DOI: 10.2428/ecea.2013.20(07)071 ECOL CHEM ENG A. 2013;20(7-8):779-790

Ewa JACHNIAK[1]* and Janusz Leszek KOZAK[1]

ESTIMATING THE LEVEL OF WATER EUTROPHICATION IN PORAJ DAM RESERVOIR BASED ON SELECTED METHODS

OSZACOWANIE POZIOMU ZEUTROFIZOWANIA WODY ZBIORNIKA ZAPOROWEGO PORAJ NA PODSTAWIE WYBRANYCH METOD

Abstract: In this publication the chosen methods of estimation of the eutrophication were presented. These methods were used for the evaluation of the trophic status of the Poraj Reservoir water. In this research the Integral trophic state index was used. In addition the loading reservoir with total phosphorus was estimated, as well as the permissible and the critical loads of phosphorus according to Vollenweider were also defined. Furthermore, the trophic classification of reservoir water was achieved on the grounds of: the concentrations of biogenic substances in reservoir water, the concentrations of the chlorophyll *a*, the biomass of phytoplankton and the species composition of phytoplankton. The every chosen methods indicated on the advanced eutrophication processes occurring in this reservoir.

Keywords: eutrophication, dam reservoir, biogenic substances, chlorophyll *a*, biomass of phytoplankton

Introduction

Eutrophication is an increase of the water fertility level. The term was coined at the beginning of the 20th century by Thienemann & Naumann. This term meant precisely "water rich in nutrients" [1, 2].

The continuous addition of biogenic substances to the body of water results in the intensified eutrophication process. The problem touches especially dam reservoirs, since their catchments, as compared to *eg* lakes, occupy much larger areas [3]. Strongly eutrophic ecosystems, where the ecological balance have been seriously disturbed, are called hypertrophic ecosystems.

[1] Institute of Engineering and Environmental Protection, University of Bielsko-Biala, ul. Willowa 2, 43–309 Bielsko-Biała, Poland, phone: +48 33 827 91 61, email: ejachniak@ath.bielsko.pl, jkozak@ath.bielsko.pl

* Corresponding author: ejachniak@ath.bielsko.pl

The most notable result of water eutrophication is an excessive growth of phytoplankton [2, 4–8]. The increased algal biomass, often resulting in so-called water blooms, causes water to become feculent as a result of accumulated organic matter and colloidal substances, which are mainly released from dead photoautotrophic cells. The smell and taste of water change accordingly. Another negative effect of excessive growth of algae, in particular Cyanobacteria (Cyanophyta), is the appearance of toxic metabolites, as a result of dead or aging cells decomposing in water. Some authors claim that these toxins may not only be secondary metabolites but may play a crucial role in primary metabolism of some toxigenic species [9].

The aim of this research was to determine the level of eutrophication of Poraj Reservoir based on various research methods.

Materials and methods

The research of Poraj Reservoir water was conducted in years 2004–2006. This reservoir is located in northern area of Silesian Voivodeship, on the area of Poraj and Kozieglowy communes. The territories around the reservoir are considerably industrialised, there is an also developed farming well.

The River Warta forms the water quality of the reservoir. The water of river is polluted with sewage, which is derived from the Zawiercie and Myszkow areas, and they expose the reservoir of the delivery of a lot of pollutants. From majority of rural areas, deprived of the sewage system, the domestic wastewater is introduced directly into surface waters, which are located in the catchment area of the reservoir. This reservoir has recreation character, therefore multiple a resort centers are located in its neighborhood. They constitute a points sources of pollutants, which the considerably part get directly into the reservoir [10].

The reservoir of Poraj is typical lowland and shallow (the average depth is 4 m), about large surface (573,21 ha) (Table 1). The some morphometric-hydrologic parameters of reservoir, also the localization of Poraj dam Reservoir are presented appropriately in Table 1 and Fig. 1. The contour of reservoir and localization places for taking samples are presented on Fig. 2.

Table 1

Morphometric-hydrologic parameters of reservoir

The parameter	The data
Surface of reservoir bowl [km^2][a]	5.73
Total capacity [$\times 10^6$ m^3][a]	25.1
Depth average [m][a]	4
Retention time of water [in days][b]	124.8
Catchment area to section of dam [km^2][c]	389
Functions of reservoir[a]	fishing, flood protection, recreation, energy and guaranteeing of the permanent inviolable flow in the River Warta below the dam

[a] The Regional Management of Water Economy in Poznan; [b] it was calculated: total capacity / average daily inflow of the River Warta (which is the main inflow); [c] [10].

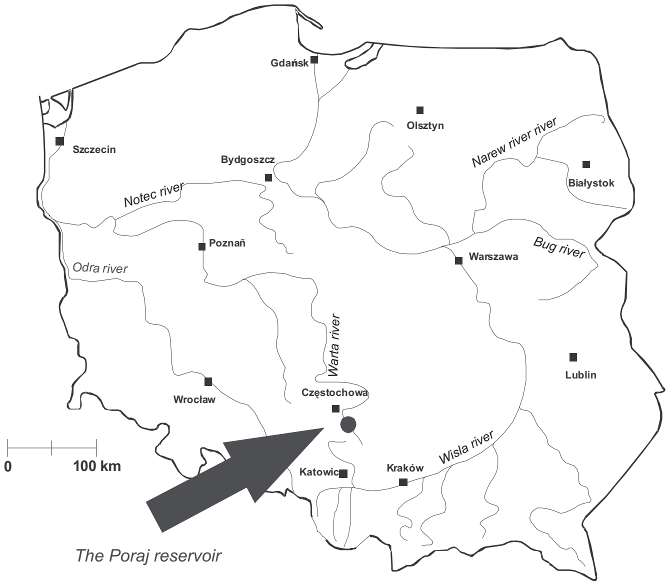

Fig. 1. Localization of Poraj dam Reservoir

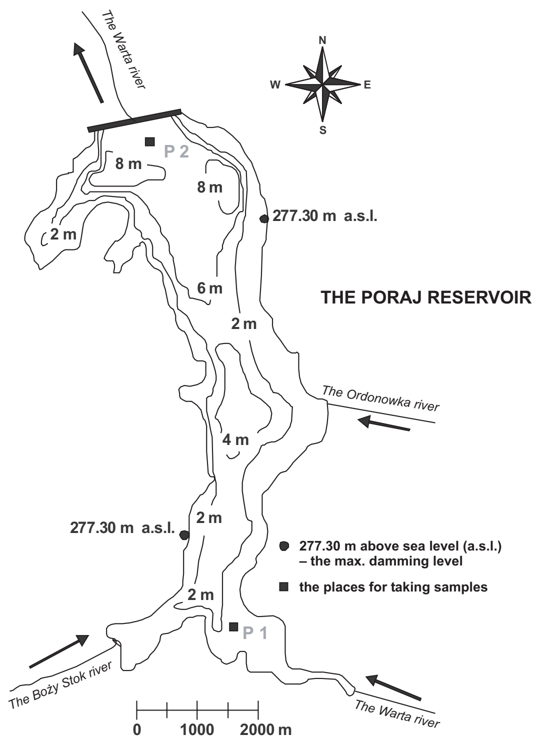

Fig. 2. Contour of reservoir and localization places for taking samples

The first of the diagnostic criteria used to establish the level of water eutrophication in the Poraj Reservoir was ITS (*Integral trophic state index*). It is calculated based on the degree to which the natural balance between production and decomposition of organic matter in the surface waters has been disturbed. If the production is greater than decomposition, the level of carbon dioxide (CO_2) decreases, while the level of oxygen (O_2) increases. In aquatic environments, the level of carbon dioxide can be determined based on the water pH, while the level of oxygen – based on oxygen water saturation [11, 12].

Oxygen water saturation was calculated by measuring the amount of dissolved oxygen and temperature according to Elbanowska et al [13].

For calculating *Integral trophic state index* the following formula was used [11, 12]:

$$\mathrm{ITS} = \frac{\sum \mathrm{pH}_i}{n} + a\left(100 - \frac{\sum [\mathrm{O}_2\,\%]}{n}\right) \tag{1}$$

where: pH_i – the measurement of the pH values during the t,
$[\mathrm{O}_2\ \%]$ – the concentration of oxygen in water in the moment of the measurement pH [%],
a – the empirical coefficient,
n – the number of measurements during the t.

The values of ITS indicator corresponding the different trophic states of water were presented in Table 2.

Table 2

The values of ITS indicator for water about different trophic status [11, 12]

The trophic status	The ITS
Ultraoligotrophy	6.3 ± 0.3
Oligotrophy	7.0 ± 0.3
Mesotrophy	7.7 ± 0.3
Eutrophy	> 8.3 ± 0.3

The trophy of reservoir water was also defined according to the criteria OECD, which are given by Dojlido [14]. The criteria OECD give a boundary values for average annual concentrations of total phosphorus ($\mathrm{mg \cdot dm^{-3}}$) and average annual concentrations of chlorophyll *a* ($\mathrm{\mu g \cdot dm^{-3}}$). The trophy of reservoir water was also estimated according to the Gizinski & Falkowska [15], who give the ranges of concentrations of total nitrogen ($\mathrm{mg \cdot dm^{-3}}$) most often appearing in water of lakes (Table 3).

For more exact illustrating of eutrophication degree of reservoir water the loading reservoir of total phosphorus was estimated, the permissible and the critical loads of phosphorus according to Vollenweider [16] were also defined. The estimated value the loading of total phosphorus was compared to the values of permissible and critical loads.

Table 3

The ranges of concentrations and the boundary values of highly mentioned parameters, which are characteristic for defined trophic types of water [14, 15]

The trophic type of lake	The boundary values of total phosphorus concentrations [mgP · dm^{-3}]	The boundary values of chlorophyll *a* concentrations [μg · dm^{-3}]	The ranges of total nitrogen concentrations [mgN · dm^{-3}]
The oligotrophic lakes	< 0.01	< 2.5	0.5–1.0
The mesotrophic lakes	0.01–0.035	2.5–8	0.6–1.5
The eutrophic lakes	0.035–0.1	8–25	0.7–4.2
The hipertrophic lakes	> 0.1	> 25	1.2–6.0

The average volume of the flow [m^3 · s^{-1}] (which is essential for estimate of total phosphorus loading of reservoir) was computed using a data including flow [m^3 · s^{-1}] in days, in which the samples were collected from Warta River, on the inflow into the reservoir. For computing the volume of water flow in the area of influx Warta River into the reservoir was applied the analogy method, because water gauge station is located in Kreciwilk locality. The data, which concerning of the flows, was obtained from Institute of Meteorology and Water Management (IMGW), department in Katowice.

The chemical and biological research of reservoir water was conducted in years 2004–2006. The analyses of chemical parameters were realized according to Polish Standards by Silesian Voivodeship Inspectorate of the Environmental Protection (WIOS), department in Bielsko-Biala. The biological analyses were conducted using the light microscope Nikon Eclipse 200 in the laboratory of University in Bielsko-Biala. For identification of phytoplankton species the following keys were used: Sieminska [17], Starmach [18], Hindak [19]. The phytoplankton biomass was calculated for biovolume by comparing the shape of algae to their geometrical figures [20]. For evaluation the phytoplankton biomass the following converter was used [20]:

$$1\ \mu m^3 = 1/1 \cdot 10^9\ mm^3 = 1/1 \cdot 10^9\ mg \quad (2)$$

Additionally, for the assessment of trophic state the classification, which including biomass of phytoplankton (mg · dm^{-3}) was accepted. This classification was suggested by Heinonen [21] (Table 4).

Table 4

The ranges of average values of phytoplankton total biomass, which are characteristic for definite trophic types of water [21]

The trophic type of lake	The ranges of average values of phytoplankton biomass [mg · dm^{-3}]
The oligotrophic lakes	0.14–0.68
The mesotrophic lakes	1.21–1.98
The eutrophic lakes	3.45–6.93
The hipertrophic lakes	17.5

The each identified species of phytoplankton was consulted with specialists.

Results

The conducted correlation analysis proved the occurrence of statistically highly significant correlation between the pH values and percentages of oxygen water saturation values, because statistically highly significant value of coefficient correlation *r* (r = 0.81***) was ascertained (Fig. 3).

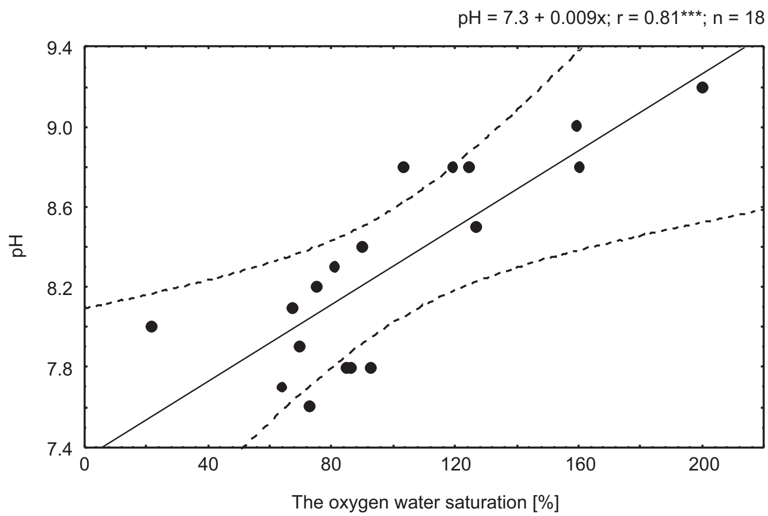

Fig. 3. The correlational relationship behind the pH values and percentages of oxygen water saturation values in the Poraj dam Reservoir

The preliminary classification of water was done as shown in Table 2. As a result of the above described research, the calculated value of ITS indicator (8.30) indicates the eutrophic character of the reservoir.

A more detailed research then followed, including the accumulation of biogenic substances such as total nitrogen and total phosphorus. The analysis concluded occurring the very highly of average concentrations of both these compounds in reservoir water. The exact amounts were respectively: 2.42 mg N $\cdot$ dm^{-3} i 0.21 mg P $\cdot$ dm^{-3}. The amount of nitrogen was slightly below the upper limit denoting eutrophic water, while the amount of phosphorus was significantly above this level, thereby concentrations of phosphorus qualified water of reservoir in the hypertrophy range (Table 5).

The results concerning of total phosphorus loading of reservoir, as well as the results including of the permissible and critical loads indicated for emphatic speedup the eutrophication in the reservoir, because the load of total phosphorus, flowing with Warta River into the reservoir, exceeded over fivefold the value of phosphorus critical load (Table 6). The minimum value of load flowing into the reservoir was jotted down in 2006 year, instead the maximum value was jotted down in 2004 year. In the course of years of research it is possible so to state a downward trend in the inflow of loads of this biogenic compound into the reservoir.

Table 5

The average concentrations of total nitrogen and total phosphorus of reservoir water

The parameter	The boundary values for eutrophy	The accounted values			
		2004	2005	2006	The average value for period 2004–2006
The total nitrogen [mgN · dm^{-3}][a]	0.7–4.2	2.57	2.51	2.19	2.42
The total phosphorus [mgP · dm^{-3}][a]	0.035–0.1	0.28	0.26	0.1	0.21

[a] It was calculated on base of spring, summer and autumn data.

Table 6

The loading of this reservoir with total phosphorus and the permissible and critical loads of phosphorus

The parameter	The accounted values			
	2004	2005	2006	The average value for period 2004–2006
The loading of total phosphorus [g · m^{-2} · year^{-1}]	6.808	3.592	2.594	4.331
The permissible load [gP · m^{-2} · year^{-1}][b]	0.417	0.387	0.411	0.405
The critical load [gP · m^{-2} · year^{-1}][b]	0.834	0.774	0.822	0.81

[a] It was calculated on the basis of average annual concentration of total phosphorus and total nitrogen (12-months data) and on the basis of average annual flow of water (years 2004–2006) – at the inflow of the Warta River into the reservoir; [b] It was calculated according to Vollenweider [16] criteria.

The final trophic classification of reservoir water was achieved on base of the species composition and biomass of phytoplankton, because a living organisms are excellent bioindicators and they constitute supplementing remaining research methods.

The high concentrations of chlorophyll *a* and biomass of phytoplankton in all years of research in water of reservoir were ascertained (Fig. 4). The values of these parameters exceeded much boundary values for eutrophy. The minimum concentrations of chlorophyll *a* and biomass of phytoplankton were jotted down in 2006 year (appropriately 39.51 μg · dm^{-3} and 10.84 mg · dm^{-3}), instead the maximum concentrations were jotted down in 2005 year (appropriately 109.66 μg · dm^{-3} and 31.18 mg · dm^{-3}).

The observed numerous species of phytoplankton, typical for eutrophic water, expressly indicated on the advanced eutrophication of water in this reservoir. These species of phytoplankton constitute bioindicators of eutrophy. The strong development of cyanophyta (*Microcystis aeruginosa* (Kutz.) Kutz., *M. viridis* (A. Br. in Rabenh.) Lemm), green algae (*Pediastrum* sp., *Coelastrum* sp., *Scenedesmus* sp.) and diatoms (*Aulacoseira granulata* (Ehr.) Ralfs (Ehr.) Simonsen), *Fragilaria crotonensis* Kitt., *Nitzschia palea* (Kutz.) W. Sm.) was ascertained in water of reservoir. The presence of

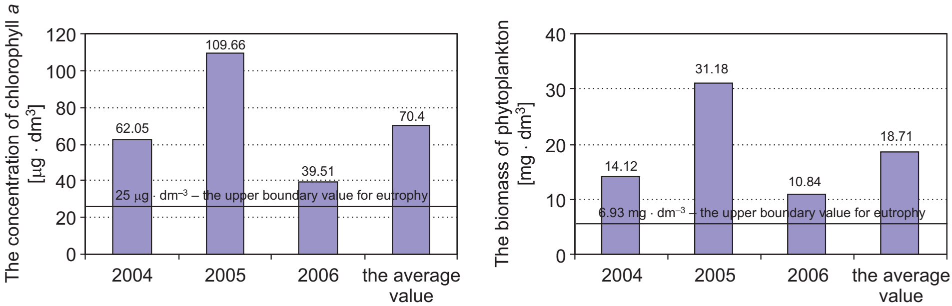

Fig. 4. The average concentration of chlorophyll *a* and the average biomass of phytoplankton on the background of boundary values for eutrophy in water of reservoir

typical species for hipertrophic water, *ia Planktothrix agardhii* (Gom.) Anagh. & Kom. was also jotted down.

Discussion

The Poraj Reservoir is located in the urban area, where the anthropogenic impact on the environment is acutely noticeable, which also includes water pollution.

The increasing eutrophication of the reservoir was confirmed not only by the ITS index but also by chemical analyses of water (raised levels of total nitrogen and total phosphorus), but mainly by the load of total phosphorus contributing with Warta River into the reservoir. A well-advanced eutrophication has also been confirmed by biological indicators (the total biomass of phytoplankton, determined by direct measuring and determined by indirect calculations based on concentrations of chlorophyll *a*) and the appearance of certain species of phytoplankton, which are typical for eutrophic water.

Whenever a significant eutrophication of water occurs, the carbon balance is seriously disturbed, resulting in the raised levels of oxygen as well as raised pH of water. This is due to the intensive photosynthesis process, during which a phytoplankton organisms absorb the carbon dioxide present in water and make for simultaneously to increase alkalinity of water. At the same time, the levels of oxygen water saturation go up. Raised pH of water, caused by water blooms during summer stagnation have been observed by researchers: Mazurkiewicz-Boron [22] wrote about it in the context of Dobczycki submountain Reservoir, Szelag-Wasielewska [23] in the Rusalka lowland Reservoir, while Neverova-Dziopak [11] and Kowalewski [12] in the strongly eutrophic Sulejowski Reservoir.

The concentrations of biogenic substances (total nitrogen and total phosphorus) in this reservoir were very high and in every case exceeded norms indicating water eutrophication (in case of total nitrogen, the amounts exceeded the lower boundary value, while in case of phosphorus also the upper boundary value for eutrophy). Phosphorus, as one of the most eutrophogenic substances, is one of the main culprits of speedup eutrophication process. In case of the discussed reservoir this biogenic substance played the particular role, because the load of this element carried in by the River Warta exceeded the critical load of total phosphorus more than fivefold. Such high levels of phosphorus may possibly come from the sewage treatment plant in Myszkow, as well as from improperly led farming on the banks of the river. The fact that the Poraj Reservoir is located in the urban area is also an important factor. In addition, the catchment here has a agriculturally – industrial character, which prompts in a considerable surface water inflow and the presence of various industry-related pollutants. The catchment area of this reservoir is located nearby of urban agglomerations (Myszkow and Zawiercie), therefore the supply of the public and industrial wastewater undeniably has the serious participation in water pollution. According to Strutynski et al [24] the urban wastewater is one of important sources of nitrogen and phosphorus in water environment. Some additional pollution may occur in the summer months due to several tourist sites and camps located near the reservoir.

The water eutrophication has also been confirmed by the high levels of chlorophyll *a* and large amounts of phytoplankton biomass (the eutrophication boundary values were exceeded by them). As pointed out by Ryding and Rast – after Wilk-Wozniak [25] – eutrophic reservoirs are characterized by high levels of phytoplankton biomass. On the other hand, according to research by Dojlido [14], the concentrations of chlorophyll *a* exceeding 8 $\mu g \cdot dm^{-3}$ also indicate eutrophication, while the levels above 25 $\mu g \cdot dm^{-3}$ classify water reservoir as hypertrophic.

The appearance of various species of algae, characteristic for eutrophic water, also constitutes as proof of the progressive eutrophication and the water degradation in the reservoir. These are mainly: (cyanobacteria *Microcystis viridis* (A. Br. in Rabenh.) Lemm., *Microcystis aeruginosa* (Kutz.) Kutz., green algae *Coelastrum* sp. and *Scenedesmus* sp., diatoms *Fragilaria crotonensis* Kitt.) [26–28]. Similar species of phytoplankton have been observed in the above mentioned eutrophic Sulejowski reservoir by Rakowska et al [29] and Lepistö & Rosenström [26] in the context of eutrophic Finnish lakes. Moreover, the research conducted by Negro et al [27] confirms that *Aulacoseira granulata* (Ehr.) Ralfs (Ehr.) Simonsen), which has been detected in the reservoir, prefers eutrophic water. According to Reynolds [28] the cyanobacteria *Microcystis* sp. is characteristic for sunny and eutrophic waters, instead cyanobacteria *Planktothrix agardhii* (Gom.) Anagh. & Kom indicates hipertrophy.

The biological analyses of the Poraj Reservoir confirmed that throughout the years of research, planktonic algae and cyanobacteria have thrived in the water. The case is serious especially where cyanobacteria are concerned, because they produce toxic substances, which may be dangerous for health of people. The recreation functions of the reservoir obligate to its protection and the matter of water cleanness should be priority. Unfortunately the biogenic substances flowing into the reservoir favour the growth of cyanobacteria, as a result the toxins secreting by some of cyanobacteria constitute threat for health of resting people. These toxic substances often trigger not only skin allergies (mainly dermatotoxins), but also damage to deeper body tissues, *ia* liver cells (mainly hepatotoxins) [9].

The building some new sewage treatment plants and sewage systems in particular localities will certainly enhance sanitary conditions of this reservoir.

Conclusions

1. Every apply methods indicated on a deepening eutrophic processes in Poraj Reservoir.

2. The calculated value of the ITS indicator (8.30) showed eutrophic character water of reservoir.

3. The load of total phosphorus, flowing with Warta River into the reservoir, exceeded that over fivefold the value of phosphorus critical load. It indicates on a speedup the eutrophic processes in this reservoir.

4. The high concentrations of biogenic substances, as well as the high concentrations of chlorophyll *a* were ascertained in water of reservoir (the average values of these parameters appropriately amounted: 2.42 mg N $\cdot$ dm^{-3}, 0.21 mg P $\cdot$ dm^{-3} and 70.4 $\mu g \cdot dm^{-3}$).

5. The high trophic status of reservoir water was confirmed by the high biomass of phytoplankton and the species of phytoplankton, typical for eutrophic water (i. a. *Microcystis viridis* (A. Br. in Rabenh.) Lemm., *Aulacoseira granulata* (Ehr.) Ralfs (Ehr.)).

Acknowledgements

The author wish to thank the Institute of Meteorology and Water Management, Department in Katowice and Silesian Voivodeship Inspectorate of the Environmental Protection, department in Bielsko-Biala (Poland) for essential data for analyses. The author wish to also thank the specialists, who consulted designated species of phytoplankton.

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OSZACOWANIE POZIOMU ZEUTROFIZOWANIA WODY ZBIORNIKA ZAPOROWEGO PORAJ NA PODSTAWIE WYBRANYCH METOD

Instytut Ochrony i Inżynierii Środowiska
Akademia Techniczno-Humanistyczna w Bielsku-Białej

Abstrakt: W artykule zostały zaprezentowane wybrane metody oszacowania poziomu eutrofizacji. Metody te użyto do oceny statusu troficznego wód zbiornika zaporowego Poraj. W badaniach został zastosowany Integralny wskaźnik stanu troficznego. Dodatkowo oszacowano obciążenie zbiornika ładunkiem fosforu ogólnego oraz obliczono ładunki dopuszczalne i niebezpieczne fosforu ogólnego według Vollenweidera.

Ponadto, klasyfikacji troficznej wód zbiornika dokonano na podstawie koncentracji związków biogennych oraz chlorofilu *a*, a także biomasy fitoplanktonu oraz składu gatunkowego fitoplanktonu. Wszystkie wybrane metody wskazały na postępujące procesy eutrofizacyjne w wodach tego zbiornika.

Słowa kluczowe: eutrofizacja, zbiornik zaporowy, związki biogenne, chlorofil *a*, biomasa fitoplanktonu