ECOLOGICAL STATE OF DUROWSKIE LAKE

HYDROLOGY AND WATER QUALITY

WĄGROWIEC – POZNAŃ 2018

Anastasiia Vasiullina (CAU)
Alua Dyussenbayeva (CAU)
Almagul Zhakiyenova
Mateusz Draga (UAM)

Supervisor: Dr. Naicheng Wu (CAU)

25.06.2018 – 08.07.2018

Contents

Introduction

Freshwater ecosystems, such as lakes and rivers are important providers of supporting, provisioning, cultural ecosystem services for human exploitation. Therefore, they are negatively affected by urban development, industrial and agricultural activities (Klapper, 2003). Lake Durowskie is an essential local ecosystem carrying great touristic importance for Wagrowiec town's income. It is a narrowly-shaped water body covering an area of 143.7 hectares, supplied by the flows of Struga Golaniecka River coming through the lake from upper lakes and is located in the West of Poland. Mainly the town flourishes because of the lake's recreational purposes, such as kayaking, fishing, bathing, and agricultural activities in its northern part. All of this and the increase of human settlements, waste water treatment are contributing a lot towards deterioration of the water quality. Disposal of sewage water, drainage from agricultural surrounding lands and nutrient inputs from upstream lakes led to the blooming of the water with cyanobacteria resulting in critical eutrophic state of the lake, bad water transparency. Such adverse effects prevent the pursuit of achieving a good ecological state of aquatic ecosystems, as determined by the European Water Framework Directive (WFD) or other similar standards.

To enhance the ecological state of the lake and restore its ecosystem services, several actions have been taken since 2009 with the support of the Wagrowiec municipality by building two wind aerators for hypolimnetic waters oxygenation, biomanipulation measures - artificial augmentation of pike fingerlings populations, phosphorus immobilization following iron treatment and establishment of monitoring project for efficient Durowskie Lake restoration (Goldyn et al., 2013).

Aims of the work on physico-chemical study:

I. Assessment of the current ecological state of lake water quality
II. Evaluation of the long-term changes of the water quality
III. Determination of nutrient inflows and outflows of the lake
IV. Recommendations for the lake state improvement

To assess the water quality, and thus the ecological state of the lake Durowskie, physical and chemical parameters, such as Electrical conductivity (EC), Temperature, Turbidity (Secchi disc depth), flow velocity, pH, Oxygen concentration, Chlorophyll-*a* content, total Phosphorus (TP), Nitrate concentrations are taken into consideration. In addition, Chlorophyll-*a* content, total Phosphorus (TP), Turbidity (Secchi disc depth) are used as indicators for the assessment of the lake's trophic state implementing Carlson's Trophic State Index (TSI) equations (Carlson and Simpson, 1996).

Materials and methods

Study area

The main study area is Lake Durowskie. The lake is located at Wagrowiec, the city with population around 30,000 people. The main income of the city comes from tourism and recreation services, which is based on the natural features of the lake (Figure 1).

Figure 1. The station of water transportation renting on Lake Durowskie, one of the touristic services of Wagrowiec

The lake is the last aquatic body in the chain of six lakes of post-glacial origin: Zamkowe, Laskowickie, Grylewskie, Bukowieckie, Kobyleckie and Durowskie itself. Those lakes are described as elongated in north-south direction and relatively deep water objects with steep slopes.

The land use of the catchment area around Lake Durowskie is characterised by the predominance of agricultural lands at the north (58,26%), occupation of the banks of the middle part by forests (33,52%) and dislocation of urban areas at the southern and south-eastern edges of the lake (8,25%) (Figure 2).

Lake Durowskie occupies the territory of 143.7 ha and has a volume of 11 322 900 m^3. The maximum depth is 14,6 m at the southern part of the lake near the aerator 1 while the average depth is 7,9 m.

Sampling sites

In order to observe the water quality of the lake eight sampling points were located on the lake itself: two at the beaches at the southern part of the lake that are the areas with the main recreational stress (Beach 1, Beach 2); two near aerators (Aerator 1, Aerator 2); two at the middle part of the lake (Middle 1, Middle 2) and sites close to inflow and outflow points (Figure 3). Moreover, the physical-chemical measurements and samplings at inflow and outflow sites between lakes were done to observe a flow of nutrient load down the stream (Inflow_G, Inflow_B, Inflow_K, Inflow_D, Outflow_D). The additional sampling points were located at the lake Zamkowe, Laskowickie, Grylewckie and Bukowieckie.

Figure 2. Map of the land use around Lake Durowskie (created by Hydrology Group Summerschool 2011).

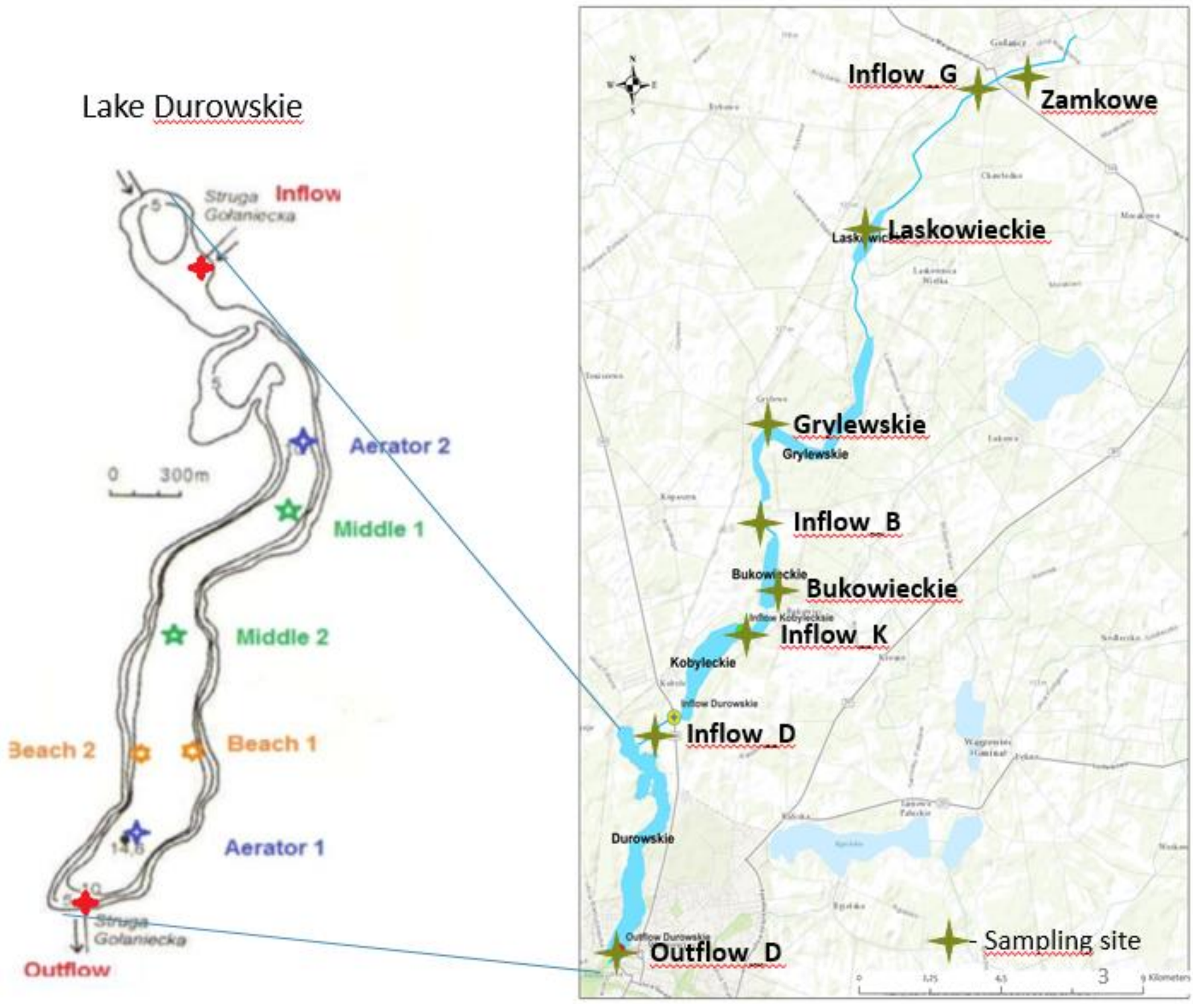

Figure 3. Location of sampling sites at Lake Durowskie and the whole studied aquatic system

Field methods

At the inflow and outflow points the water flow velocity, pH, conductivity, dissolved oxygen and water temperature were measured in situ (Figure 4). The samples for later laboratory analysis of nutrient content and chlorophyll a concentration were taken (around 2 litres at each site). During sampling and the streams' measurement it was important to ignore stagnant water places.

The samples at the sites at Lake Durowskie were taken from four depths: 0, 1, 2 and 3 m. The measurements of physical-chemical parameters were performed from the surface until the lake bottom with every one meter step.

The samples (1 l for nutrient and chlorophyll a analysis) and the physical-chemical data at the other lakes were collected at one point close to the shore at the middle part of the lake.

The field works took place from 25th July till 30th July.

Figure 4. The measurement of pH, dissolved oxygen and temperature in situ

Water flow velocity

The water flow velocity was measured at inflow/outflow sites of the studied aquatic system in order to calculate discharge for further analyses (Figure 5). The discharge is a function of the flow velocity and the surface of the stream cross section.

Figure 5. The measurement of flow velocity at Inflow_D site

As water velocity is not constant in all points of the cross section because of the friction of the water with the stream bed, vegetation and wind the stream speed should be measured at different distance from the river bank and at different depth (Figure 6). The cross section is divided into several subsections with equal horizontal extend (x) (Figure 7). The number and width of every subsection depends on the river width and parameters of the river bed.

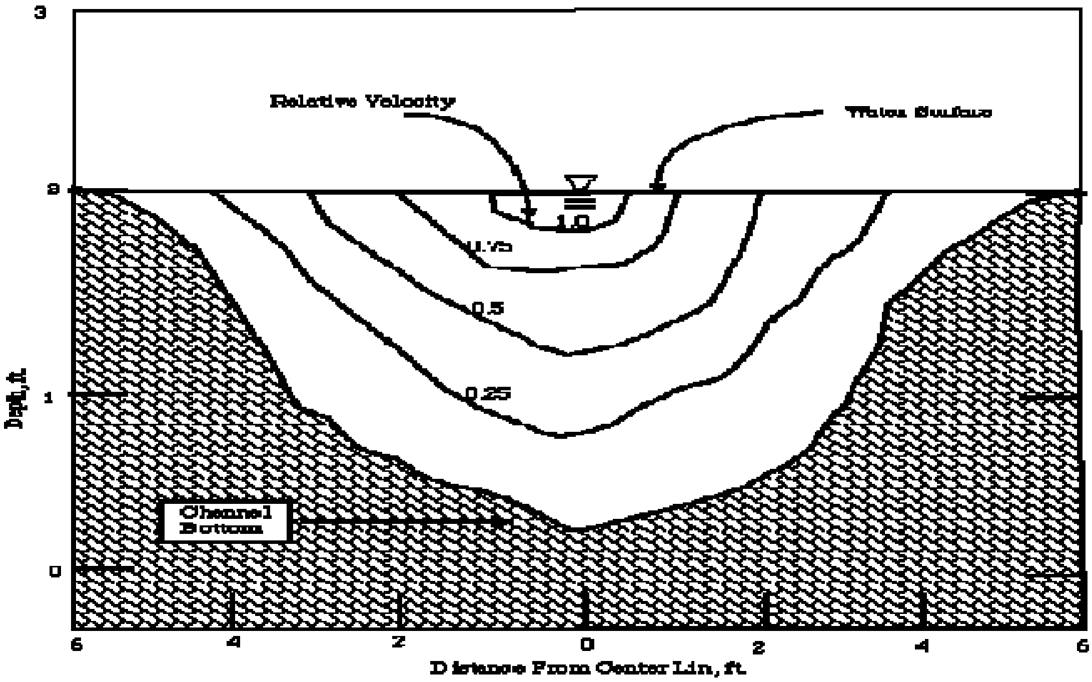

Figure 6. Distribution of flow velocity in a river cross section (Shaw, 1989)

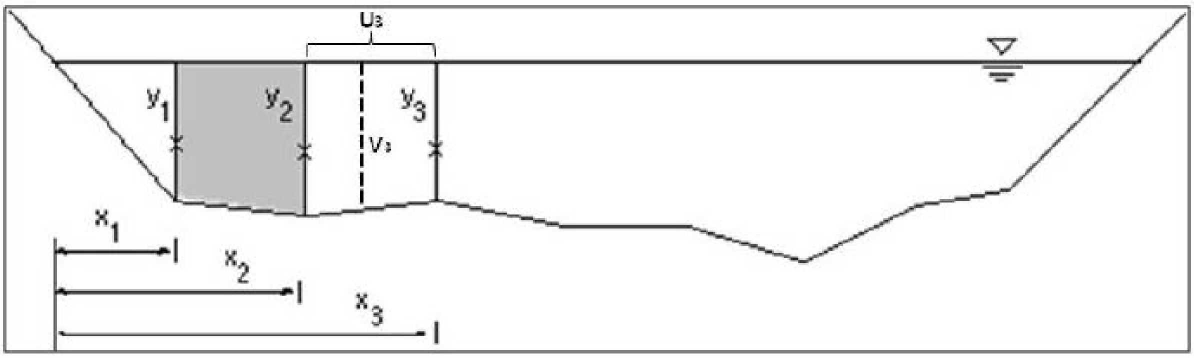

Figure 7. Subsection of a river cross section to determine flow velocities for every subsection (Source: unknown)

The velocity is measured at each vertical (y) at different depths. The first measurement is 5 cm higher than the stream bed and the last one is 5 cm lower from the water surface. The distance from the first and last measurements along the vertical is divided equally and velocity is determined at these points. Similarly, the number of collected data depends on the depth of the vertical.

In this study, an Electromagnetic velocity meter (FlowSens) was used for data collection. Faraday's law is in the principle of the velocity calculation. The position of a sensor can be changed manually along the metal stick. It produces magnetic field and the movement of conductor in the water flow is resulted in certain voltage amount that is used for velocity calculation (Song et al., 2012). The sensor should be positioned parallel towards the water flow direction. The velocity is measured every second during 30 seconds. The digital control unit displays the average water velocity and the standard deviation of the measured data set. If the standard deviation is more than 0.1 the velocity should be re-measured. If the velocity is negative, it means that the water flows at the same direction as the sensor is positioned.

The total discharge Q (m^3/s) is obtained as a multiplication of the area of each subsection (m^2) and the average velocity (m/s) of each cross section:

$$Q = \sum_{i=1}^{n} a_i \overline{v_i}$$

The discharge of water flows from a lake to a lake down the stream was calculated in order to calculate later the nutrient load (m^3/s).

pH

pH is one the basic water parameters that is measured in vast majority of hydrological studies. pH corresponds to the concentration of hydrogen ion in a solution. The pH value varies between 0 (acidic) and 14 (basic) and is neutral at the value of 7 (theoretical value). The water pH determines the forms of the nutrients and heavy metals existed in the water: whether they are dissolved or are in solid form.

The dissolved carbon dioxide reacts with water molecules and creates the carbonic acid, which might lower the water pH. If pH is more than 8,3 there is a lack of carbon dioxide in water, which indicates the increased decay rate of organic material and the respiration of living organisms (according to Prof.Goldyn). Therefore, the water with high pH value is expected to be affected by algae bloom phenomena.

The pH values were measured by potentiometric method, which is based on the potential measurement between glass and reference electrodes.

Temperature

Temperature is another basic water parameter that indicates the biological activity in the water body and development of the aquatic organisms. Basically, an increase of water temperature leads to an increase of biological activity. Additionally, various species prefer the water of different temperature and this characteristic influences the number or the presence of certain organisms.

Conductivity

Conductivity is a measure of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds. Compounds that dissolve into ions are also known as electrolytes. The more ions that are present in the water there are, the higher the conductivity of water is. Conductivity, in particular specific conductance, is one of the most useful and commonly measured water quality parameters. In addition to being the basis of most salinity and total dissolved solids calculations, conductivity is an early indicator of change in a water system. A sudden increase or decrease in conductivity in a body of water can indicate pollution.

Dissolved oxygen

Dissolved oxygen is essential to healthy streams and lakes. The dissolved oxygen level can be an indication of how polluted the water is and how well the water can support aquatic plant and animal life. Generally, a higher dissolved oxygen level indicates better water quality. If dissolved oxygen levels are too low, some fish and other organisms may not be able to survive. Much of the dissolved oxygen in water comes from oxygen in the air that has dissolved in the water. Some of the dissolved oxygen in the water is a result of photosynthesis of aquatic plants.

Secchi Disk

Secchi disk method measures the water transparency. The device consists of the white circular disk with 30 cm diameter, weight to make it stable and the ropes. The disk is lowered into the water until the moment it is no longer visible with the naked eye. The length of the rope at that moment indicates the secchi disk depth and is an indicator of water transparency. The value depends on turbidity and biological activity. Turbidity can be caused by high concentrations of biota such as phytoplankton, or by loading of abiotic matter such as sediments. Turbidity is important in aquatic systems as it can alter light intensities through the water column, thus potentially affecting rates of photosynthesis and the distribution of organisms within the water column. Lowered rates of photosynthesis may in turn affect the levels of dissolved oxygen available in a given body of water, thus affecting larger populations such as fish.

Laboratory methods

Nutrient concentration

All live on the Earth is built up from composition of elements, from which maybe the most important are those that we call “macroelements” (N, P, S, K, Mg, Ca, Na, Cl) because each of them correspond to at least 0,1% of organism weight. Each of them could become a limiting factor for growth of any population if access to them would be difficult or their local presence would be low, but normally their accessibility in fresh or salt water is very high. The only exceptions are nitrogen and phosphorus, and commonly these two elements control an amount of algae or phytoplankton in ecosystem and prevented them from uncontrollable, massive growth that can be harmful not only for ecosystem but also for humans. However nowadays, a lot of organic matter from fields or sewers gets into the water or rivers and lakes and with them, straight into the sea, supplying those ecosystems with extremely high amount of N and P in the form of ammonium nitrogen (NH4-N), nitrate nitrogen (NH3-N), nitrite nitrogen (NO2-N), phosphate (PO4) and total phosphorus (TP). Thus is very important to check their abundance in water if we want to gain any knowledge about trophic state and pollution level of fresh and saltwater environments.

43 (1 for each zone and day) of water samples for nutrient concentration were taken between 25th and 28th of June. Later they were transported to Department of Biology and studied during 3 days of laboratory work.

Figure 8. Photometer used for the analyses

Ammonium nitrogen (NH4-N)

To calculate the amount of ammonium nitrogen, first we poured 50 ml of sampled water into 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. In this method, strong yellow colour shows high concentration of ammonium nitrogen in the sampled water (Figure 9).

Figure 9. Properly prepared samples showing different levels of ammonium nitrogen concentration.

Nitrate nitrogen (NO3-N)

To measure concentration of nitrate nitrogen in the water samples, first we prepared evaporating dishes upon which we poured 5 ml of our samples. After that we added 3 drops of 0,5% NaOH and 1 ml of 0,5% sodium salicylate and placed evaporating dishes on water bath and started evaporating our samples. When we were we removed our dishes from water bath so they could cool down and then we spreaded 1 ml of concentrated sulphuric acid on their surface. After 10 minutes we moved the acid into Nessler glass by washing each dish two times with distilled water. During our next step we added 7 ml of alcalic sodium-potassium tartrate, mixed it and then we filled up Nessler glass up to 50 ml with distilled water. Next, we measured absorbency using photometer at light wavelength of 410 nm. Strong yellow colour in this method indicates high amount of nitrate nitrogen in samples.

Nitrite nitrogen (NO2-N)

We started by adding 100 ml of sampled water to 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 photometer. In this method, intensive pink colour indicates strong presence of nitrite nitrogen in the samples (Figure 10).

Figure 10. Properly prepared samples showing different amounts of nitrite nitrogen inside

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. Strong blue colour of liquid informs us about high abundance of phosphate in our samples (Figure 11).

Figure 11. Properly prepared samples, showing different amounts of phosphate concentration

Total phosphorus (TP)

To determine concentration of total phosphorus we started with pouring 50 ml of our water samples into mineralization tube. Next we added a few drops phenolphatalein and if the mixture turned pink, we added a few drops of sulfuric acid. Then we added to each sample 1 ml of sulfuric acid and 10 ml of potassium peroxidisulfate. In the next step we started mineralization process that took place in a fume hood, heated our mixtures up to lasted for 40 minutes, during which time our mixtures were heated up to 220°C. After that time we waited for our tubes to cold down and then we washed them inside with distilled water and then after mixing we poured that solution into Nessler glass. With the next step we added 1 ml of phenolphatalein and then we started adding drops of concentrated NaOH until solution changed its colour to pink. After that we filled the cylinder up to 50 ml of its volume with distillate water and added 1 ml of ascorbic acid and 2 ml molybdenum acid and mixed the solution and waited for 10 minutes. Finally, we used photometer to measure the absorbance for a wavelength of 850 nm. Strong blue colour was a sign of strong concentration of total phosphorus.

Chlorophyll a

Chlorophyll a is very important molecule. Different species of algae, phytoplankton and macrophytes use it to bind the solar energy so they could turn inorganic matter into organic, thus becoming primary producers of theirs ecosystems. Chlorophyll a molecule consist of 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 it's green colour from which plants are so well known.

Number of Chlorophyll a molecules found in water samples can be very useful in estimation an amount of photosynthesizing plants living in aquatic ecosystems and thus becoming very important indicator for water quality, informing us about the trophic state of waterbody.

43 water samples were taken from 15 different sites between 25 and 30 of June, each containing 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 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 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).

The next day 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 photometer for two wavelength: 663 nm and 750 nm and after that, 0,1 ml HCl was added to each of cuvettes so acid could remove organic matter from the course of the beam of light that photometer uses (Figure 12). 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 in our samples 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)

Figure 12. Photometer used for Chlorophyll a measurement

Trophic State Index

Carlson's Trophic State Index (TSI) is a very quick and easy method that we used to estimate the trophic level of Lake Durowskie. The only indicators that are required to be able to use it are: Chlorophyll a, Total Phosphorus and Transparency. To calculate TSI, first you need to calculate TSIm(Chl a), TSIm(TP), TSIm(Sd) from the following equations:

$TSIm(Chl\ a) = 9.81\ ln(Chl\ a) + 30.6$

$TSIm(TP) = 14.42\ ln(TP) + 4.15$

$TSIm(Sd) = 60 - 14.41\ ln(Sd)$

Where: Chl a stands for Chlorophyll a (µg/L), TP stands for Total Phosphorus (µg/L) and Sd is Secchi transparency (m).

So we could calculate TSIm using the following:

$TSI = 0.54\ TSI\ (Chl\ a) + 0.297\ TSI\ (Sd) + 0.163\ TSI\ (TP)$

And then choose the corresponding trophic class (table 1).

Table 1. Classification of Trophic State Index (TSI) (Carlson & Simpson, 1996)

TSI_M	Chl*a* (µg/L)	TP (µg/L)	Sd (m)	Trophic Class
<30—40	0—2.6	0—12	4—>8	Oligotrophic
40—50	2.6—7.3	12—24	2—4	Mesotrophic
50—70	7.3—56	24—96	0.5—2	Eutrophic
70—100+	56—155+	96—384+	<0.25—0.5	Hypereutrophic

Results and discussion

pH

The average pH recorded along the lake ranged between 7.74 and 8.20 (Figure 13). The figure shows little variation in pH at different part of the lake. According to the data, the medium of the lake is described as neutral to alkaline. The relatively higher pH recorded at the two beaches could be a result of pollution from bathing creams and detergents.

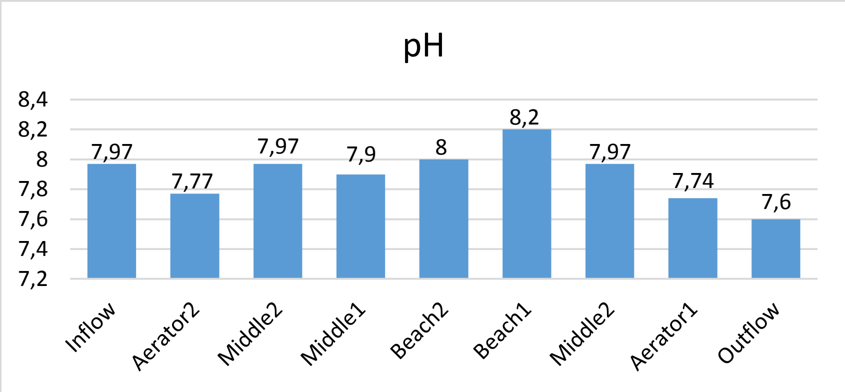

Figure 13. pH distribution of Lake Durowskie in 2018

Transparency

Transparency data at Lake Durowskie shows the better water quality at the Aerator 2 site and the worse conditions at Inflow point (Figure 14). It is explained by high concentration of cyanobacteria and high turbidity rate because of constant water flowing from the stream. Moreover, the heavy rain during the week of field work brought extra sediments to the site.

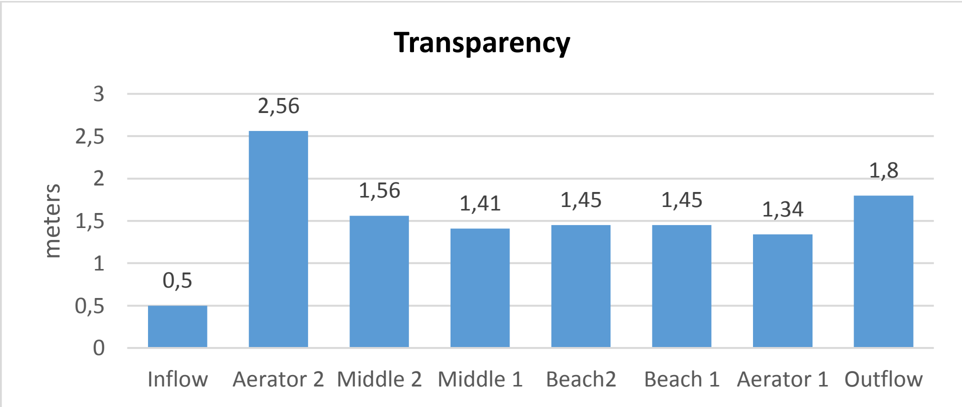

Figure 14. Transparency distribution at the sites at Lake Durowskie in 2018

The transparency trend over the years shows the decline of the data (Figure 15). This year the lower values are explained by weather conditions: dry spring weather increased the concentration of the sediments and heavy rain during the field work week that brought extra sediments into the lake decreased the values.

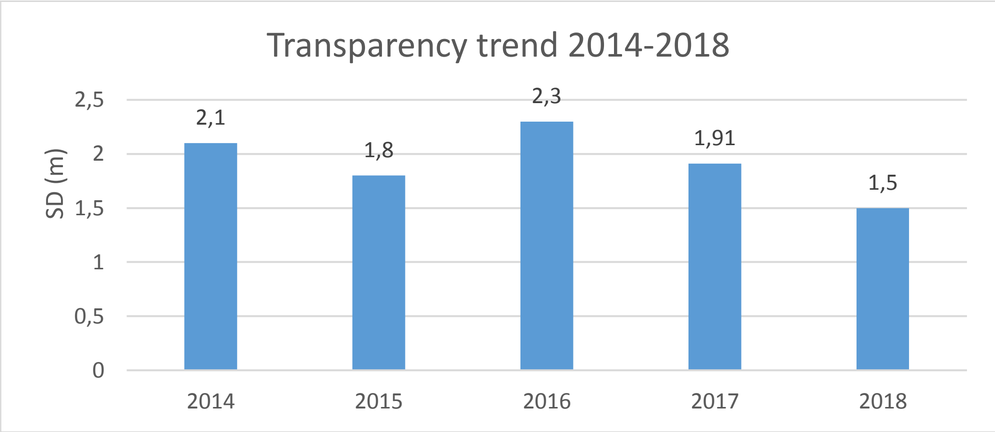

Figure 15. The transparency trend of Lake Durowskie from 2014 to 2018

Dissolved oxygen

Dissolved oxygen refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a water body. A too high or too low dissolved oxygen level might harm aquatic life and affect water quality.

From the analysis, the highest dissolved oxygen on the lake was recorded at Beach 1 and Outflow (Figure 16). Also Middle 1 and Middle 2 had much higher dissolved oxygen than Aerator 1 and Aerator 2 sites. Logically, one would expect the sites closer to the aerators supposed to have higher dissolved oxygen than other parts of the lake. But according to our results this was not the case. One reason for the higher dissolved oxygen recorded at the beaches and at the outflow could be due to the constant mixing of the water by kayak, speed boat and other water vehicles as well as swimming in these areas. The lower value of dissolved oxygen near Inflow and Aerator 1.

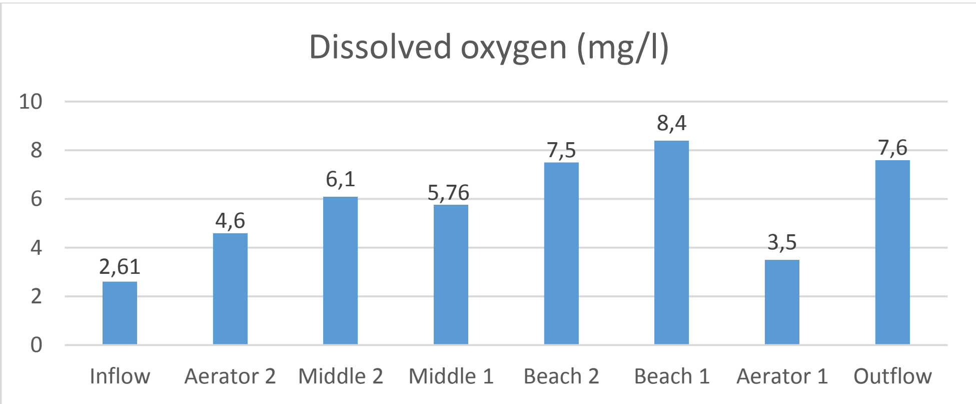

Figure 16. Dissolved oxygen concentrations on selected stations in Durowskie Lake

It can be seen that Aerator 1 and Aerator 2 have been showing lower value of dissolved oxygen than other stations during long-term period (Figure 17). In all years, the value of dissolved oxygen was higher close to the beaches, which might be explained by human activity. Also, this year the value is higher in Middle 1 and Middle 2. It also might be due to the activities of speed boats.

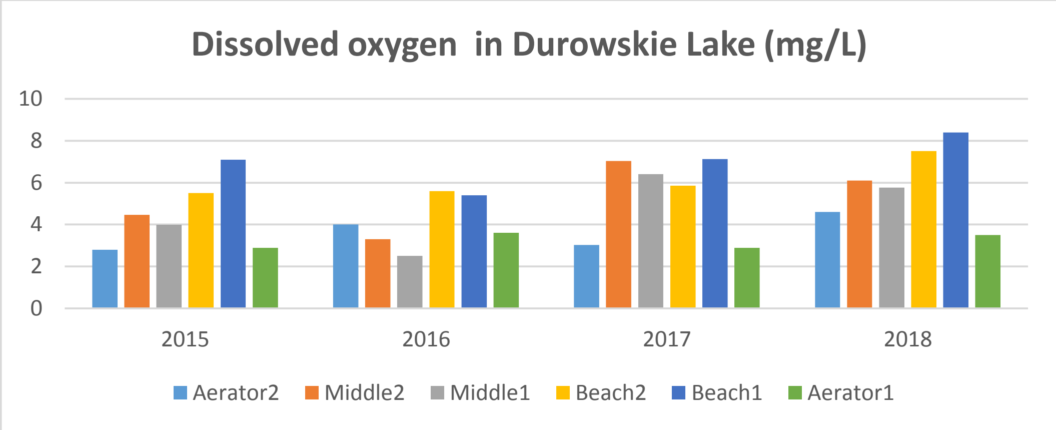

Figure 17. Trend of Dissolved oxygen concentrations on selected stations in Durowskie Lake

Chlorophyll a

The comparison between the years 2011-2018 in the graph given below shows a steady and stable decrease of Chlorophyll *a* concentration in the whole lake starting from the year 2013 (Figure 18). It is possible that after the implementation of the restoration management program it was gradually declining from 2011, but due to the missing part of data on beach 1 and beach 2 sample points in 2012, the result of that year with a sudden drop in concentration up to 2 µg/l might have been misleading. According to the classification of trophic state index (TSI) (Carlson and Simpson, 1996), Durowskie Lake has been identified as a Mesotrophic for the last 5 years. It proves that the restoration effort makes a mere and good progress in diminishing phytoplankton blooms and in enhancing the general lake condition.

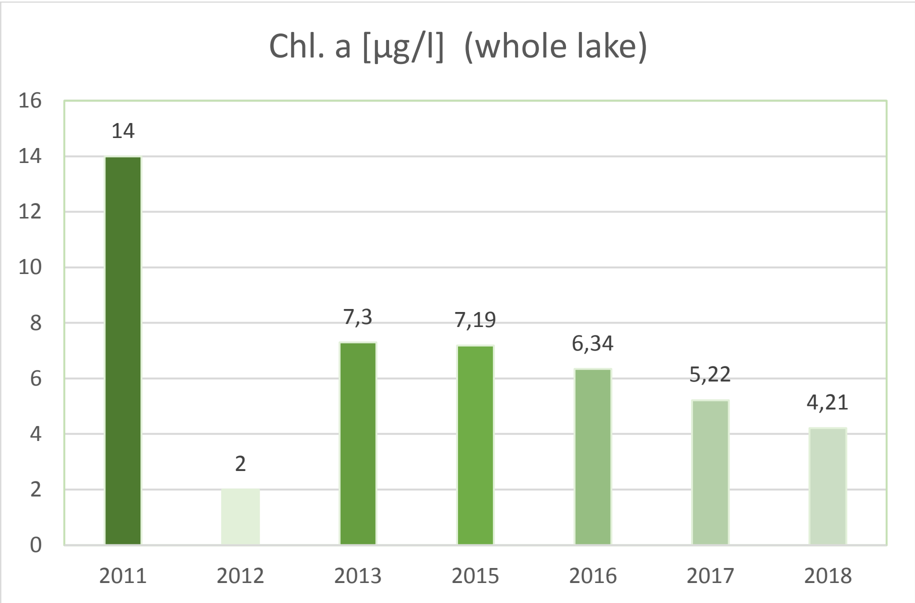

Figure 18. Chlorophyll *a* concentration in the lake Durowskie throughout the years 2011-2018

The results of Chlorophyll *a* concentration in sample collection points of the lake Durowskie in 2018 differ from the results of 2017, excluding the inflow and the outflow of the lake (Figure 19). In the outflow the concentration has changed just slightly. However, the data on inflow of the lake was not present in the report of 2017, thus we could not conduct a comparison between these years. As a guess, it is likely that the concentration has not really changed in this area in a year, because it is like a deposit of contamination that usually comes with the waters from the upper lakes with nutrients and phytoplankton. In 2018, the sites with the highest concentrations are inflow of the lake, aerator 2 and middle 1. Regarding the inflow, it can be explained by being highly rich with the *cyanobacterium Microcystis* population which grows only in that area of the lake, whilst the outflow of the lake has the lowest concentration of Chlorophyll *a* estimating nearly four times lower concentration in this area in 2018. However, it is hardly possible to explain why exactly this year aerator 2 and middle 1 have the greatest concentrations, but last year aerator 1 had almost as high as inflow concentration this year which is rather strange. In fact, the southern region of the lake should have much less concentration, because normally it is diluted in the water by the water flow and wind movements. We assume that last year there must have been a human factor in getting such high value while collecting samples by aerator 1. Generally, there is a noticeable change in the trend between these years, and in 2018 we can observe a decrease of phytoplankton in those sampling sites where its concentration was higher last year. It is possible that it is due to the minimization of motor boat usage on the lake at high speed that usually induces big waves bringing phytoplankton from the bottom to the medium and surface layers of the water body. In 2018, the concentration in the southern part of the lake is lower than that of the northern side, which is opposite to the comparison of these regions in 2017. It is also correlated with the motor boats driving at a high speed and their limitations this year. Additionally, the explanation of the chlorophyll *a* greater concentrations in the Northern region is that it is surrounded by the settlements and agricultural lands where the nutrients come from with water run-offs. Also, the erosion of soils have an impact forming steep slopes by the lake.

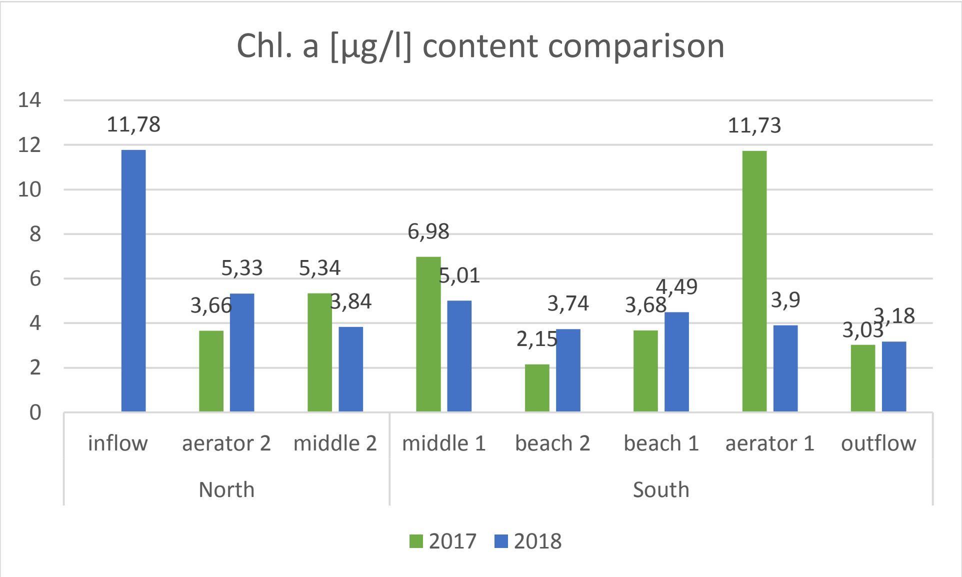

Figure 19. Chlorophyll *a* concentration in different sampling points of the lake Durowskie's Northern and Southern regions in 2017/2018.

The diagram below illustrates that in comparison with the previous years of 2015 and 2016, this year only Bukowieckie, Durowskie Lake and its outflow are showing the declining trend of Chlorophyll *a* concentration (Figure 20). In 2018, including Grylewskie Lake they all fall in a mesotrophic category. Zamkowe, Laskowickie, Durowskie inflow are classified to be in a eutrophic state. The current year, the concentration of chlorophyll *a* increases after

Grylewskie in Bukowieckie due to the surrounding settlements and then it increases again in Durowskie inflow. The reason of quiet a great difference between the concentrations in Bukowieckie and Durowskie inflow is because there is a small shallow lake before Kobyleckie Lake which deposits all sediments and it is responsible for further output to the downstream lakes. In conclusion, this year all catchment areas are predominantly in a mesotrophic state which is a good indicator. To have a better understanding of the nutrient flows and high chlorophyll *a* concentrations in all catchment areas it is crucial to investigate the upstream lakes more thoroughly every year and also seasonally, because last year there was no data on Durowskie's upper lakes. Therefore, the comparison with three consecutive years, including 2017 year, could not be effectuated. Generally, we could say that in 2018, the trend of Chlorophyl *a* concentration coming from Zamkowe to Durowskie could be characterized as decreasing. The red vertical line on the graph indicates the threshold (7,3 μg/l) between mesotrophic and eutrophic state of lakes (Carlson and Simpson, 1996). And it stipulates that with the greater the concentration, the worse is the trophic state.

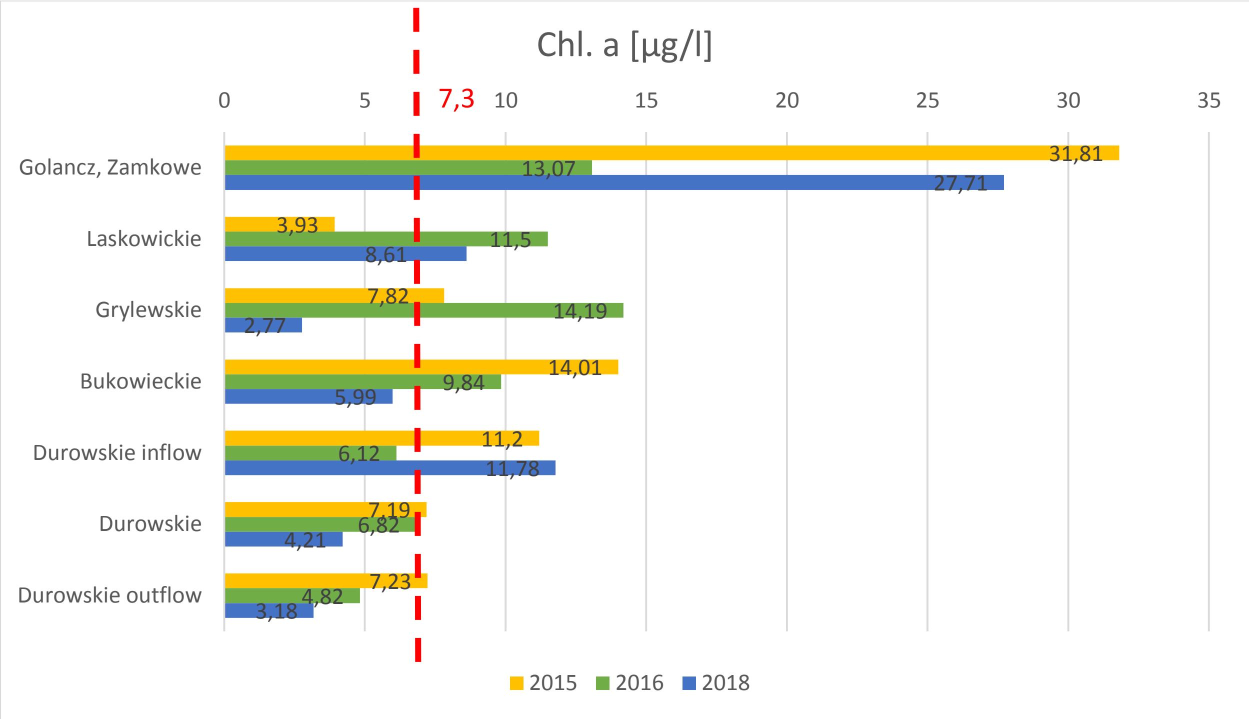

Figure 20. Comparison of Chlorophyll *a* content in the upper lakes and in Durowskie Lake between 2015, 2016, 2018

Nutrient concentration

As a result of laboratory work we got the concentration of ammonium nitrogen (NH4-N, mg/l), nitrite nitrogen (NO2, mg/L), nitrate nitrogen (NO3, mg/L), orthophosphate phosphorus (PO4, mg/L) and total phosphorus (TP, mg/L). The measured nitrogen is in inorganic form, therefore, for further analyses the sum of three concentrations will be used as a concentration of inorganic nitrogen concentration. Orthophosphate content represents a concentration of dissolved phosphorus in water, while total phosphorus is the sum of dissolved and solid phosphorus.

Total phosphorus is a biological activity indicator of 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 nutrient concentrations at sites of Lake Durowskie represent the characteristics of upper part of the lake because of the summer stratification phenomena (Figure 21). The higher total phosphorus concentrations are observed at the Inflow site and near Aerator 1, which might be an indicator of the local input of nutrients: at the inflow point the higher concentration is connected to water input from the aquatic system above and the possible inflow of nutrients at the area of Aerator 1 might be originated from the urban area. The organic phosphorus concentration at other sites is quite similar that might indicate the comparable levels of biological activity. The increased nitrogen concentration at sites Middle 1, Beach 1 and Aerator 1 is connected to the more intensive use of the south-eastern part of the lake. The main touristic activities (beach, boats rental base, main embankment, aquapark and sport facilities) and inhabitable areas are located at this part. The nitrogen concentration at Beach 2 site is the lowest despite of the recreational use. It might be explained by the low anthropogenic pressure on the western part of the lake in comparison with eastern part. Moreover, the eastern bank is steep and the nutrients inflow is much higher while the western bank is rather gentle.

Presumably the cottages at the northern edge of the lake impact the quality of the lake and, therefore, the nutrient concentration at Aerator 2 site combines the inflow water and these cottages' impact. The comparatively low concentration at Middle 2 site tells us of the absence of any direct inflows at the middle part of the lake.

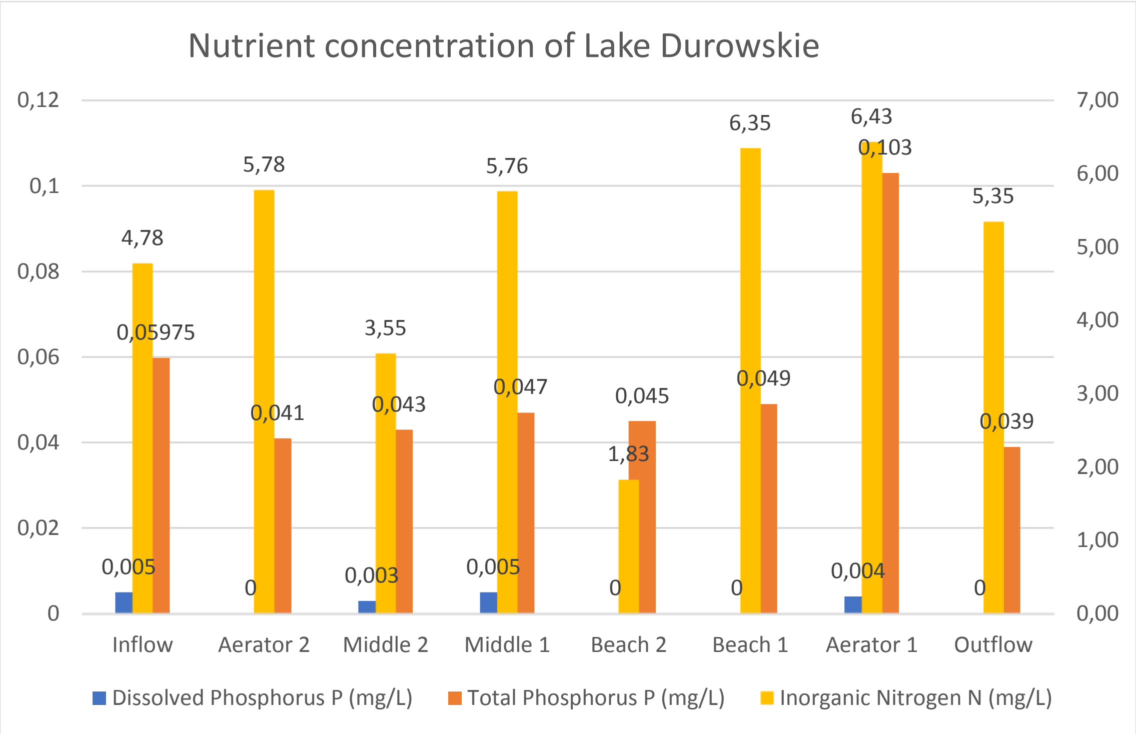

Figure 21. Nutrient concentration of Lake Durowskie in 2018

The graph of nutrient distribution down the stream from Lake Zamkowe to the outflow of Lake Durowskie shows the slow decrease of the concentration of nutrients towards Lake Durowskie (Figure 22). The maximum of the concentration of dissolved phosphorus and total phosphorus and high nitrogen concentration is observed in Lake Zamkowe. The reason might be former activity of no longer functioning alcohol production factory to the lake. The factory discharged residues with high nutrients concentration to the lake that were sedimentated at the bottom. Despite the ceasure of pollution, the consequence of technological procedure residues deposition in the lake is still present. The water dissolves the polluted sediments and nutrients are freed and, moreover, are distributed along the flow to the other lakes. What is more, the sewage plant is still active at the area and the direct inflow of hazardous materials goes to the sensitive aquatic ecosystem.

The second lake in a studied system is Lake Laskowickie, which is characterised by the steep slopes and presence of the animal farms on one of the banks, which are supposed to be the main source of the nutrients inflow. Additionally, the project of the dam construction of the lake confirmed, whose aim is to raise the water level of the lake and create the conditions for recreational development of the area. No doubts that the realisation of the project will lead to the degradation of the water quality and nutrient concentration increase.

The decreased nutrient concentrations of Lake Grylewskie might be explained by large volume of the water body that facilitates the dissolution of incoming pollutants in water and end up in drop of the nutrient concentration. Moreover, total phosphorus is better consumed by the water organisms than inorganic nitrogen. However, the nitrogen concentration stays quite high, which is supposedly the result of the nutrients input from the agricultural fields located at the banks of the lake.

This year the outflow of Lake Grylewskie was dammed at its lower part and, additionally, because of the low discharge values the volume of outflowing water was restricted and the nutrient concentration of inflow of Lake Bukowieckie is high.

The lake Bukowieckie is characterised by the increase of the nitrogen concentration. The reason is the location of summer houses, which were transformed into cottages, close to the lake. The construction of such buildings is not the novity for the region but the problem is that these houses lack the centralised sewage system and every household has its own sewage hole. The official minimal distance from such household to the lake is 100 m but in reality its distance to Lake Bukowieckie is around 30 m that creates the dangerous situation of the water pollution of the lake due to the nutrients leakage of the nutrients from the sewage.

We don’t obtain data of the water quality of Lake Kobylewskie but the nutrient input into the lake is produced by the discharge from the agricultural fields on the east bank and households on the west one.

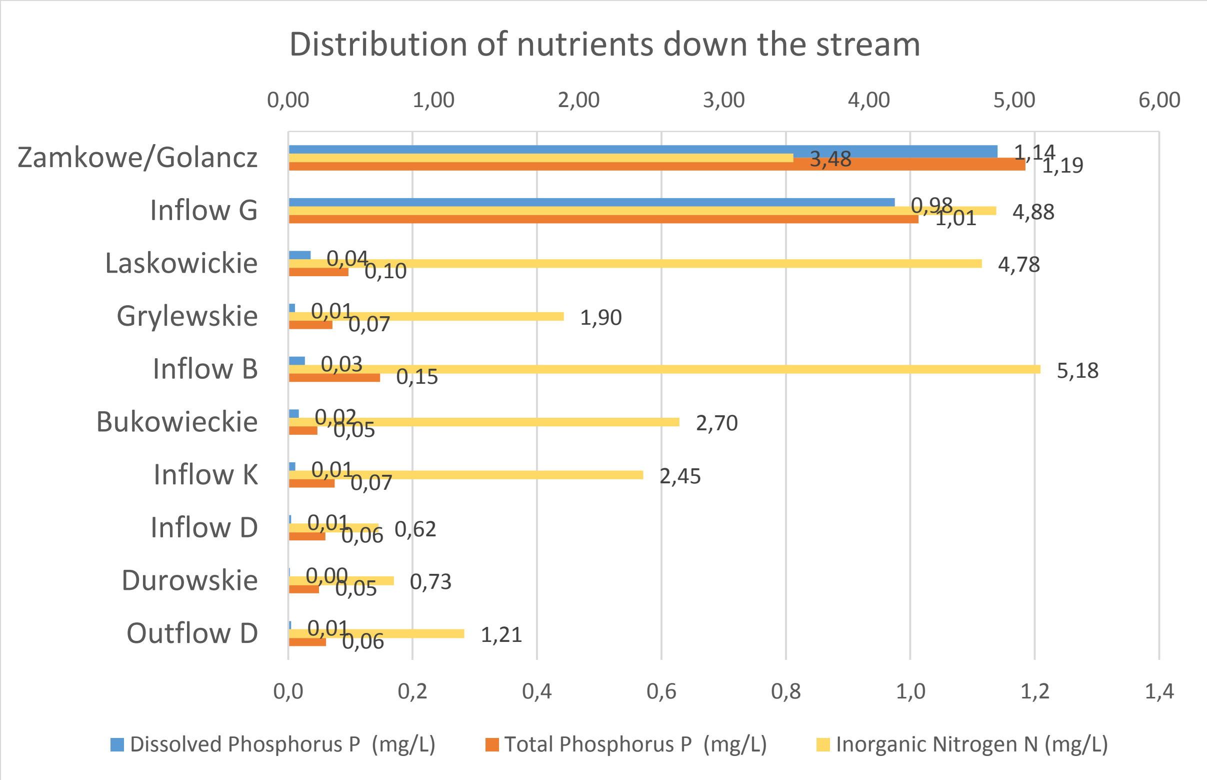

Figure 22. The nutrient concentration down the stream of the studied aquatic system in 2018

The distribution of total phosphorus and inorganic nitrogen loads over the water streams between the lakes shows us the abrupt drop in nutrient loads for all of the water bodies from 2017 to 2018 (Figure 23, Figure 24). The reason of such phenomena is not connected to any improvement of the water quality but is explained by the natural phenomena: the streams' discharges were significantly lower this year in comparison with year 2017 because of unusually dry spring period in 2018 (Figure 25). The huge difference of the discharge values does not allow us to make any significant conclusion about the nutrients load.

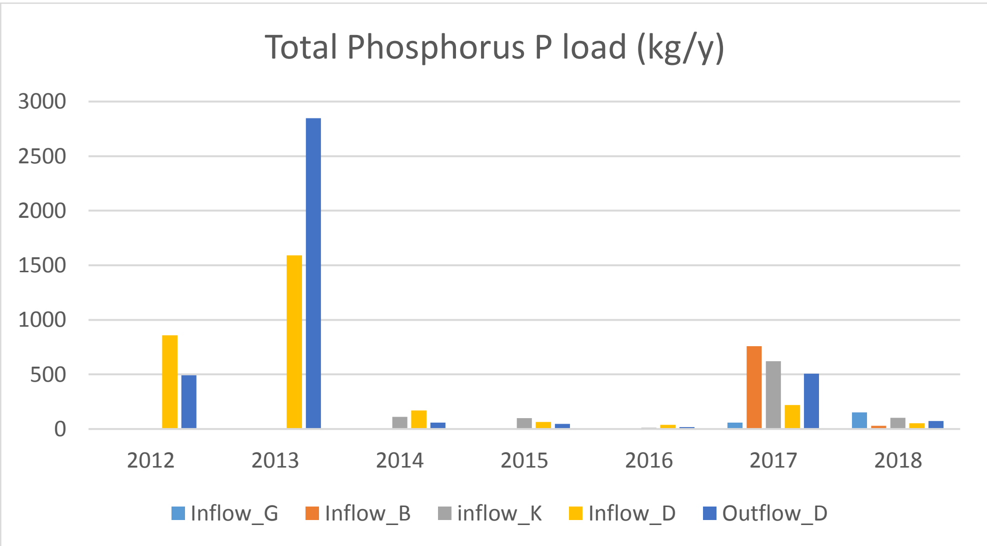

Figure 23. The trend of Total Phosphorus concentrations from 2012 to 2018

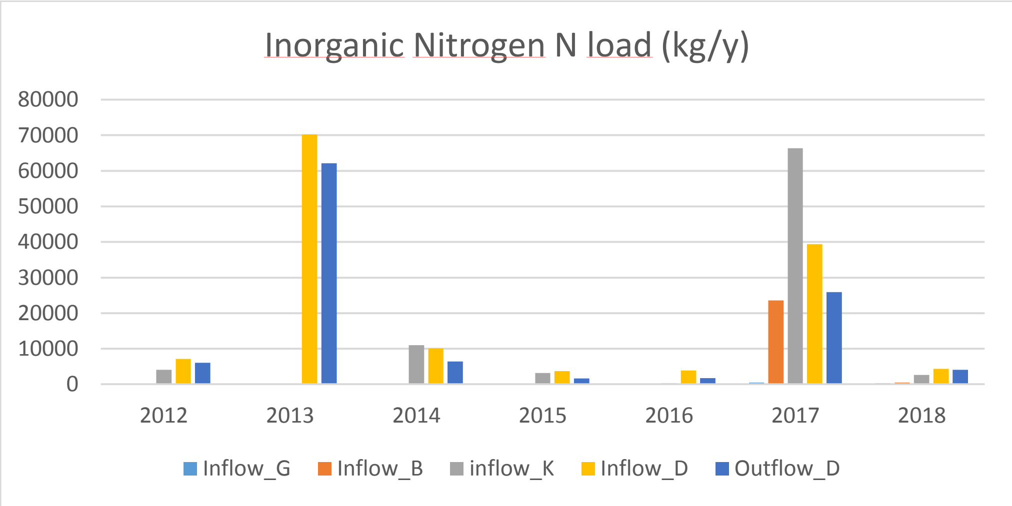

Figure 24. The trend of Inorganic Nitrogen concentrations from 2012 to 2018

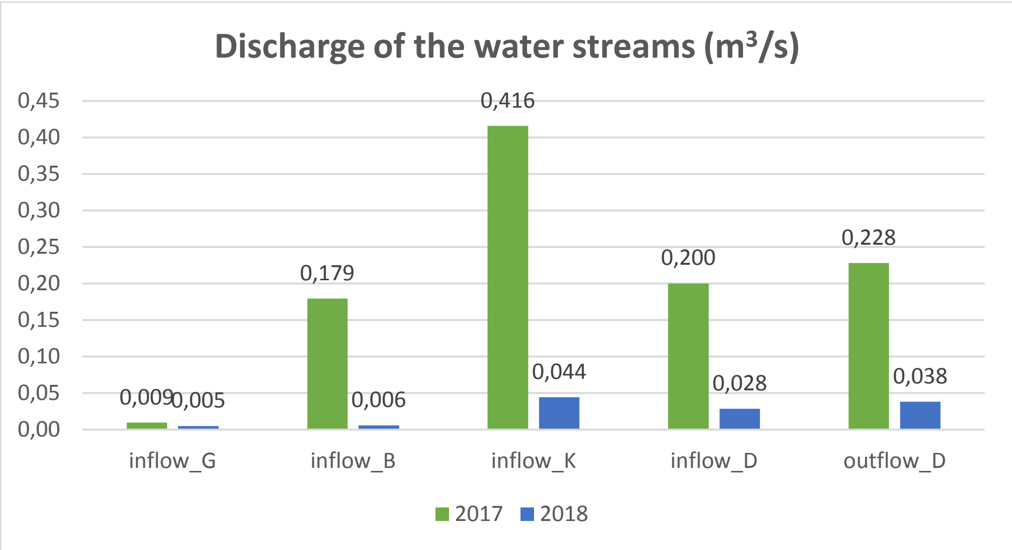

Figure 25. The comparison of streams' discharges of 2017 and 2018

Trophic State Index

This year Trophic State Index (TSI) for Lake Durowskie shows significant decrease in water quality. During the previous 3 years (2015 – 2017, Figure 26) we could see stable growth in the water quality, with the lake going from almost eutrophic to almost oligotrophic. Right now TSI for 2018 is almost as high as in 2015, showing significant change from TSI for 2017. This rapid change that looks so alarming is caused by dry and hot spring period that leaded a significant rise of nutrient density (like Total phosphorus) and therefore, its concentration. This situation could be even further expanded by very strong rain that took place for the first time in months in this area during the week of field work and possibly caused massive import of nutrients from the shores to the lake and from the lakes above. A decrease in amount of Chloryphyll a this year seems to support this idea. Also, 2017 was a very wet year, during which the water level of Durowskie Lake was raised that could lead to decrease of nutrient concentration and therefore, to decrease of TSI. The combination of these effects made the results of 2017 and 2018 even more contrasting. Further research is needed to estimate if this rapid growth of TSI is a new trend or if it is just caused by atypical weather of 2017/2018.

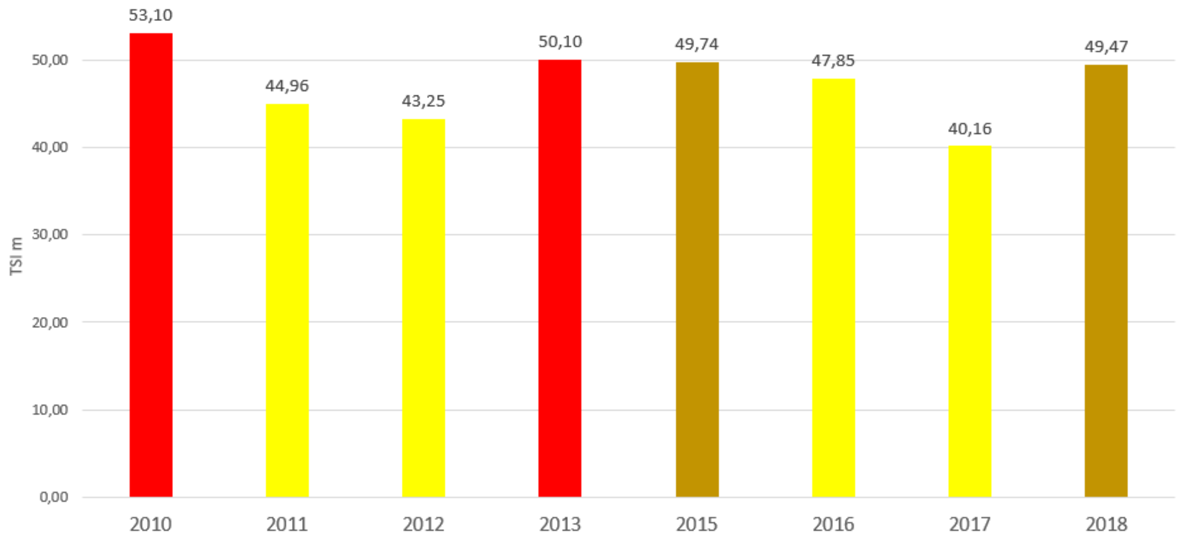

Figure 26. Trophic State Index trend of Lake Durowskie from 2010 till 2018

Comparing the data from 2017 and 2018 (Figure 27) we can see another big difference: TSI for different sites in 2017 varies greatly, from 16,73 at Outflow D to 46,14 at Beach 1 while TSI of sites in 2018 differs insignificantly. The reason for such result in 2018 could be strong wind and rain that we observed during our field work that could mix the top layer of water resulting in smaller differences than those that were observed in 2017. Another interesting result is strong decrease in water quality around Aerator 1, which could mean that area is strongly affected by human activity and pollution from nearby town of Wągrowiec. Moreover, during this year research we took samples from new site “Inflow” area that is close to the inflow point from Struga Gołaniecka. TSI for this place is the highest (66,7!) among TSI values of Durowskie Lake, putting this area in a eutrophic tropic class. It show how significant is the effect of Struga Gołaniecka for water quality of Durowskie Lake and that without any preventing actions, state of the lake will only decrease.

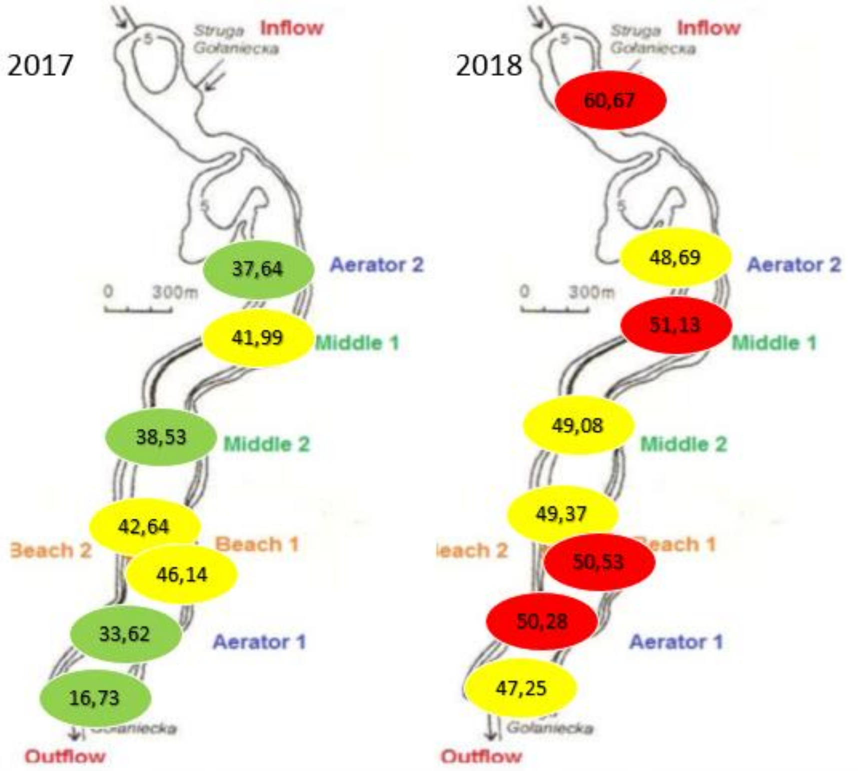

Figure 27. Trophic State Index trend in years 2017 and 2018

Recommendations

Recommendations for the improvement of the water quality of the lake Durowskie should be addressed not only the lake itself but also the lake system above as the pollutants of those lakes are the main reason of the lake Durowskie eutrophication hazard.

Recommendations for Lake Durowskie

1. The slopes near the lake are rather steep and its erosion contributes to the nutrient inflow into the lake. Moreover, the walking paths and even track for mountain bikes are constructed along the eastern bank that obviously accelerate the soil erosion.
    - Therefore, it is recommended to strengthen the slopes with special materials or by increasing the vegetation projective surface on the slopes.
2. The increase in nutrient concentration at the southern part of the lake (mostly close to Aerator 1) is seen to be the reason of some local nutrient input. Moreover, the construction of cottages at the northern shore of the lake seems to raise the sediments and nutrients inflow into the lake as well.
    - It is recommended to supervise those households to control the sewage and the recreational activity.
3. The touristic aquatic activity that involves the powerful motorboats that create waves rather strong could lead to the erosion acceleration and disruption of local aquatic ecosystems.
    - Thus, it is advised to ban or limit the usage of such water transportation.

Recommendation for the other lakes

1. The maximum nutrient concentration is observed on Lake Zamkove, which is the first lake of the studied system. Due to the discharge of the nutrients of nowadays closed production at its vicinity the nutrients stored at the bottom are slowly dissolved and influence the whole lake system.
    - It is recommended to do an ecological restoration of the lake Zamkowe. The more appropriate and less invasive method is conservation of nutrients at the bottom and prevention of its further dissolution.
2. The project of the dam creating on Lake Laskowickie in order to raise the water level for recreational purposes exists. Undoubtedly, it will lead to higher nutrient inflow into the water system and will alter the normal water flow down the stream, which is critical to the already such a sensitive aquatic system.
    - Therefore, it is insisted to forbid the implication of the project.
3. The ecological state of lakes are extremely dependant on the precipitation and discharge rates. Any conscious alterations of hydrological regime of an aquatic system by engineering constructions lead to the dangerous situations especially during the unusual weather conditions as draughts or oppositely high precipitation events. For instance, this year due to combination of the small dam constructed at the outflow site of Lake Grylewskie and the dry spring season the nitrogen concentration at the site Inflow_B was unprecedentedly high.
    - Thus, we insist that any hydrological regulations should be forbidden and the management changes should consider the hydrological and weather cycles.
4. Ones of the main nutrient, especially nitrogen, contamination sources is the agriculture and the households that are situated at the catchment area. It is worth to highlight the

household localisation out the reach of centralised sewage system at the extremely close vicinity from the lake Bukowieckie is illegal.

- It is advised to control those objects and strictly follow all the law prescriptions. For instant, to keep the construction of hazardous buildings at appropriate distance from the water.

5. Lake Zamkowe receives the extreme nutrient inflow of the sewage plant and there are quite a few food productions that is located at the catchment area.
    - The advice is to improve the purification quality of the residues of the production. It might be applied to all types of production of the catchment area.
6. Year by year the recommendations are given to improve the ecological state not only concerning Lake Durowskie itself but also the catchment area. Unfortunately, the actions are taken only by the Wagrowiec administration and address only the lake itself while the source of the issue that is the state of the lakes above stays untouched.
    - Therefore, it is highlighted that it is vital to create and nourish the connections of local authorities in order solve the ecological issue of Lake Durowskie and the whole catchment area.

Conclusion

In 2018, the ecological state in the whole lake has not improved according to the data that we have collected, analyzed and synthesized in comparison with previous years. Trophic State Index has declined from 40 in 2017 to 49 in 2018, still classifying Durowskie Lake as mesotrophic, but with a great risk of almost reaching the eutrophic state. Although Trophic State Index indicators such as transparency and Chlorophyll *a* have rather good results for the current year, total Phosphorus stands out with higher concentrations than in the previous year. It is possible that water evaporation was induced by hot spring which in its turn caused the increasing density of total Phosphorus in the lake. Additionally, this year Trophic State Index trend of each sampling point has exceeded its moderately accepted values of the previous year. It is most likely because of unstable weather conditions that we have witnessed during our field studies with strong winds and heavy rainfalls. There is a great difference between the water streams' discharges in 2017 and 2018. This year they are really low, it is due to the precedent dry spring and a sudden rainfall at the time of the beginning of this year's summer school. Therefore, it is almost impossible to make a conclusion which would encompass a long-term scale of discharges with nutrient loads, especially compared to the last year's higher values.

The water quality of the lake is highly dependent on the ecological state of the upstream lakes which have a negative impact of contamination on the lake with nutrients and phytoplankton, thus the sustainable management of upper-located lakes is required to be implemented in the coming years. Moreover, the lake Durowskie is directly affected by the weather conditions, human activities in its recreational areas, probable illegal sewage discharges, therefore strongly needing more frequent monitoring of all kind of natural and anthropogenic effects on it, to have the possibility to assess the results of the lake restoration in a long-term scale.

In conclusion, it is recommended to resolve the problems in the first place coming from the lake Zamkowe which is located at the very top of all upper lakes connected to Durowskie Lake. And further improvements of the state of the lake are urgently required with the help of local authorities and local people.

References

- Klapper, H. (2003). Technologies for lake restoration. *Journal of Limnology*, *62*(1s), 73-90.

- Gołdyn, R., Messyasz, B., Domek, P., Windhorst, W., Hugenschmidt, C., Nicoara, M., & Plavan, G. (2013). The response of Lake Durowskie ecosystem to restoration measures. *Carpathian Journal of Earth and Environmental Sciences*, *8*(3), 43-48.

- Carlson, R. E., & Simpson, J. (1996). A coordinator's guide to volunteer lake monitoring methods. *North American Lake Management Society*, *96*, 305.

- Shaw, E. M. (1988). Hydrology in practice. VNR International, 2nd Edition, London.

- Song, S., Schmalz, B., Hoermann, G (2012). Accuracy, reproductivity and sensitivity of acoustic Doppler technology for velocity and discharge measurements in medium-sized rivers. Hydrological Sciences Journal, 57:8, 1626-405.