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Ecological State of the Durowskie Lake During Restoration Measures Physical-Chemical Quality

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Introduction

Freshwater ecosystems are one of the most affected ecosystems, when it comes to human influence and alteration. These alterations affect a wide range of properties, from the morphology, ecosystem functioning, invasive species up to biodiversity loss and changes in the chemical properties of these systems (Carpenter et al. 2011).

These ecosystems have an intrinsic value, but beyond provide humans with valuable ecosystem services. These include recreational and cultural values, food production, hydration of other ecosystems, as well as dilution and degradation of pollutants (Carpenter et al. 2011). Therefore, freshwater lake ecosystems are very valuable and should be preserved in the best possible state. Their uniqueness and importance becomes even more pronounced, when looking at the proportion of freshwater on the total waters of the world; only 2,5 % of the world's waters are freshwater, of which only 0.26 % is found in lakes, reservoirs and rivers (Carpenter et al. 2011).

But not all of these freshwaters are in a good ecological and chemical state. In Europe, the Water Framework Directive (WFS), which came into force in 2000, is an important legislation to ensure this. In the WFS, the chemical status of waterbodies was defined through limits for certain substances, and member countries are obliged to keep their lakes within these limits and take measures to improve the quality, if limits are not met (European Environment Agency. 2018).

Despite that, in 2018, 46 % of the European water bodies did not achieve a good chemical condition defined by the WFS (European Environment Agency. 2018).

Since they do not meet the requirements, measures have to be taken to improve the water quality in these waterbodies. Many methods of restoration are very expensive, disruptive and only lead to a short term improvement of the water quality. Therefore, gradual improvement methods of water quality are an interesting new approach. Lake Durowskie is one example, where these gradual methods are applied to (Dondajewska et al. 2019).

The lake in question is located in the Northwest of Poland, 50 km from Poznań and Bydgoszcz. With geographic coordinates of N 52°49'6" and E 17°12'1", Lake Durowskie is situated in the centre of Wagrowiec (Stefan, A., 2012).

In the upper part of the lake, the city of Gołańcz is located, a modern wastewater treatment plant was installed to clean the waters flowing into the lake. Even though it reduces the impact, it does not fully remove the nutrient inflow. Despite this impact, the aim is to achieve a good ecological status in Lake Durowskie, in order to maintain the ecosystem services of the lake. To achieve this goal, inexpensive methods of restoration were applied and their effect on the lake is monitored annually (Dondajewska et al. 2019). These restoration methods include 2 aerators, which should oxygenate the water, iron treatment to bind the phosphorus as well as biomanipulation, in this case the stocking of the lake with pike fingerlings (Goldyn et al., 2013).

To assess the water quality and the success of these measures different physical and chemical parameters were analysed for this report and the Carlson's trophic state index was calculated to evaluate the state of eutrophication (Carlson and Simpson 1996; North American Lake Management Society 2022).

The aim of this report is therefore to assess the current water quality based on physical and chemical parameters and compare the results to the ones from the previous years to evaluate the long term changes in this waterbody. These results will lead to some recommendations for the improvement of the ecological state of the lake in the future.

Materials and Methods

Study area:

Durowskie is an urban lake in the Wielkopolska Region (Western Poland). The River Struga Goaniecka, a tributary of the River Wena, runs through this dimictic, flow-through, postglacial ribbon-type lake (River Odra basin) (Dondajewska, R. *et.al.,* 2019).

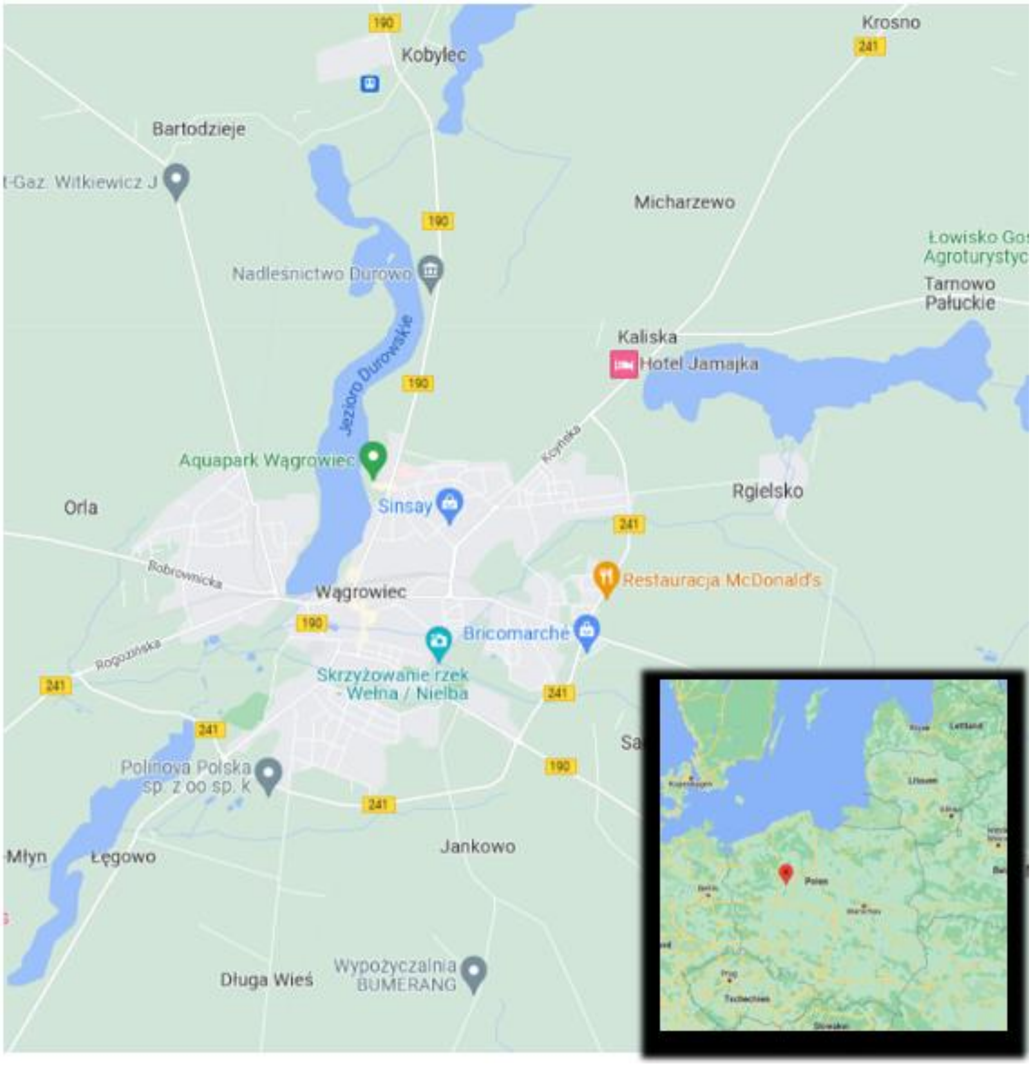

Figure 1: Location of Lake Durowskie in Poland and at the town of Wagrowiec. The inflow in the north east of the lake can be seen, where it is connected to hypertrophic lakes above (Google earth, 2022).

Lake Durowskie receives nutrients from the watershed of this waterway, which has a total length of 28 km, and a cascade of hypereutrophic lakes located above (Lakes Kobyleckie, Bukowieckie, Grylewskie, and Laskownickie) (Gruss, Ł. *et al.*, 2021). The lake's volume is 11,322,900 m3, its maximum depth is 14.6 m, its mean depth is 4.6 m, and its surface area is 143 ha. (Gruss, Ł. *et al.*, 2021). The length is 4340 m, and the shoreline measures 10,515 m. The lake is flanked by forests in the north and by cities in the south. Therefore, there is a lot of demand for recreational activities like swimming, sailing, and fishing (Dondajewska, R. *et.al.,* 2019).

Along the eastern and southern coastline, a promenade connects the leisure centres. Along the beaches and marinas, there are several fishing piers and jetties. Durowskie Lake's entire catchment area measures 236.1 km2 (covered mainly by rural areas). The nearby catchment area is 1581 ha, with 58.3 percent of the area being farmed, 33.5 percent forest, and 8.2 percent urban areas (Dondajewska, R. *et.al.,* 2019).

At the turn of the 20th and 21st centuries, Durowskie Lake was becoming increasingly eutrophic, with summer water blooms dominated by cyanobacteria, low transparency, oxygen depletion, and the presence of hydrogen sulphide in the water's deeper layers (Dondajewska, R. *et.al.,* 2019). Therefore, the following three sustainable restoration techniques were applied.

They are:

1. Hypolimnetic water aeration using two wind-driven aerators.
2. Phosphorus inactivation in the water column using low doses of iron sulphate (PIX type coagulant) and magnesium chloride.
3. Biomanipulation is based on pike and pikeperch fry stocking to increase the contribution of predatory fish in the lake ichthyofauna.

The restoration team installed two aerators in the lake, one in the deepest section next to the city and the other at a depth of 12 meters in the section surrounded by forest (Dondajewska, R. *et.al.,* 2019). Aerators work by oxygenating the hypolimnetic water above the lake's top layer and redistributing it to the bottom following oxygenation. Instead of coagulating the floating particulates, the tiny doses of iron sulphate, or 4 to 15 kg per ha, are utilized to restore inactivated orthophosphates in the water column. Phosphorus was removed from the water column by administering the treatment 3–5 times over the vegetation period. The stocking of pike was done erratically in 2011, using 100,000 more fries than usual. The greatest quantity of pikeperch fry was introduced in 2010, 114,000 specimens (Dondajewska, R. *et.al.,* 2019).

Sampling sites

In order to evaluate the water quality of the lake, four different points were selected at which water parameters were measured and water samples were taken to perform chemical analysis in the laboratory: middle 1, middle 2, aerator 1, aerator 2. The selected points are representative places of the entire lake, resampling previous annual surveys.

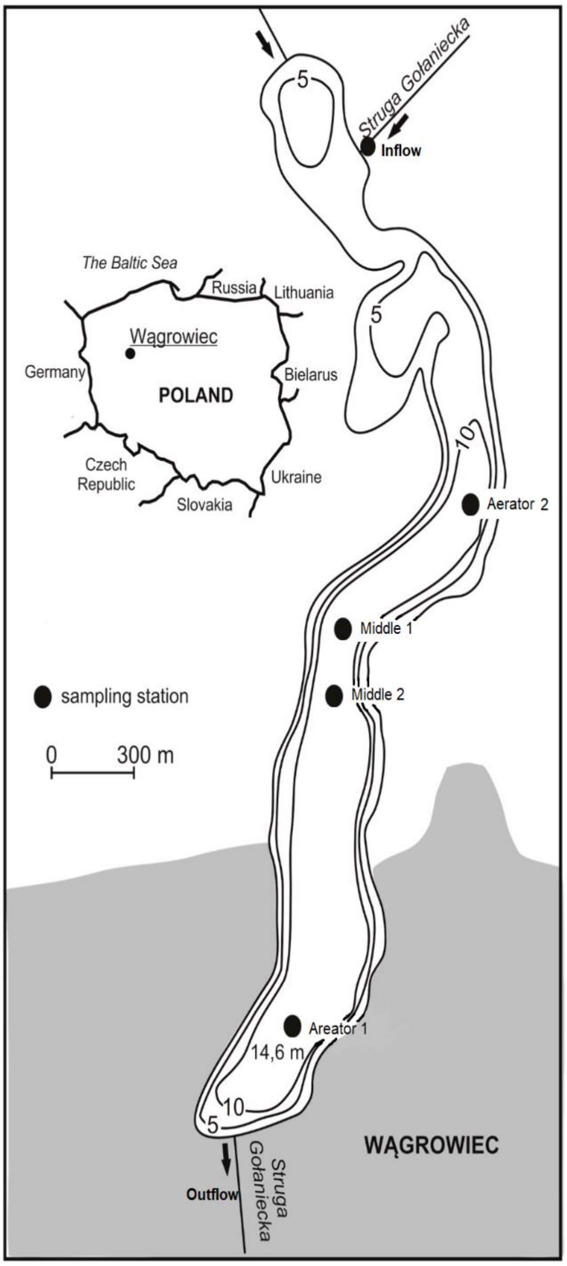

Figure 2: Sampling sites in lake Durowskie in the year 2022.

Field methods

Physical-chemical measurements taken at designated points on the lake provided information on: water temperature, DO value, percentage of dissolved oxygen in water, pH value, ORP value and Conductivity value. Measurements were taken from the water surface to the bottom (depending on the depth at the selected point, from 9 to 14 meters). The lake water samples were taken at four depths: 0, 1, 2 and 3 meters (approximately 2 litres per sample).

The field work took place from 27th June till 29th June. Laboratory tests took place from 30th June till 2nd July.

pH

The pH scale ranges from 0 (acidic) to 14 (basic), with 7 being neutral. It provides information on how many free hydrogen ions are in the solution. The biological availability of chemical compounds like nutrients (phosphorus, nitrogen, and carbon) and heavy metals is determined by the pH of water (lead, copper, cadmium). The pH range for natural waters is 4 to 9. Rain, sewage, or pollution can alter pH levels, which affects aquatic life. A stream's pH fluctuation may signal escalating pollution or other environmental issues (Islam, R., et al., 2017).

Temperature

Temperature is an important parameter for stream water ecology because it is a controlling factor in many biological processes. It also impacts other physical and chemical parameters in lake environments. For instance, the temperature increase causes a decrease in dissolved oxygen. That leads to the acceleration of chemical processes and increased microbiological productivity. The temperature of surface waters depends on different factors: climate zone, the season of the year, the origin of water and pollution distribution (for instance, a sewage load) (Islam, R., et al., 2017).

Conductivity

Conductivity is the ability of water to conduct an electrical current. It is often used as the first ratio of mineralization and pollution of water. It highly depends on the number of dissolved solids in the water. The more dissolved solids are in the water, the higher the conductivity value. Surface waters in Poland usually reach a conductivity of 100 to 500 µS/cm.

Dissolved oxygen

Oxygen concentration is an important ecological and biological parameter. Too little oxygen combined with high temperatures and a significant amount of nutrients may cause severe eutrophication in fresh waters. Nearly all aquatic plants and animals require oxygen to survive, yet dissolved oxygen concentration in water is significantly lower than that found in the atmosphere. Measuring the dissolved oxygen in water is the most critical water quality test to determine the suitability of water quality for many aquatic organisms (Islam, R., et al., 2017).

Secchi Disk

The Secchi Disk is an instrument for testing the transparency of water. It is a round, white disc with a diameter of 30 cm. The pulley is loaded and lowered on the rope. The disc is lowered until it is no longer visible to the naked eye. From then on, the disc is pulled out and the length of the rope immersed in the water is measured. The length of the rope at that moment indicates the secchi disk depth and is an indicator of water transparency. This value depends on the presence of suspended objects in the water, biological activity or turbidity. Objects suspended in the water column appear when solid objects are introduced into the water or, for example, when bottom sediments are disturbed. Turbidity may also come from loading of abiotic matter such as sediments or from a high concentration of biota such as phytoplankton. The transparency of the water is very important for the functioning of the aquatic ecosystem. The high transparency of the water allows sunlight to reach the deeper layers of the water reservoir, thus allowing the water to be heated in the entire range, and also allowing photosynthesis to be carried out by bottom plants, which increase the level of dissolved oxygen in the water and supply all layers of the water reservoir, eliminating the places where oxygen is absent.

Laboratory methods

Ammonium nitrogen (NH4-N)

To calculate the amount of ammonium nitrogen, first we poured 50 ml of sampled water into a Nessler glass. Then we added 1 ml of sodium-potassium tartrate and 1 ml of Nessler's reagent, mixed it and waited for 10 minutes. After that time, we measured absorbency for our samples using photometer at a wavelength of 410 nm.

Nitrate nitrogen (NO3-N)

To measure the concentrations of nitrate nitrogen from the water samples, we used evaporating dishes to which we added 5 ml of our water samples. Then we added 3 drops of 0.5% NaOH each. After that we added 1 ml of 0.5% sodium salicylate. The next step was to place evaporating dishes on a water bath and evaporate the samples. After the samples were evaporated, we cooled them down. After cooling the samples, we added 1 ml of concentrated sulphuric acid, spread the acid on the dish sides and left it for another 10 minutes. The next step was to remove the acid into the Nessler glass by washing the evaporating dish two times with distilled water. Then we added 7 ml of alkaline sodium-potassium tartrate and mixed. Later we filled the cylinder up to 50 ml of volume with distilled water. The last step was to measure the absorbance by the 410 nm wavelength.

Nitrite nitrogen (NO2-N)

We started by adding 100 ml of sampled water to the Nessler glass. Next we poured 5 ml of sulfanilic acid mixed cylinder and waited for 5 minutes. After that time, we added 1 ml of naphthylamine and 1 ml of acetate buffer and mixed it all again and waited for another 10 minutes. Then we measured absorbency by the wavelength of 510 nm using a photometer. In this method, medium pink colour indicates small presence of nitrite nitrogen in the samples.

Figure 3 Nitrite nitrogen analysis

Phosphate (PO4)

To analyse the amount of phosphate in our samples firstly we poured 50 ml of our sampled water into Nessler glass. Next we added 1 ml of ascorbic acid and 2 ml of molybdenum acid and mixed it. Then, after 10 minutes of waiting we started measuring absorbance by the wavelength of 850 nm.

Total phosphorus (TP)

In order to determine the concentration of total phosphorus using the ascorbic acid method, we poured 50 ml of the sample to the mineralization tube. After adding a few drops of phenolphthalein, we also added 1 ml of sulphuric acid to all samples and 10 ml of potassium peroxydisulfate ($K_2S_2O_8$). Then we placed our test-tubes in a warm place. The next step was to put on the suction overlay on the tubes and turn on the suction pump and start the mineralization unit on program 01 at 220^oC for 40 minutes. After the process was completed and the tubes had cooled down, we washed the tubes inside using distilled water, then mixed and poured that solution into a Nessler glass. The next step was to add a few drops of phenolphthalein. Then add drops of concentrated (6N) NaOH to neutralize the solution until a pink colour appears. After that we filled the cylinder to 50 ml of volume with distilled water. Then we added 1 ml of ascorbic acid and mixed. Then we added 2 ml of molybdenum acid and mixed. The final step was to measure the absorbance by a wavelength of 850 nm after 10 minutes.

Chlorophyll a

Chlorophyll a is a very important molecule. Different species of algae, phytoplankton and macrophytes use it to bind the solar energy so they can turn inorganic matter into organic, thus becoming primary producers of their ecosystems. Chlorophyll a molecule consists of a tetrapyrrole ring with a single ion of magnesium inside and one long phytol chain. Chlorophyll is able to absorb light with wavelength of 650- 700 nm (red light) and 400- 500 nm (blue-violet), at the same time deflecting green light which wavelength is around 550 nm and thus the molecule gains its green colour from which plants are so well known.

The number of Chlorophyll a molecules found in water samples can be very useful for estimating the amount of photosynthesizing plants living in an aquatic ecosystem and thus a very important indicator for water quality and the trophic state assessment.

The samples were around 1 L of water. After collection, samples were concentrated on the filter Whatmann GF/C by filtering the known amount of water containing seston. Later that filters were taken to the Biology Department of University of Adam Mickiewicz, where students measured the amount of chlorophyll a on each of them.

At first, filters were grated in a mortar with an addition of 2 ml of acetone. Then the pulp that was left from grating the filter was put into a centrifuge tube and filled up to the volume of 10 ml with acetone. After quick mixing, tubes were left for less than 24 hours in a dark fridge (4°C).

On the next day's morning samples were put into a centrifuge for 10 minutes and after that time 2 ml of extract were put into cuvettes. During the next step absorbance of each sample was checked in a photometer for two wavelengths: 663 nm and 750 nm and after that, 0,1 ml HCl was added to each of cuvette so acid could remove organic matter from the course of the beam of light that photometer uses. Then after 10 minutes, absorbance was again checked for every extract, this time for the wavelength of 665 nm and 750 nm.

The amount of chlorophyll a was then evaluated by using the following formula:

$$Chl_a = 26.73 * [(\mathrm{A663b} - \mathrm{A750b}) - (\mathrm{A665a} - \mathrm{A750a})] * \frac{\mathrm{Ve}}{\mathrm{Vw}} * \mathrm{L}$$

Where:

- A663b and A750b - marked absorption of the extract before adding acid
- A665a and A750a - marked absorption of the extract after adding acid
- Ve - volume of the prepared extract
- Vw - volume of the filtered water sample
- L - thickness of absorption in cuvette [cm]
- 26,73 - conversion factor
- X- amount of Chlorophyll a in a sample (μg/l)

Trophic State Index (TSI)

To classify TSI of Lake Durowskie, the amount of chlorophyll a in μg/L, transparency/Sd in meters, and the total P in μg/L were first used in some calculations. Then the TSI of each parameter was added together, to create the overall trophic state, TSIM. The trophic state class was then classified with Table 1 from Carlson and Simpson (1996):

1. TSIM(Chla) = 9.81 ln(Chla) + 30.6
2. TSIM(Total P) = 14.42 ln(Total P) + 4.15
3. TSIM(Sd) = 60 – 14.41 ln(Sd)
4. TSIM = 0.54 TSIM(Chla) + 0.297 TSIM(Sd) + 0.163 TSIM(TP)

Table 1 Trophic state class

Trophic Class	TSI_M	Chla (μg/L)	Total P (μg/L)	Sd (m)
Oligotrophic	<30-40	0-2.6	0-12	4 to 8
Mesotrophic	40-50	2.6-7.3	12 to 24	2 to 4
Eutrophic	50-70	7.3-56	24-96	0.5-2

Results

Dissolved oxygen

According to the results, the highest dissolved oxygen values were obtained at the “Outflow” and “Middle 1” stations, being 7.08 mg/l and 6.61 mg/l. Similarly, the lowest values of dissolved oxygen were obtained at the "Aerator 2" and "Inflow" stations, being 4.21 mg/l and 4.66 mg/l, respectively (Figure N°1).

Figure N°1 shows that the highest values of dissolved oxygen do not appear in the monitoring stations near to the aerators as it would be expected, but rather the results are contradictory, showing lower levels of dissolved oxygen near to the station "Aerator 2".

According to the results obtained by Dyussenbayeva et al. (2018), values with a higher amount of dissolved oxygen were obtained in the same “Outflow” and “Middle 1” stations, these being 7.6 mg/l and 5.76 mg/l, respectively. Likewise, the areas with the least amount of dissolved oxygen were "Aerator 1" and "Inflow" being 3.5 mg/l and 2.61 mg/l, respectively.

In contrast to the monitoring carried out in 2018, the amount of dissolved oxygen is lower this year.

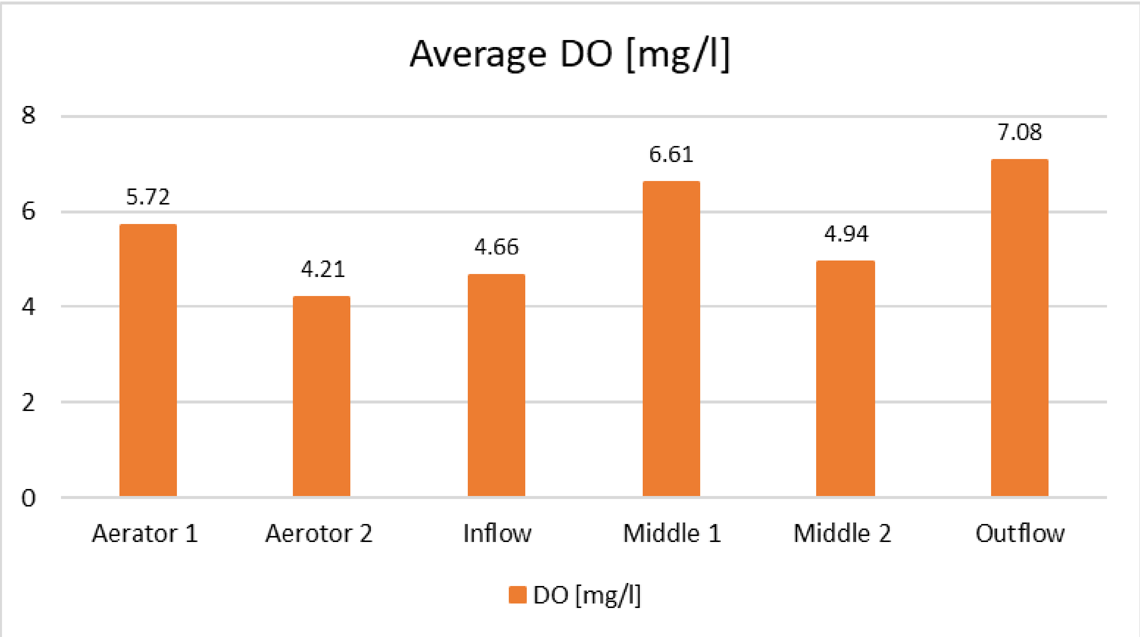

Figure 4 Dissolved oxygen distribution of Lake Duroswkie. Own elaboration 2022

pH

According to the results obtained in the field, the average pH of the sampling stations varies between 8.70 and 9.05. As it can be seen in Figure N° 2, the stations "Aerator 1", "Aerator 2", "Inflow", "Middle 1", and "Middle 2" present a slight variation in pH. These stations have a neutral to alkaline tendency. Regarding the "Outflow" station, it presented the highest pH (9.05) being slightly alkaline.

Taking as a reference the results obtained from previous pH monitoring (Dyussenbayeva et al., 2018) in which the range was from 7.74 to 8.20, a comparison of both results indicates that the pH has slightly increased in 2022.

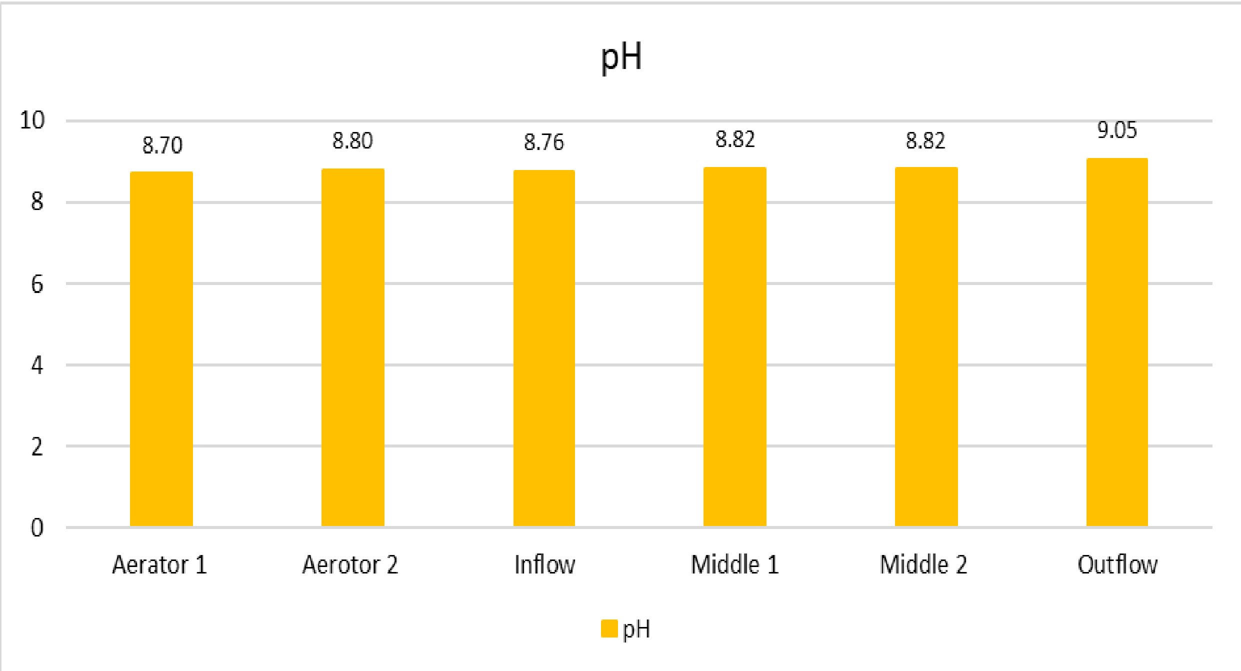

Figure 5 pH distribution of Lake Duroswkie. Own elaboration 2022.

Water temperature

Figure N° 3 shows the results of the average temperature by monitoring stations. The station with the highest temperature was the "Outflow" station with 17.43°C and the one with the lowest temperature was the "Aerator 1" station with 13.22°C. Likewise, it is important to note that the “Outflow” station was the shallowest, with a maximum depth of 9m, and the “Aerator 1” station was one of the deepest, with a depth of 15m. We can observe that in each station the deeper it is; the water temperature tends to decrease.

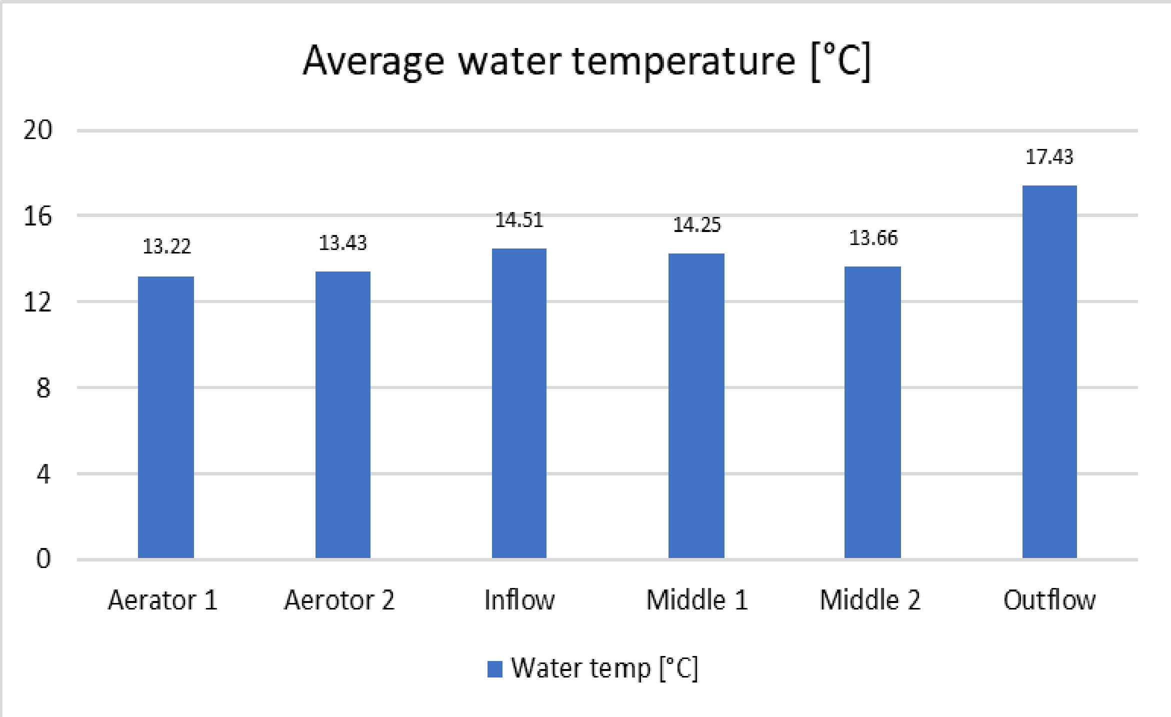

Figure 6 Water temperature distribution of Lake Duroswkie. Own elaboration 2022.

Transparency

The transparency parameter indicates that the stations with less turbid waters were "Aerator 1" and "Middle 1" (Figure N°4), being able to observe the Secchi Disk to a depth of 4.41m and 4.40m, respectively. The stations that presented the most turbidity were “Aerator 2” and “Inflow”, with a transparency of 3.78m and 3.77m, respectively.

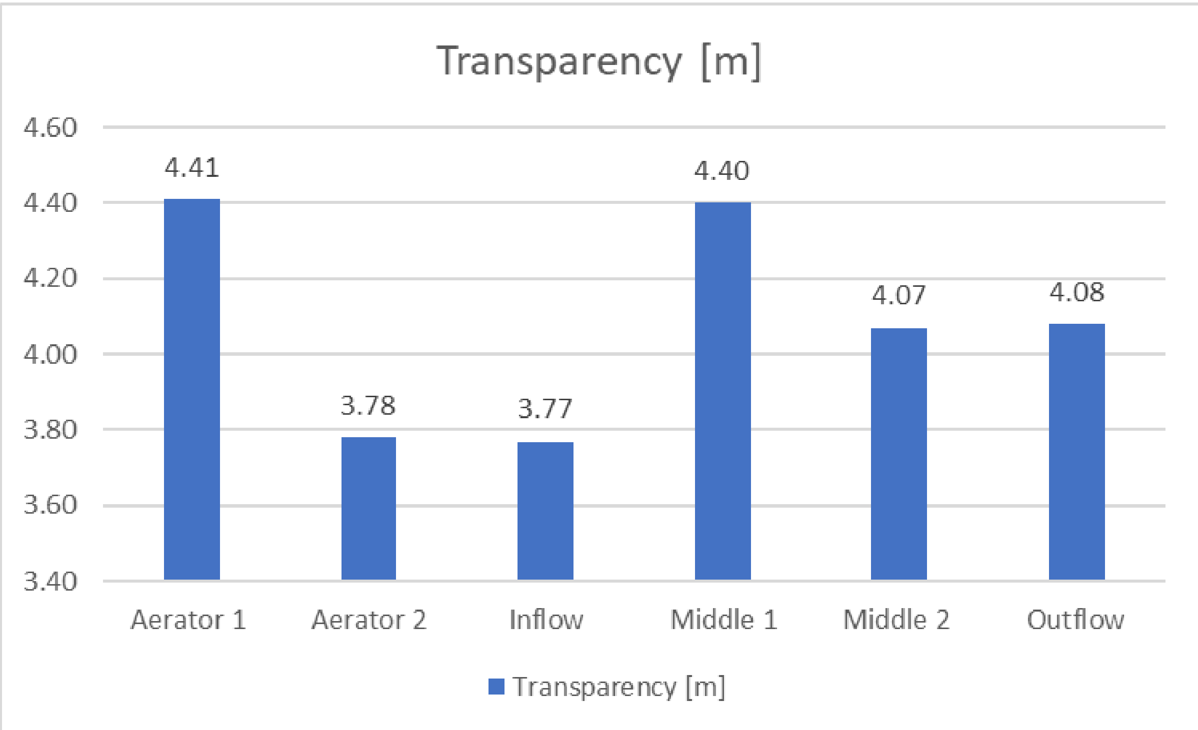

Figure 7 Transparency distribution of Lake Duroswkie. Own elaboration 2022.

Figure N°5 shows that the transparency in the lake has varied over the years. In previous years (2017 and 2018), the results showed that there was greater turbidity in relation to depth. However, in 2022 results there is less turbidity, in which it is possible to see the Secchi Disk up to an average depth of 4m.

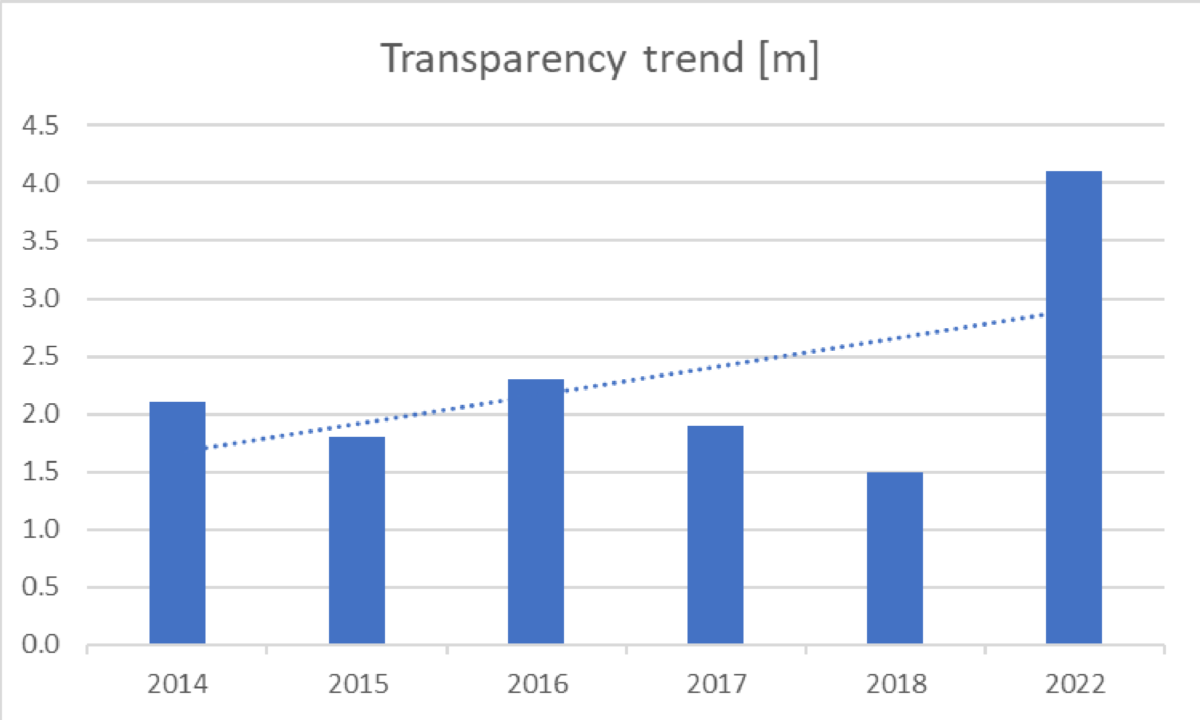

Figure 8 Transparency trend of Lake Duroswkie. Own elaboration 2022.

Chlorophyll a

Chlorophyll a measurements showed some variations, at aerator 2 they were much lower than in other parts with 2,99 micrograms per litre and the highest at aerator 1 and the inflow with 6,65 and 6,89 respectively. The other values were around 4,5 each.

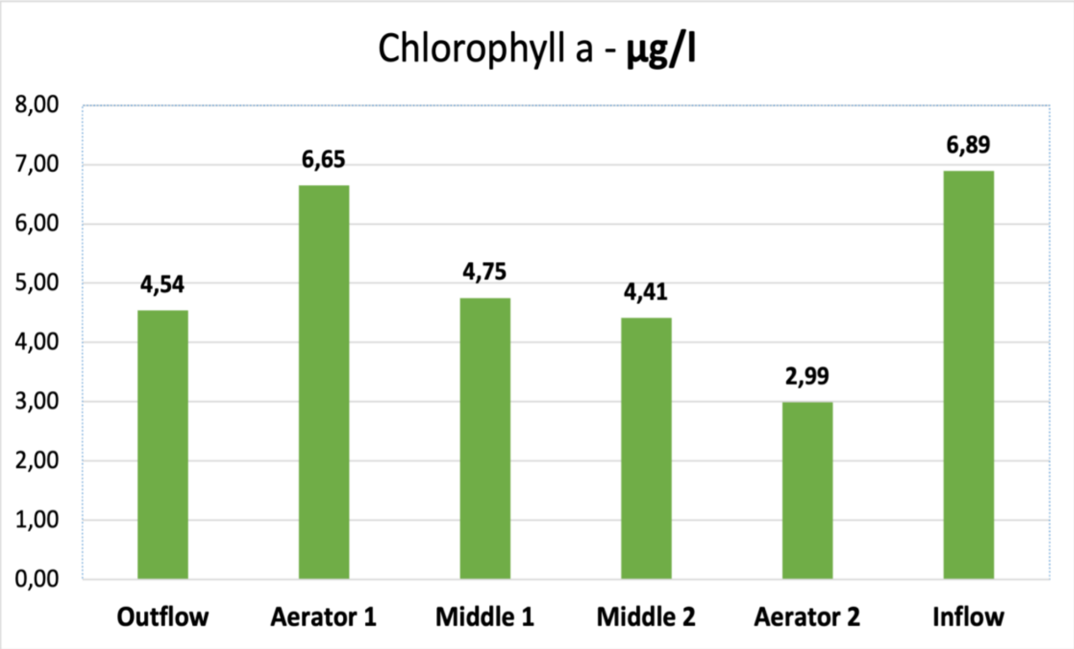

Figure 9 Chlorophyll a content

TSI Chlorophyll a

The calculated trophic state index had all values between 4 and 5 although the Aerator 2 site was again the lowest with 4,13 and the Inflow the highest with 4,95.

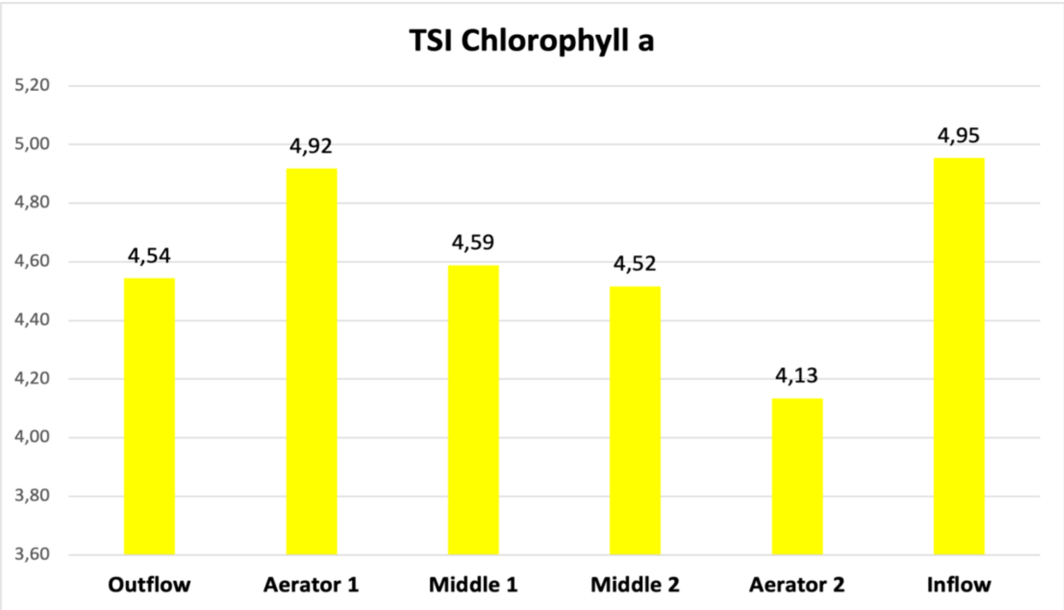

Figure 10 TSI based on Chlorophyll a on the different measuring points.

Total Nutrients

Total phosphorus is a biological activity indicator of the water body as the living organisms use phosphorus for their living processes and the less TP there is, the higher the biological activity is.

The higher total phosphorus and nitrogen concentrations are observed at the Inflow site and Outflow. Comparatively with 2019, the total nutrient concentration has increased.

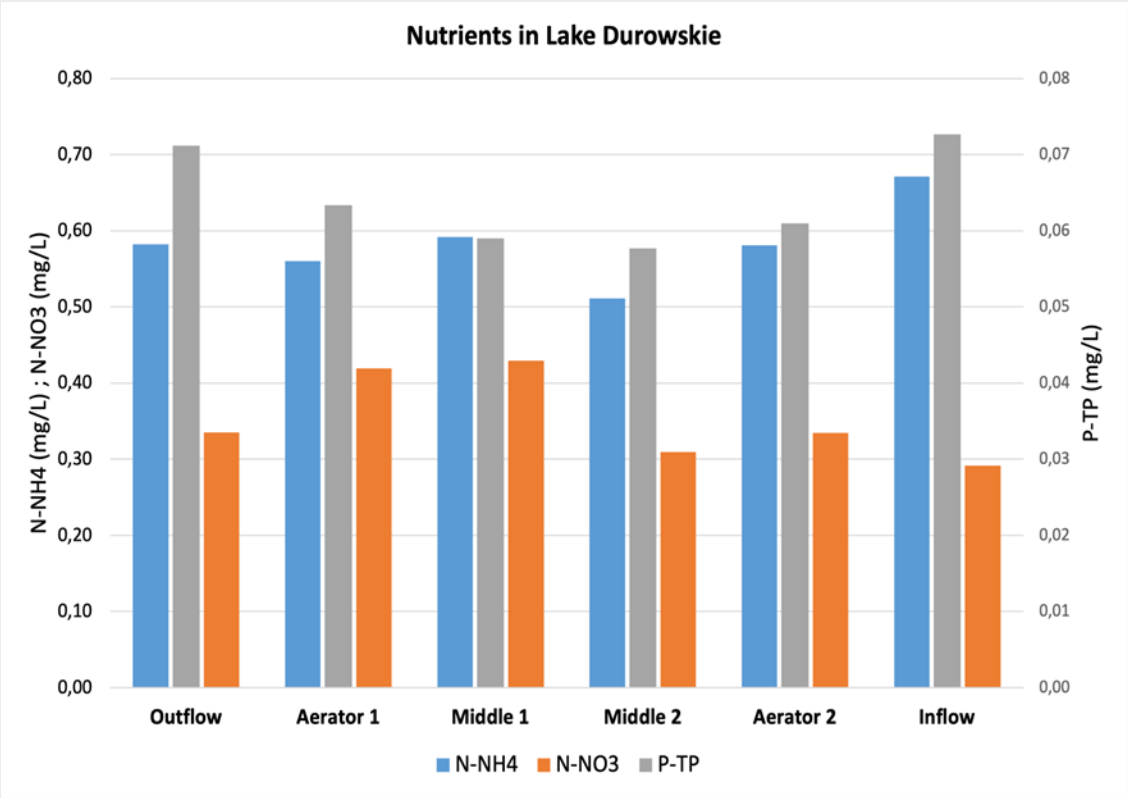

Figure 11 Total nutrient concentration 2022

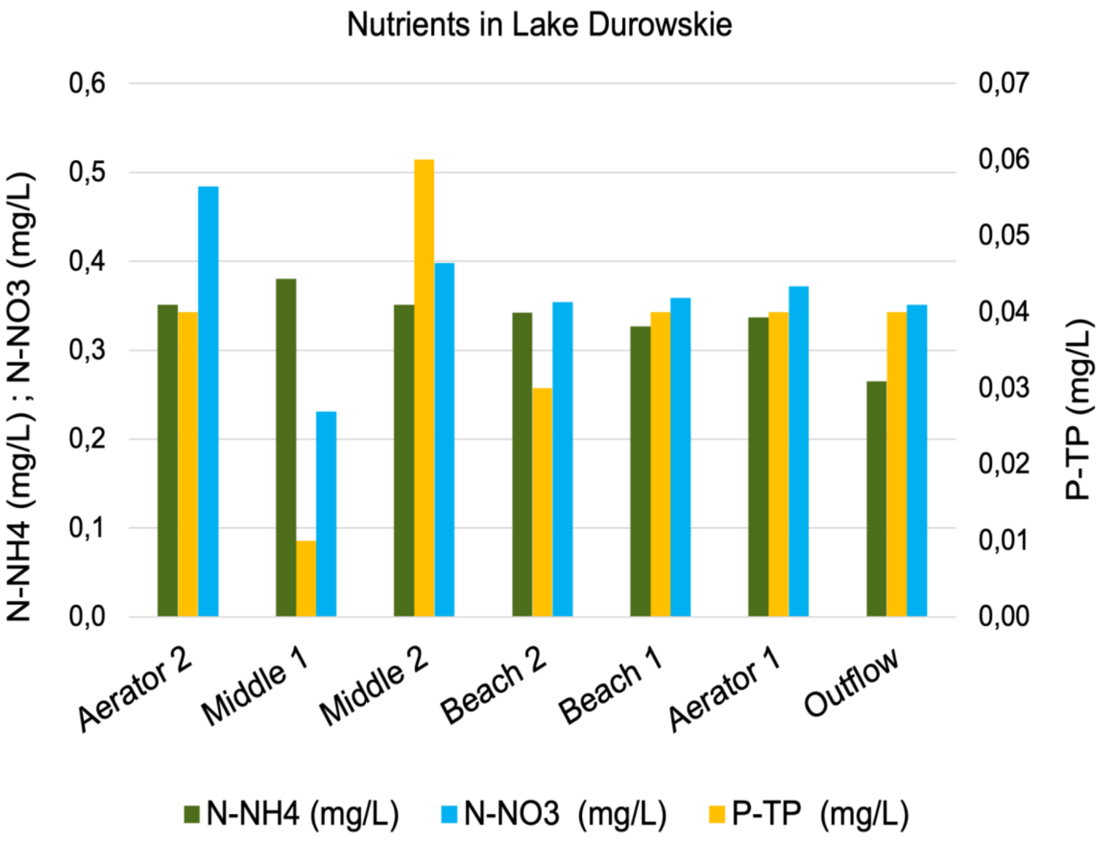

Figure 12 Total nutrient concentration 2019

Trophic State Index

This year Trophic State Index (TSI) for Lake Durowskie shows slight increase in water quality, compared to 2018. But, comparing the data with the year 2017 we could see instability in the water quality, with the lake going from almost oligotrophic to almost eutrophic and now to mesotrophic. Especially the value at the inflow, as well as the lower part of the lake are high. The next year analysis will tell us the direction of the water quality.

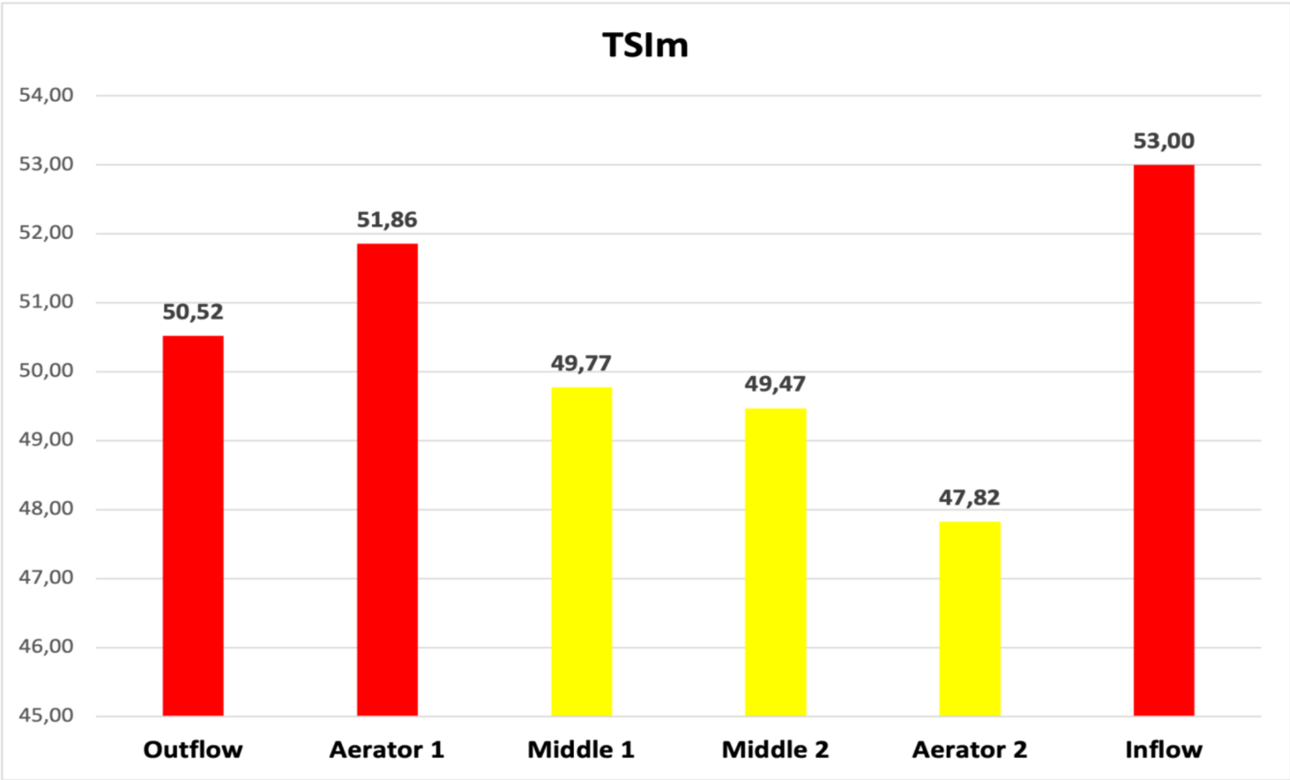

Figure 13 TSI measured 2022

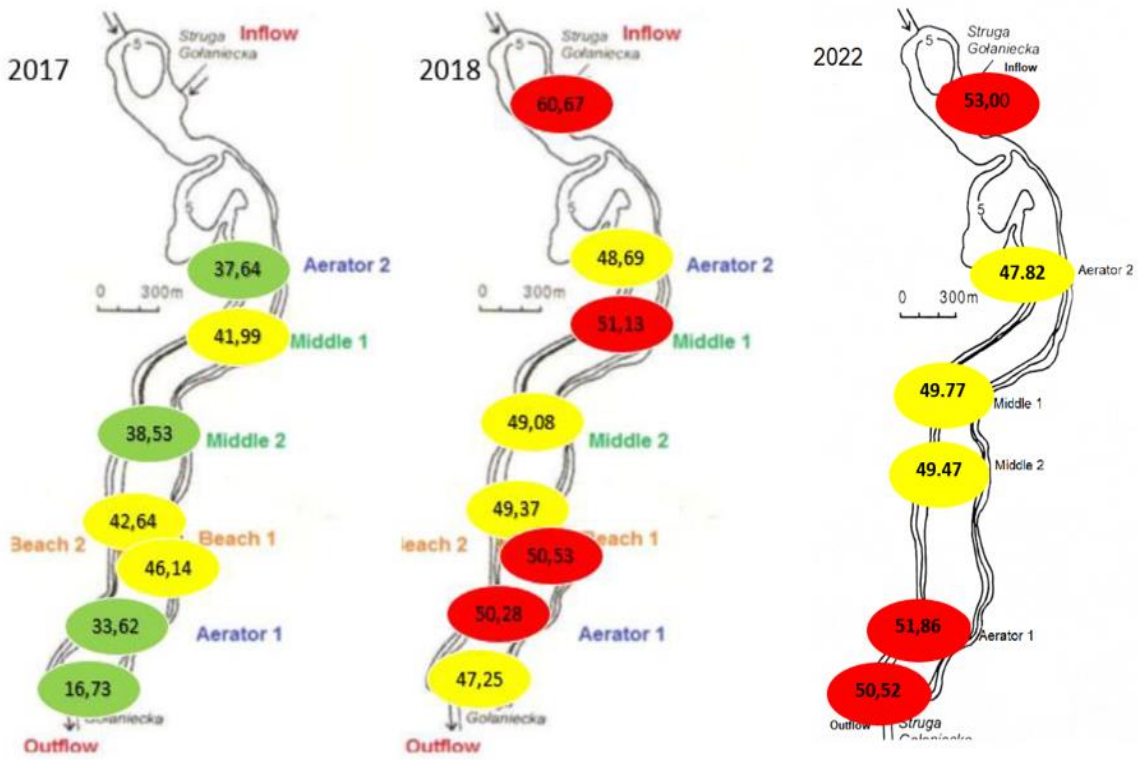

Figure 14 TSI in comparison from the years 2017 - 2022

Discussion and Conclusions

As we can see some of the parameters show better results, than in the previous years. For example, the oxygen content could be an indicator of improved water quality for the organisms that inhabit the lake. However, it is important to point out that the monitoring stations near the aerators have not shown a higher dissolved oxygen index compared to other stations as it was expected. Besides, due to the influence of recreational activities near the middle zones of the lake, it is possible that the higher movement induces aeration.

But also the turbidity was for example lower, than in the previous years. Although we have to be careful, as this parameter might be influenced by the weather. Also this year it is important to highlight that the transparency monitoring in the less turbid stations was carried out on a sunny day and the monitoring of the more turbid stations was carried out on a cloudy day, which could have influenced the difference in the results.

Moreover, also the lower chlorophyll A content in the lake suggests, that less Cyanobacteria are present influencing the Secchi disk values.

Still, as we could observe, the total nutrient content has increased, and is especially high at the inflow. The Inflow is connected to the water input from the aquatic system above and the possible inflow of nutrients at the area of Outflow might have originated from the urban area or from the fact that Aerator 1 is not functional at the moment. The organic phosphorus concentration at other sites is quite similar that might indicate comparable levels of biological activity.

Presumably the cottages at the northern edge of the lake impact the quality of the lake and, therefore, the nutrient concentration at the inflow. The comparatively low concentration at Middle site suggests the absence of any direct inflows at the middle part of the lake.

The nutrient content is therefore a point of concern, as it can lead to an algal bloom with the rising temperatures in the summer, although this hasn´t happened yet. Also the TSI suggests that the development of the lake is not stable and we will only see in the future, where the lake is heading to.

Suggestions

As the nutrient inflow from the hypereutrophic lakes is a concern it might be advisable to work with the other municipalities to limit the nutrient inflow and consider the lakes as a holistic system. Also is the northern part a state of concern, as the values indicate, that excessive nutrient inflow takes place. This needs to be further studied and evaluated where these nutrients originate from.

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