Rybnik lake as an unconventional water reservoir

Kopernik

IV Liceum Ogólnokształcące im. Mikołaja Kopernika w Rybniku

Poland

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Abstract

Rybnik is located in southern Poland in Central Europe. It is inhabited by 140 000 people. The landmark of our region is a water reservoir (known as Rybnik Lake), created for the needs of Rybnik coal-fired power station. It was built in 1972 and its original role was to cool down machines producing electricity. No one expected that nowadays it would get a new role which is not connected with industry. The aim of our project is to show the history, the construction plan and the usage of Rybnik water reservoir in technological processes of energy production. Furthermore, we intend to present it as a place which has combined Rybnik inhabitants' professional work with their private lives.
We would like to show the importance of Rybnik Lake in everyday life of the local community and the natural environment.

Key words:
water, power station, Rybnik, Daphnia

1. The construction, history and functions of Rybnik Reservoir

"Rybnik" reservoir is a facility that is used to collect water by the power station in order to cool the power generating installations. It is a construction which is 4.5 km long and 2 to 9 m. deep. The reservoir has a frontal dam with a reinforced concrete screen. [Fig.1]

It has two tributaries: the Ruda river and the Nacyna River. [Fig. 2]. The Ruda river, which is a natural inflow of the reservoir, has an outlet behind the dam and it also constitutes a place of discharge of excess water from the reservoir in the event of exceeding the water level. Around the reservoir there are three reservoirs: Pniowiec, Grabownia and Gzel. They perform floodcontrol or intensifying functions depending on the season, energy demand and water level in the reservoir.

The water temperature of the reservoir reaches a maximum of 26 ° C and a minimum of 9 ° C. The high water temperature with a small annual amplitude influences, on the one hand, positively, the development of vertebrate organisms (fish), on the other hand, negatively, causing excessive and sudden increases in algae and Cyanobacteria (water blooms). This makes it difficult to use water to cool generators, and also causes oxygen deficits and accelerates eutrophication processes. [1,4]

The reservoir possesses its own water circuit which is controlled by a special controlling system (an embankment enabling the separation of inlet and outlet waters of Rybnik Power Station).

The water reservoir performs the following functions:

- enables the uptake of water for the purpose of cooling the power generating components of the power station;
- cools the outlet waters;serves as a retention reservoir - flood protection reservoir (1.5 million m3, i.e. 1500 tonnes of flood reserve);
- provides conditions for organising sports events, eg Rybnik Scandinavia Yachts Cup 2016;
- is used by military mechanical plants to carry out tests of KTO Rosomak wheeled armored personnel carriers;
- the immediate vicinity of the reservoir is a place of recreation for the residents of the city.

Working on the construction of the reservoir was started in 1968 in the village of Stodoły. Twenty-one households were demolished for the needs of the reservoir construction. The first element of the works was the construction of a dam with a target length of 12 meters. Next, the works consisted of the construction of an embankment and water intake. The controlling system of the large gate valves, which were created at the very bottom of the reservoir, was placed inside the built tower. [1]

After the completion of the above works, the filling of the reservoir was started by digging the river bed of the Ruda river. The entire process leading to reaching the minimum water level (219 meters above the sea level) lasted a year. The reservoir was artificially created in 1972 and covers an area of 550 hectares. [1,4]

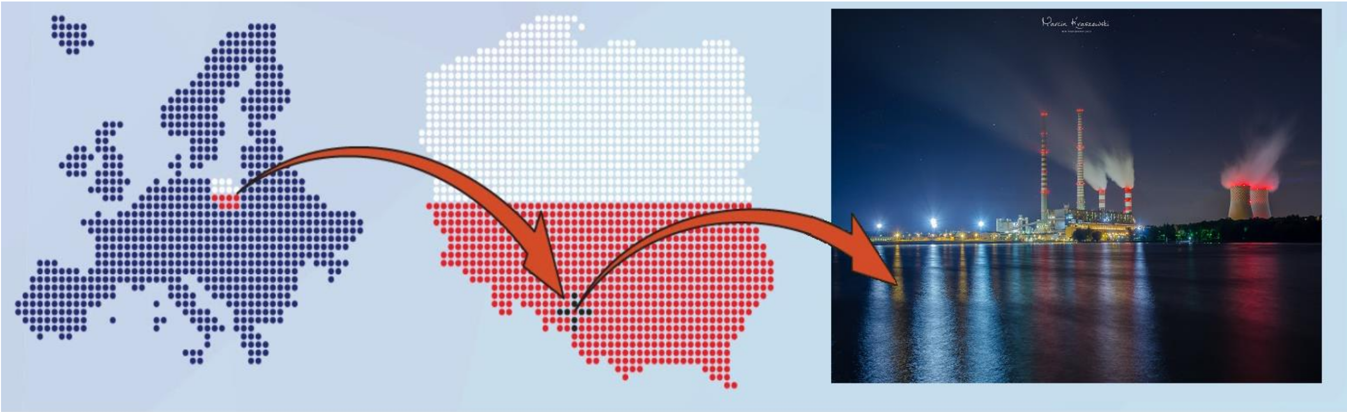


Figure 1. Localization of Rybnik in the Europe.

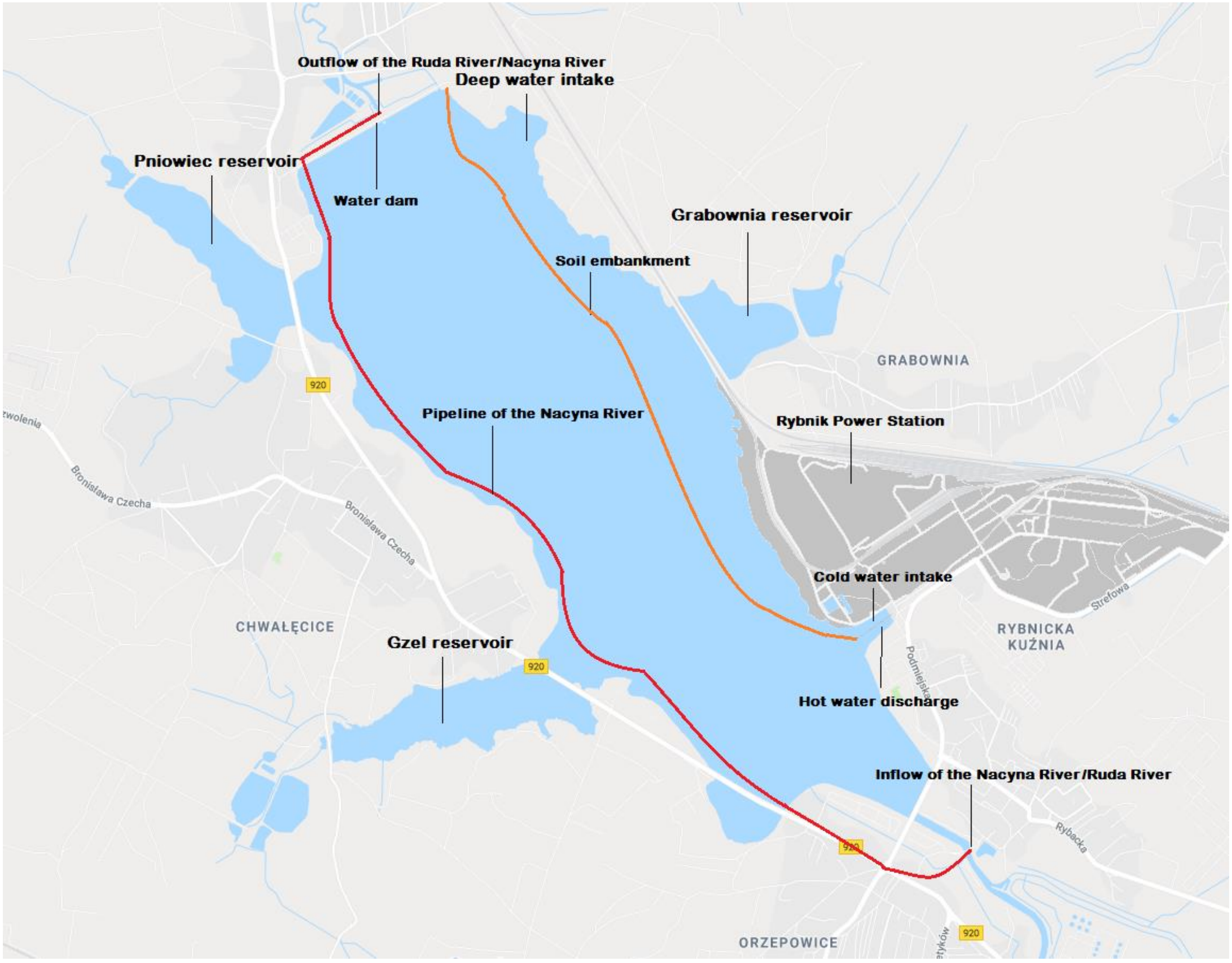


Figure 2: Map of the reservoir

2. Tourism and recreation

Rybnik Lake is an excellent place for rest and recreation, widely known in the region and the country because of its diverse use. Over the period of several dozen years, it has gained new functions. Currently, the reservoir is the basis for five different sailing clubs, three yacht clubs, a fishing section and a water equipment rental company. [Fig.3] There are kilometers of paved bicycle paths along the banks of the lake. Not only are they frequented by cyclists, but also runners and ordinary walkers. section and a water equipment rental company. There are kilometers of paved bicycle paths along the banks of the lake. Not only are they frequented by cyclists, but also runners and ordinary walkers. The attractiveness of this place is appreciated by people of all ages. Rybnik reservoir and its surroundings are used by both individuals and groups. One of the most interesting groups, operating since the beginning of Rybnik Lake, is the 6th Scout Sailing Team named after the commander Zbigniew Przybyszewski. The team is called “Wodniacy” by Rybnik inhabitants; the name may be translated into English as “Water People”. Thanks to the availability of the reservoir, it allows children and adolescents to develop sailing and rowing skills. The sailing season on Rybnik Lake is the longest one in Poland, lasting for half a year (from April to October)

Figure 3: A marina on the bank of the lake

A part of the reservoir waters maintains a temperature above zero throughout the year, which means that the surface of the water never freezes, which favors the development of many fish species, including the white amur and silver carp.

Thanks to regular fish stocking and excellent development conditions for fish, Rybnik reservoir is one of the best fishing spots for large fish in Poland. Due to its great reputation, many fishing lovers come here from all over Poland. On the banks of the lake you can often spot tents of anglers who want to devote to their passion for as long as possible and also fans of sleeping under the stars. There is also a possibility of renting holiday houses.

A lot of regional and national fishing competitions are organized on Rybnik Lake, which are very popular. Fishing is not the only sport in case of which games are organized here. On the waters of the lake there compete sailors, among others in the Optimist Polish Championships, the Silesian Regatta League and the Polish Championships in match racing; windsurfers, for example, in the windsurfing and sailing camps, and rescue dogs in the National Rescue Dogs Competition for the Upper Silesia Cup. [Fig.5]

A special event organized annually for many years is a mass on the water. Poland is a mainly Catholic country, which is why it attracts the attention of believers. Hundreds of Christians - Rybnik inhabitants and visitors, come to the banks of the lake to participate in this one-of-a-kind ceremony. [Fig.4]

Figure 4: A mass on the water.

Figure 5: Sailing race

3.Technological use of water

Rybnik Power Station is the largest coal (thermal) power station in Upper Silesia and one of the largest power plants in Poland. It generates enough energy to meet the needs of 4.6% of the Polish energy market. All its power and production of electricity totally (100%) depend on the water in the reservoir and nearby reservoirs. [1,2]

The dependence of the Power Station on water results from the need to cool the capacitors in which electricity generating turbines are driven by dry steam. As a result, there are temperature changes in Rybnik reservoir depending on the energy demand. This does affect the biology of the reservoir. In the summer, continuous heating of the water in the reservoir leads to fluctuations in its ecosystem, while in the winter, due to the elevated temperature, it constitutes an ideal environment for the development of many representatives of fauna and flora.

Each power station using water circuits to cool electricity generators is limited by restrictive legal standards.[8] Therefore, the water in the reservoir constantly undergoes a series of tests in the power station laboratory. Rybnik Power Station uses water from the lake in many aspect.

There function four water circulations in the Power Station [Fig. 6]:

- cooling circuit
- boiler circuit
- deslagging circuit
- flue gas desulphurisation circuit

We distinguish two cooling circuits:

a) open circuit - it is used for cooling the turbine capacitors of blocks No. 1,2,3,4. It consists in:
- a single use of water taken from the reservoir and using it to cool the capacitors,
- after passing through the cooling systems of blocks No. 1,2,3,4, the (warm) water is transferred to the reservoir by pipelines to the overflow wells and then by the reinforced concrete canal to the reservoir discharge canal. [Fig.6]

b) closed circuit - it is used for cooling the turbine capacitors of blocks No.5,6,7,8. It uses two cooling towers. It consists in:
- a repeated use of water from the reservoir and its reuse for cooling the capacitors. After passing through the cooling systems of blocks No. 5,6,7,8, water goes to the condensers from where it is pumped through the discharge pipelines to the cold store;
- there it is cooled down and flows gravitationally through the reinforced concrete canals to the central pumping station, completing the work cycle. The reservoir water used in the open and closed circuits is subjected to mechanical filtration through sieves. Then it is transferred to the pumping station where it is used to cool the capacitors.

The boiler circuit - it consists in the demineralised water circulation in the boiler.

- demineralized water circulation in the boiler: boiler → turbine → condenser (consisting of a capacitor);
- due to water losses in boilers as a result of their being desludged and desalinated as well as leaks, the supplementary sources completing a given circuit are: groundwaters and Grabownia side reservoir waters (after their having been demineralized);
- water in the boiler circuit is converted into high pressure and temperature steam (dry steam), then it goes to the turbine from where it is converted into electricity;
- the next step is the change of state into gas and the steam goes to the condenser (capacitor) where it becomes liquid again. [1,9]

The deslagging circuit - it is not supplied with water from the reservoir. The source of water in the deslagging circuit is the slag leachate flowing from the sludge beds and the leachate from vibrating sieves. The water created in this circuit goes through pipelines and reinforced concrete canals to the sewage treatment plant, from where it is pumped to Rybnik Lake.

The wet desulphurisation circuit consists in the following:

- the basic source of WFGD power supply (Wet Flue Gas Desulphurisation installation) is surface blowdowns while water is an additional source of intake.
- wet flue gas desulphurisation – this method consists in washing flue gases with aqueous lime slurry in the absorption tower, as a result of which calcium sulfite is formed, completing the losses in the cooling towers,
-flue gases are in direct contact with the aqueous solution of the binding agent.

The advantage of this process is high efficiency. The disadvantage is lowering the temperature of the gases, which must be reheated. Water is used to bind volatile sulfur compounds and carbon dioxide. [2,9]

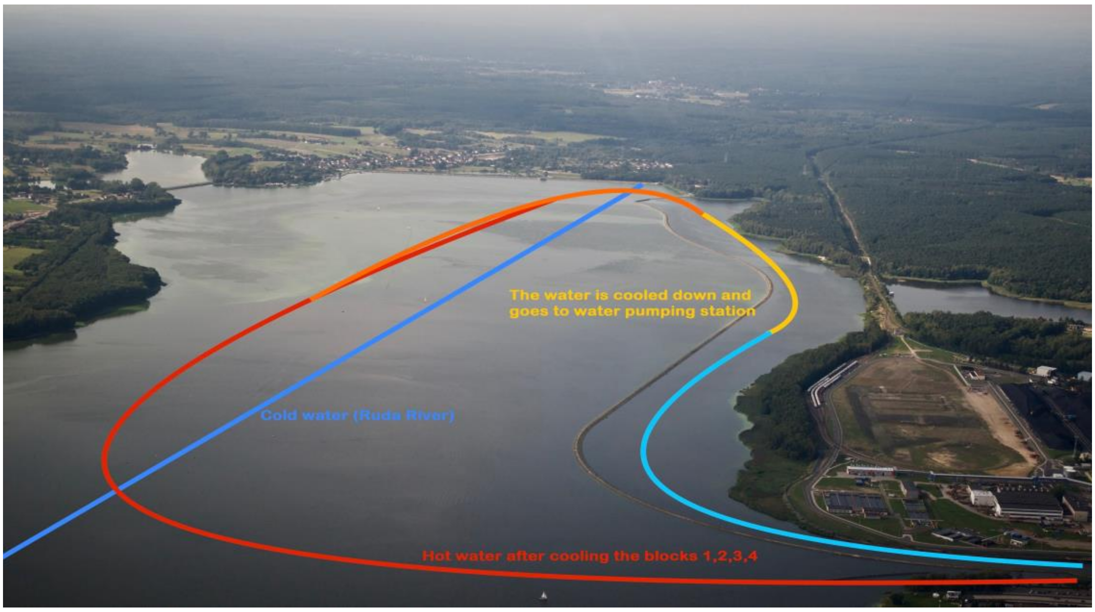
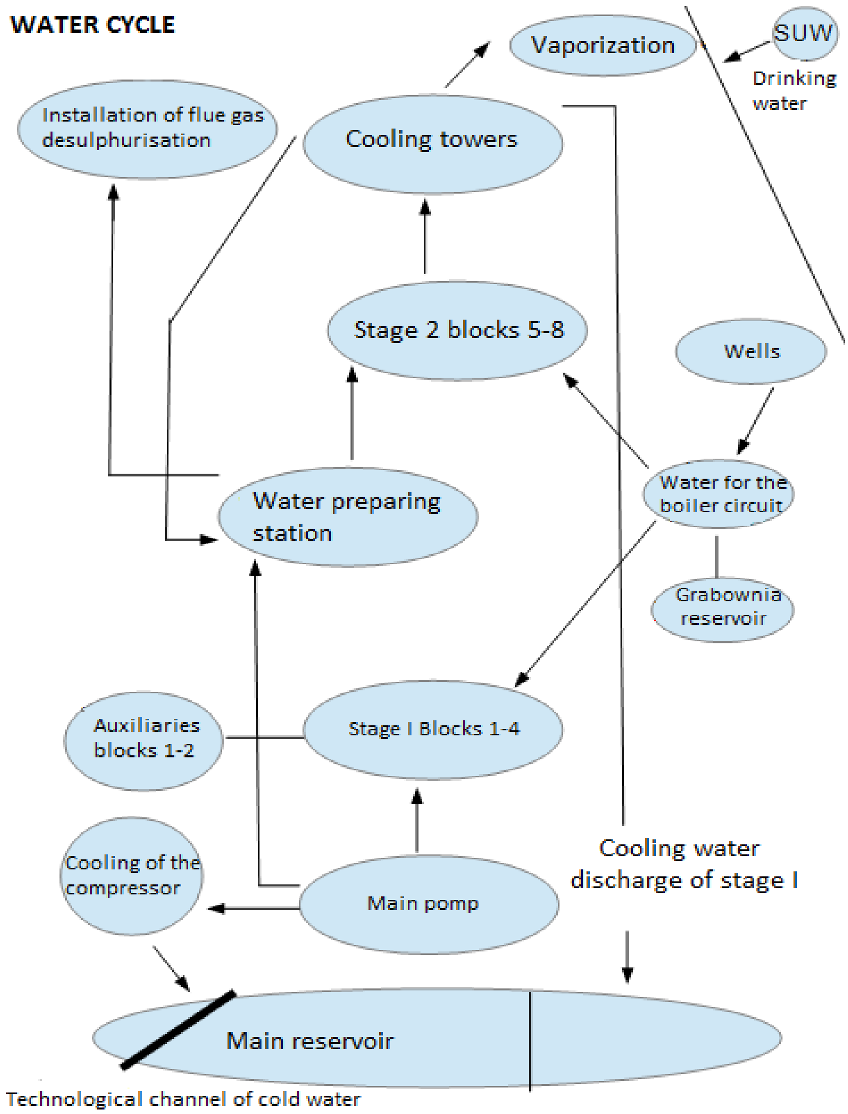


Figure 6: The water cycle in the reservoir for Blocks No. 1,2,3,4

Figure 7: Water cycle in blocks



The general water cycle of blocks No.1,2,3,4 in Rybnik Power Plant -summary

The Ruda and the Nacyna rivers flow into the reservoir. [Fig.2] Cold water is pumped to block capacitors No. 1,2,3,4. Warm water is discharged via pipelines to the part of the reservoir with warm water. After the circumna vigation of the entire lake, the cycle is repeated. The general water cycle of blocks No. 5,6,7,8 in Rybnik Power Plant consists in the fact that water circulates in a closed cycle, and its loss is supplemented with water from the reservoir by means of feed pumps. Cold water is pumped to capacitors No. 5,6,7,8, and warm water is dumped via pipelines to the cooling towers where it evaporates. After cooling down, it is used again for capacitors No. 5,6,7,8.

*Surface blowdowns - boiler water with a relatively high salt content [2]

4. Biology of the reservoir

In the vicinity of the reservoir there are forests dominated by pine trees. On the lakeshore there are stands of:

- Canadian goldenrod *(Solidago canadensis)*
- Gallant soldier *(Galinsoga parviflora)*
- Himalayan balsam (*Impatiens glandulife)* [3]

The water temperature in the most unfavourable summer conditions is 25.5^{o}C at the power station intake (this is where water from the reservoir flows into the power plant) and 34^{o}C at the discharge.

Heated discharge waters from a thermal power station cause twofold effects:

- negative effects - disturbance of the natural biological balance;
- positive effects - no ice sheet (in the pelagial zone) and favorable conditions for fish farming. [Fig. 8]

In the reservoir there are clearly visible tendencies for the formation of oxygen losses in the bottom layers of the water. This phenomenon was found in the upper, middle and lower parts of the reservoir. It occurs, at the earliest, in the middle of May and last until October, in the deepest, dam zone of the reservoir. The individual years differ in terms of oxygen ratios in the reservoir.

The reservoir is characterised by fauna poor in terms of quality, which is dominated by *Oligochaeta* from the Tubificidae family, the species characteristic for anaerobic conditions. However, the spatial diversity of benthic fauna is clearly visible: in the hot water zone besides *Oligochaeta* and *Chironomidae* larvae, there are *Gastropoda* and *Ceratopogonidae* larvae that are not present in the rest of the reservoir. The changes in benthic fauna show cyclicality, which indicates the stability of the habitat conditions essential for animal life and reproduction. [4]

In the waters of Rybnik reservoir there are many species of vertebrates, among others catfish (*Silurus glanis*), common bream (*Abramis brama*), pike-perch (*Sander lucioperca*), Northern pike (*Esox lucius*), European perch (*Perca fluviatilis*), common carp (*Cyprinus carpio*), rudd (*Scardinius erythrophthalmus*), roach (*Rutilus rutilus*) , Stone moroko (*Pseudorasbora parva*), silver carp (*Hypophthalmichthys molitrix*) or grass carp (*Ctenopharyngodon idella*). [3] The last two species were brought to Rybnik from Russia. They help to clean the reservoir out of algae (phytoplankton), thus reducing the possibility of damaging the cooling installation of Rybnik power station. In Rybnik reservoir fish often reach record sizes due to favorable conditions [Tab.1] The shorelake areas are inhabited by the Raccoon (Procyon lotor), the Mute Swan (Cygnus olor), the Mallard duck (Anas platyrhynchos), The Eurasian blue tit (Cyanistes caeruleus), The common blackbird (Turdus merula), The long-tailed tit (Aegithalos caudatus). [4]

Table 1: Record specimens of fish in Rybnik reservoir

Species	**Record size**	**Record mass**
Wels catfish *(Silurus glanis)*	107 kg	251 cm
Common carp *(Cyprinus carpio)*	30 kg	107cm
Pike-perch *(Sander lucioperca)*	9kg	99cm
Northern pike *(Esox lucius)*	10,20kg	112cm

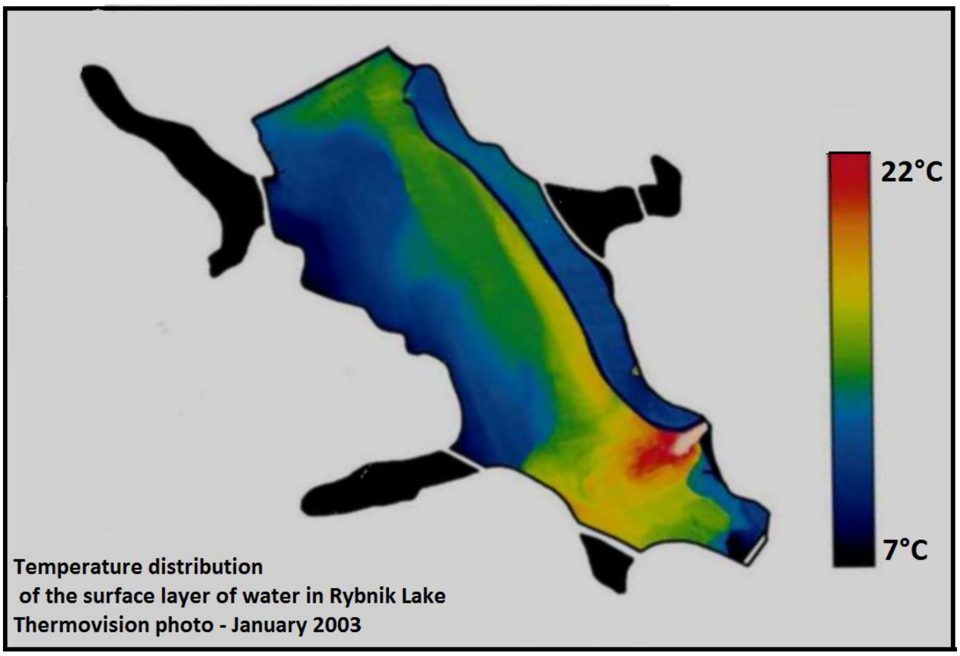


Figure 8: Temperature distribution in Rybnik Lake

Rybnik reservoir is constantly monitored in order to observe the biological state and chemical composition of the water. Basing on literature data covering studies from 2001 to 2017, we have found out that [4]:

- the concentration of nitrogenous compounds in the reservoir waters is higher than in the Ruda river flowing into the reservoir; however, in recent years a slight decrease in the concentration of nitrogenous compounds has been observed;

- there is a decreasing tendency in average concentrations of total phosphorus and organic phosphorus (However, the ratio of nitrogen to phosphorus is decreasing, which indicates deterioration of the water quality);

- the pH of water flowing into Rybnik reservoir on the intake of water from the Ruda River is constant over the year and amounts to 7.3-7.4 while in the reservoir the maximum pH ranges from 8.5 to 9. Such values already reached in the early spring months indicate the occurrence of intensified primary production and the possibility of forming early water blooms;

- over the past three years, the concentration of organic carbon Corg in water and COD (Chemical Oxygen Demand) have been constant. The parameters show that there is no increase in the concentrations of industrial pollution;

- over the years there have been fluctuations in the concentration of chloride ions. As a result of evaporation of heated water and the introduction of surface blowdowns from the cooling towers, the water in the reservoir has higher salinity than the water supplying the reservoir of the Ruda river. The problem of water salinity is important primarily due to technological reasons;

- concentrations of arsenic, chromium, zinc, copper and cobalt in water meet the standards for water class 1 and 2 [5] for cadmium, nickel, lead and iron class A1 and manganese from A1 to A3. [6]

- in the summer months, especially in the bottom layers of the reservoir, there occur oxygen deficits;

- since 2002 until now, research has been carried out, which shows that algae biomass reaches up to 90 kg / m3 in the peak period of their development.

Due to the origin and function of the reservoir remaining under the influence of many artificial, also anthropogenic factors (elevated temperature, increased amount of chemical compounds), the waters of the reservoir constitute a very interesting ecosystem.

A part of our project was devoted to the observation of the changes in the elements of this ecosystem taking place under the influence of cooling water discharge and the increased amount of chemical compounds. We focused on organisms that form the plankton of the reservoir (the so-called plankton community), which includes animal organisms: Copepods, Cladocera, Rotatoria, Ciliata (Cocepoda,Cladocera, Rotatoria, Ciliata) and plant ones - green algae, diatoms (Chlorophyta, Bacillariophyta).

We have conducted a number of experiments in laboratory conditions. We have carried out measurements of the physicochemical parameters of the water of the reservoir and one of the tributaries - the Nacyna River (with a high concentration of surface blowdowns). We have conducted studies to determine the impact of water temperature on the increase of the total biomass in the reservoir.

Methodology

To investigate the effect of temperature on the increase in total biomass, we used two 20l tanks lit with white light worth 15 W (0.75Wx20l). Both the tanks were subjected to 12/12 photoperiod. In one of them, the temperature was kept at 15^oC and in the other one - at 26^oC.
We conducted the tests in two repetitions in the period of 2 weeks, taking measurements on the first, seventh and fourteenth days.

In the test procedure we used:
Merck COD Solution A + B test, Merck Spectroquant TR620, pH - WTW-pH 340 with SenTix41 electrode, N-NH4 - Merck Spectroquant Ammonium Test, N-NO3 - Merck Spectroquant Nitrate Test, N-NO2 - Merck Spectroquant Nitrite Test, P-PO4 Merck Spectroquant Phosphate Test and Merck Spectroquant NOVA60, BZT5-WTW OXITOP 3 trials of 432ml.Incubation at 20^oC.
One liter of water was used to test the amount of chlorophyll. An AGA LABOR vacuum pump with glass fiber filters was used for filtration. The filter with the biomass was placed in a test tube, then 7ml of 90% acetone solution was added, followed by about 0.2g glass beads with a diameter of 0.25-0.5mm and 0.5g glass beads with a diameter of 1.25-1.65mm made by ROTH. The tube test with the filter was closed in the dark for 1.5h, then shaken using a Reax Control test tube shaker from Heidolph, and mixed for 5 minutes (4.4 rpm / rcf) using The Eppendorf 5702 Centrifuge, and the results were checked in the UV-Vis spectrophotometer.

Results

The averaged results are shown in Table 2.

Table 2: Results of measurements on the first and fourteenth days of experiment

	day 1	**day 14, temp 15^oC**	**day 14, temp 26^oC**
COD (Chemical Oxygen Demand)	<4,0 mg/l	<4,0 mg/l	<4,0 mg/l
BOD (Biochemical Oxygen Demand)	1 mg/l	2 mg/l	3 mg/l
pH	8,1	8,3	8,5
Optical density (OD)	0,057 ABS	0,62 ABS (+988%)	0,63 ABS (+1005%)
Chlorophyll a	0,014 µg/ml	0,083 µg/ml (+493%)	0,045 µg/ml (+221%)
Karotenoids	0,005012 µg/ml	0,025368 µg/ml (+406%)	0,013356 µg/ml (+166%)
Chlorides	164 mg/l	204 mg/l	254 mg/l
Nitrates (N-NH4, N-NO3, N-NO2)	$N-NH_4$ 0,25 mg/l $N-NO_2$ 0,03 mg/l $N-NO_3$ 2,2 mg/l	$N-NH_4$ 0,47 mg/l $N-NO_2$ 0,03 mg/l $N-NO_3$ 2,2 mg/l	$N-NH_4$ 0,49 mg/l $N-NO_2$ 0,01 mg/l $N-NO_3$ 3,8 mg/l
Phosphorus (P-PO4)	1,6 mg/l	7,1 mg/l	0,7 mg/l

Conclusions

1.The water of Rybnik reservoir meets the conditions of class II / III according to the five-point water quality rating scale [7].

2.Based on the value of COD and BOD, we can conclude that contamination with organic compounds is minimal and the conditions for conducting the experiment had no effect on them.

3.The conditions of conducting the experiment had no effect on the optical density of the culture at 750 nm. In both the cases, the optical density increased 10 times, which indicates the intensive development of microorganisms in both the cultures.

4..The concentration of N-NH4: similar in both the cultures, the increase relative to the initial sample is related to the biomass growth of microorganisms and indicates the intensification of the deammonification process, that is the transformation of nitrogen bound in organic compounds to inorganic nitrogen.

5.The concentration of N-NO2 and N-NO3: a slight decrease in the concentration of N-NO2 in the last sample, with the simultaneous increase in the concentration of N-NO3 probably results from the increased activity of nitrifying bacteria of the second phase. Nitrification is an aerobic process, and the tanks were oxygenated. Due to the low content of organic compounds and the presence of oxygen, the activity of denitrifying bacteria should be low.

6.The study of the content of photosynthetic pigments clearly shows that the conditions prevailing in the first culture, at a lower temperature, are more beneficial for the development of photosynthetic organisms: cyanobacteria and algae.

Summary

The analysis of the results of our research and source materials indicates that Rybnik reservoir is regularly and consistently maintained in the state provided for by the Polish law, to enable its technological, ecological and social functions to be carried out.[8] Each change of even one parameter of water only affects its stability. We notice a very clear need for precise monitoring of the water temperature in the reservoir. The excessive temperature increase (above 20°C) leads to blooms of cyanobacteria and algae [3], and its further increase (about 26°C) to a drastic decrease in the development of phytoplankton, which affects the entire ecosystem of the reservoir. The balance between phyto and zooplankton and successive trophic levels is disturbed. [4]. During the project search we became interested in the problem of the influence of high concentration of surface blowdowns on the development of the population of *Daphnia sp*. as an important link in the food chain of the aquatic ecosystem. We are currently conducting research concerning this subject and we hope to present the results in the scientific poster.

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