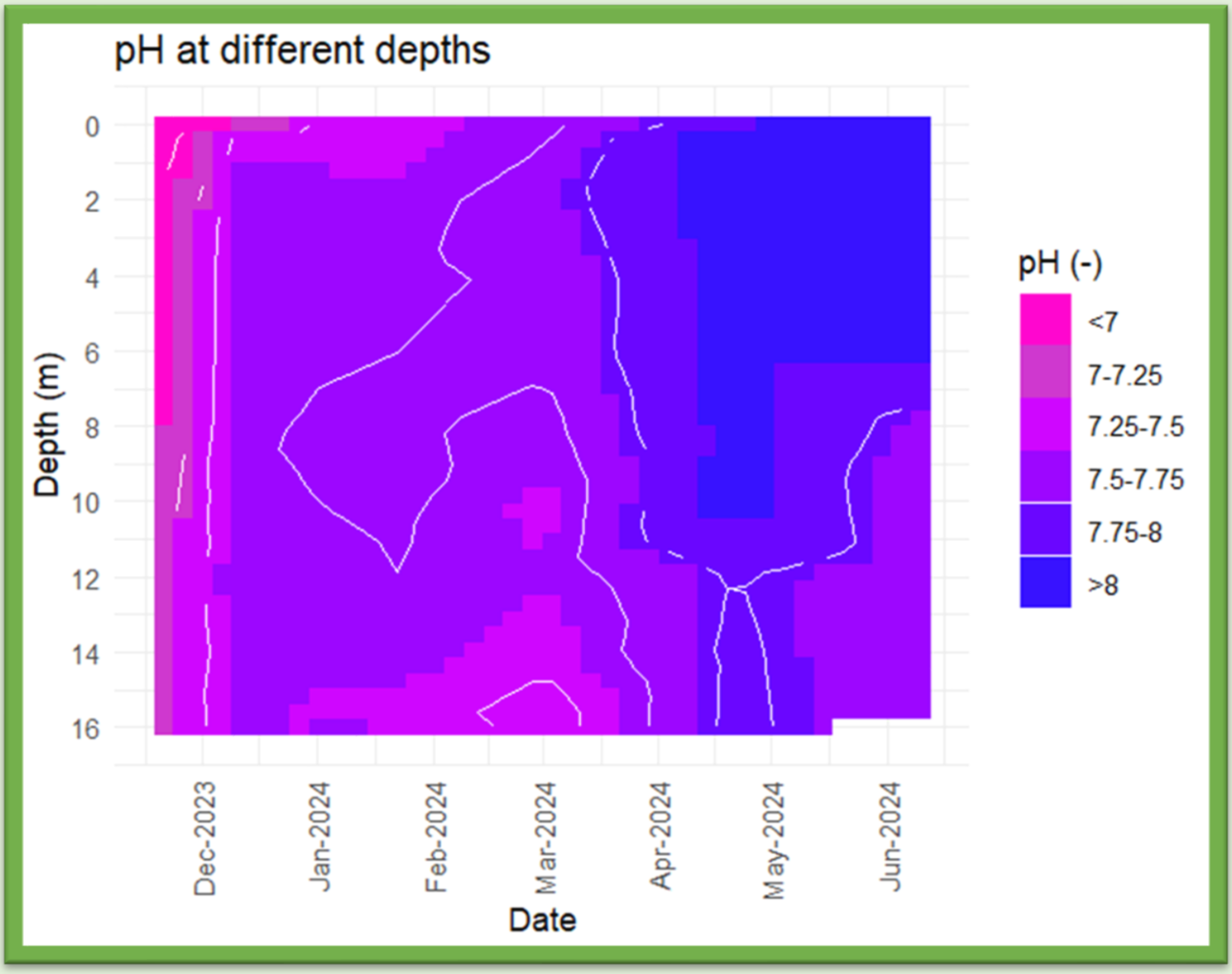

Figure 23 pH levels in de divers pond over time at different depths

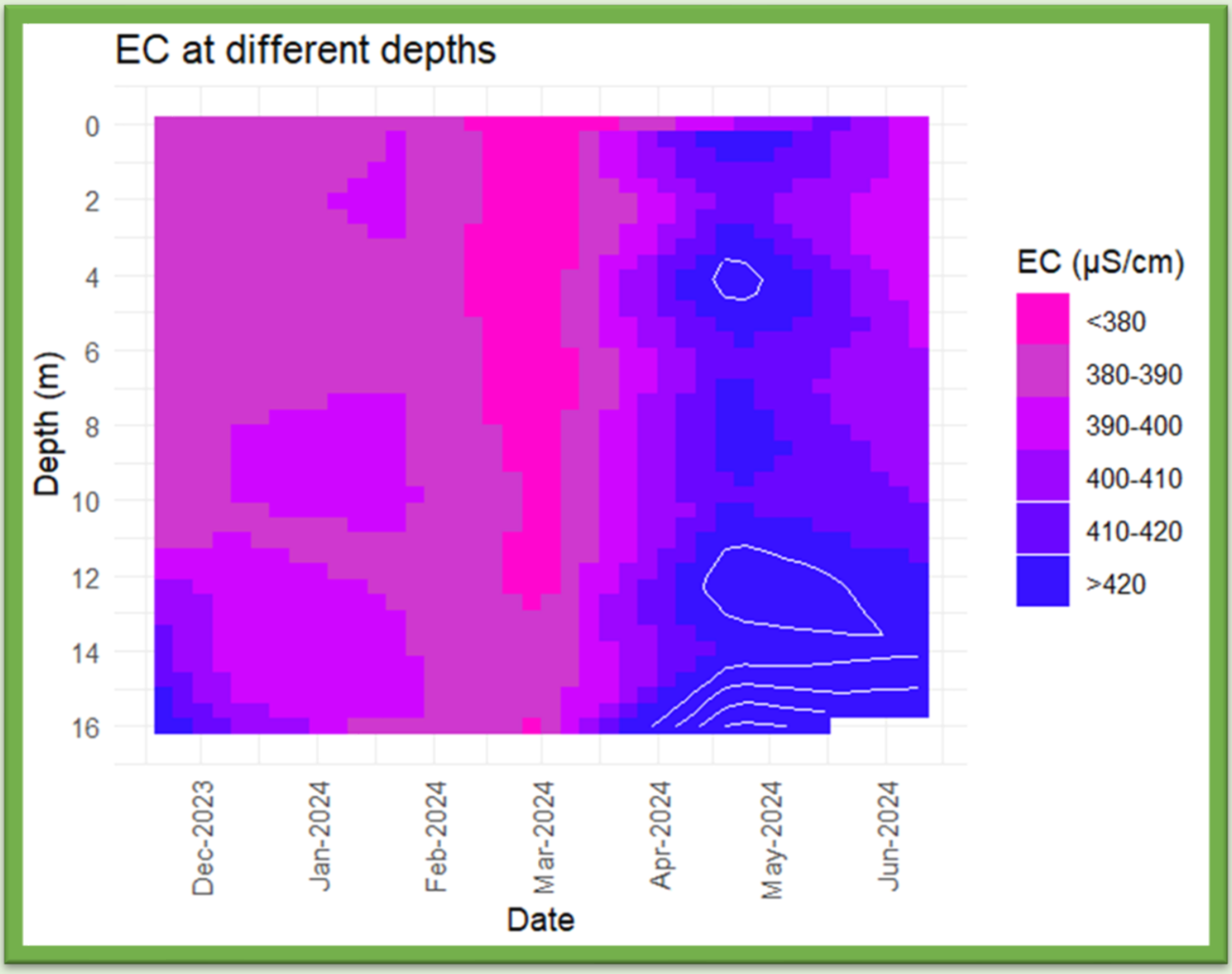

Figure 24 EC levels in de divers pond over time at different depths

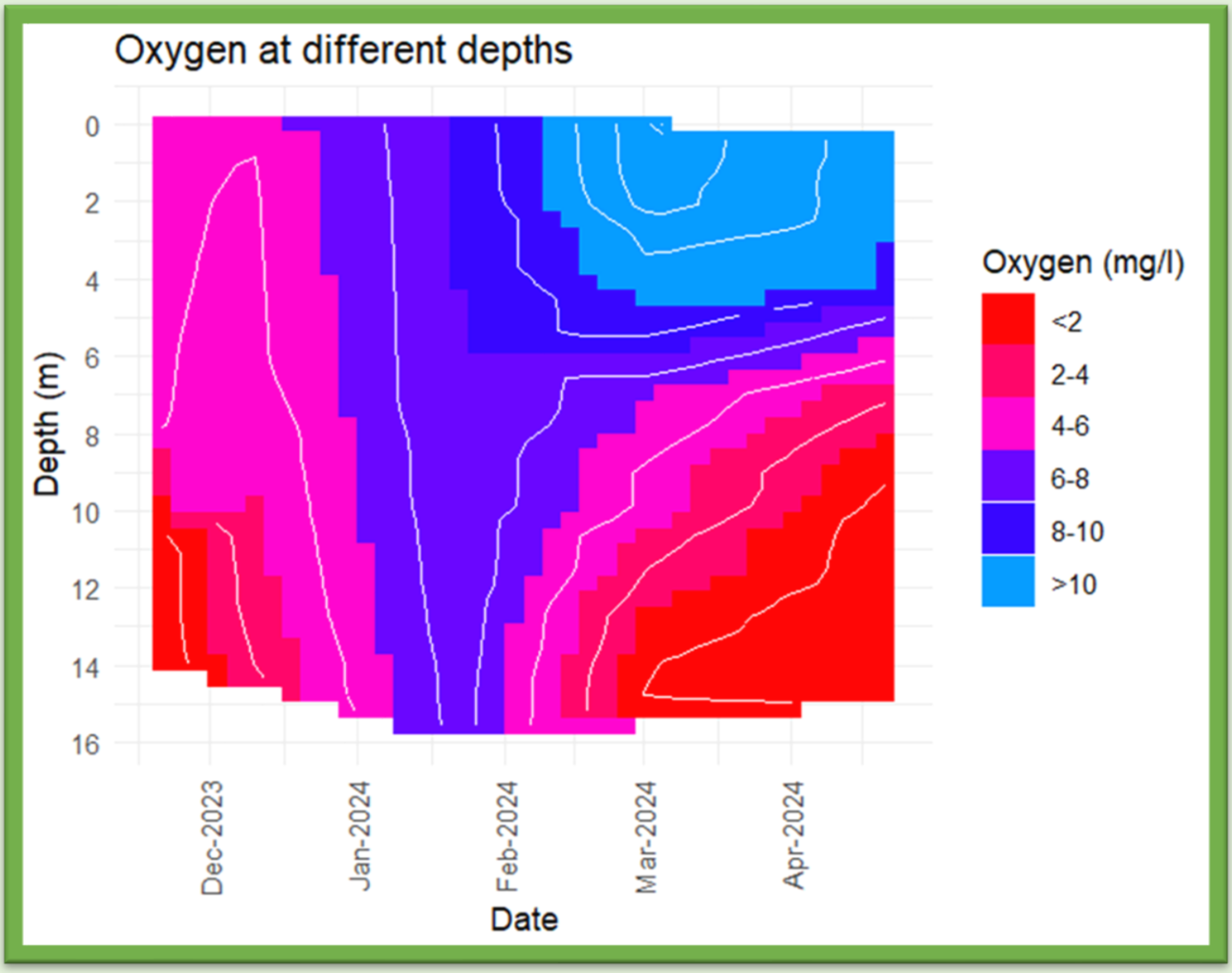

Figure 25 Oxygen concentration in de divers pond over time at different depths

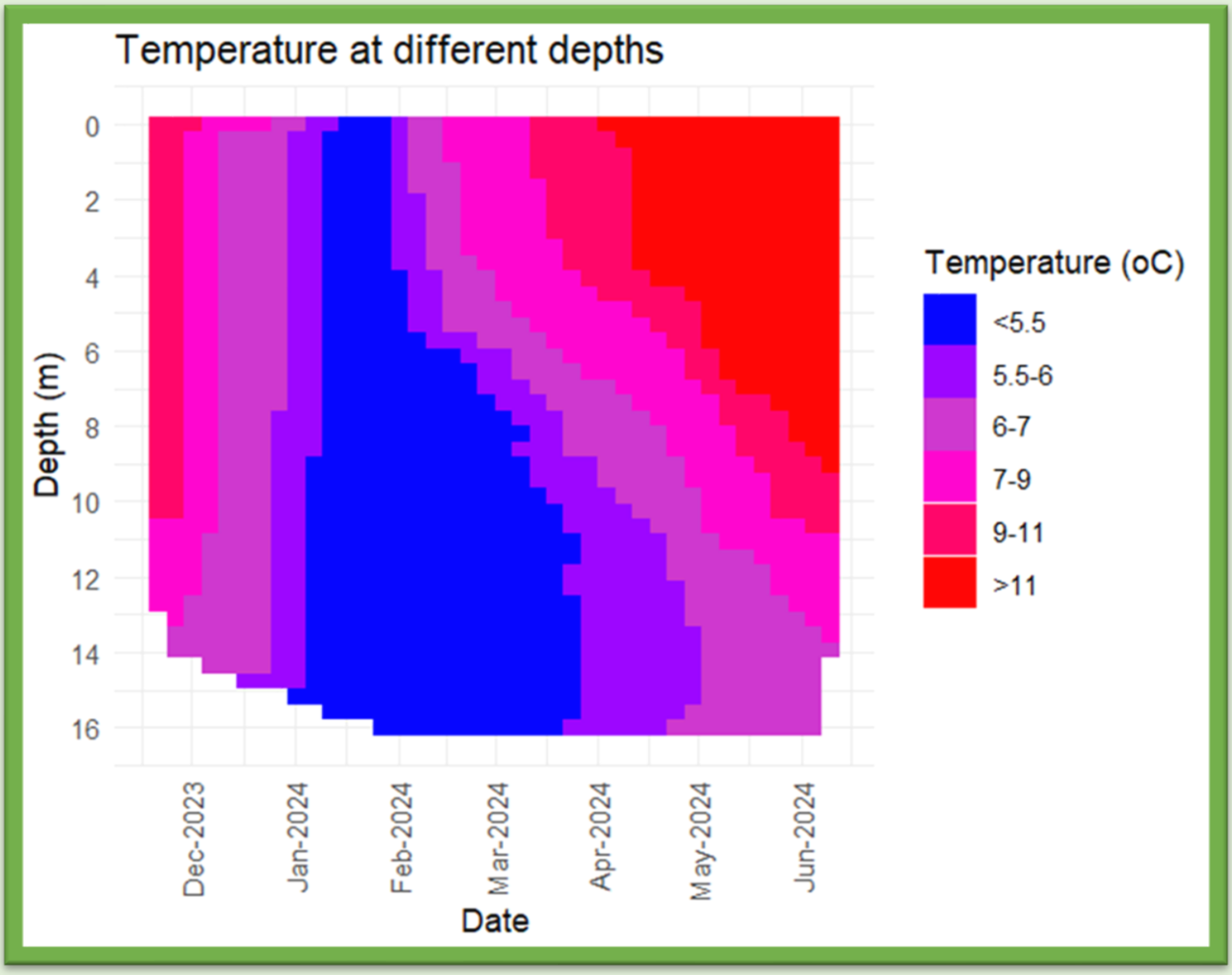

Figure 26 Temperature (in degrees Celsius) in de divers pond over time at different depths