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Loads of biogens flowing into and out of the Goczałkowice Reservoir (southern Poland)

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A b s t r a c t - The loads of nitrogen and phosphorus compounds flowing into the Goczałkowice Reservoir and out of it in the annual cycle were determined. The main source of biogenic substances was the River Vistula (78% $N_{tot.}$ and 69 $P_{tot.}$). The intermediate pumping stations supplied altogether 12% $N_{tot.}$ and 18% $P_{tot.}$. The high loading of the Reservoir with phosphorus, amounting to 0.65 g P m^{-2} $year^{-1}$ (including in the calculations the frequency of water exchange), exceeded about 4 times the admissible values.

K e y w o r d s: dam reservoirs, nitrogen, phosphorus, loads of biogens.

1. Introduction

To be able to predict the concentrations of biogens in a reservoir and what consequences are to be expected, the balance of the biogens must be prepared. Their content in the water is the arithmetic sum of the amounts of biogens brought into it (from external and internal sources) minus the amount which leaves it through the sluice and municipal intakes and which is eliminated from circulation in the reservoir.

The relations between the loads of nutrients carried from external sources and their concentrations in the reservoir water permit, among other things, determination of the volume of the load at which the danger of occurrence of water blooms by algae is very great, and in this way allow the quality of the water to be predicted (D i l l o n, R i g l e r 1975, S c h i n d l e r et al. 1978, V o l l e n w e i d e r 1979).

A knowledge of the amount of nutrients flowing into a reservoir from particular sources is not only of theoretical importance; it is needed when decisions are made concerning the protection of the reservoirs, stopping or reversing their excessive eutrophication (K a j a k 1979).

The aim of the present study was to determine the loads of biogens flowing into the Goczałkowice Reservoir from external sources and of those leaving it. The reservoir, which supplies the Silesian agglomeration with water, should meet the requirements of a source of good drinking water. The quality of the water in the reservoirs depends, inter alia, on the amount of inflowing nutrients (V o l l e n w e i d e r 1966, U h l m a n n, A l b r e c h t 1968).

2. Study area

The morphological and hydrobiological data referring to the reservoir are listed in Table I. It is a large, shallow pond-like reservoir situated on the Upper Vistula.

The main source of water fed into the reservoir is the River Vistula, supplying about 82% of the water and the small Bajerka stream, which carries 4%. About 8% of the water is brought in by 5 intermediate pumping stations which are used to drain the areas situated in the depression of the reservoir.

Table I. Morphological and hydrological characteristics of the Goczałkowice Reservoir. * - data from the investigated period; FSL - full supply level

Parameter	Data
Geographical position	18°52'E, 49°51'N
Altitude (m)	260
Capacity (10^6 m^3) FSL	168
Surface area (km^2) FSL	32
Maximum depth (m) FSL	11
Mean depth (m) FSL	5.3
Location of the sluice	bottom
Distance from the source (km)	68
Mean annual inflow* (m^3 s^{-1})	5.9
Retention time* (years)	0.91
Frequency of water exchange*	1.1
Destination	municipal intake flood control

The drainage basin includes mountane, submountane and flat areas. In the mountane area it is affected by tourism and forestry, the remaining part being used for farming. The territory is moderately populated, in 1988 the average population being 230 per 1 km^2 (K a s z a 1992). The waste-waters produced here are carried to the Vistula and the Bajerka above the reservoir and to drainage ditches. A small part of the wastes is subjected to a purification treatment.

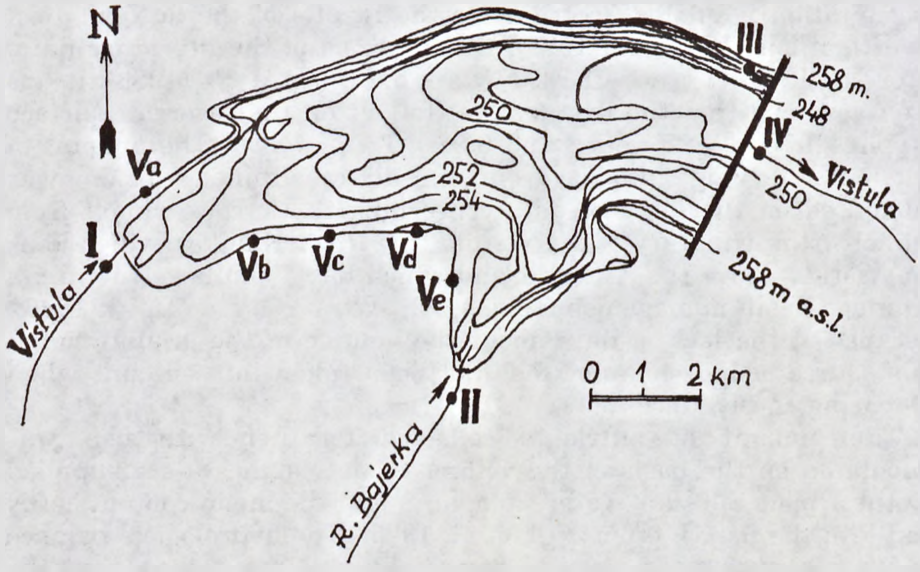

Fig. 1. Localization of the water sampling stations: I - River Vistula; II - Bajerka; III - municipal intake; IV - bottom sluice; V - intermediate pumping stations: a - Strumień; b - Zabłocie; c - Frelichów, d - Zarzecze; e - Podgrobel

3. Material and methods

The investigations were carried out from 1 November, 1991 till 31 October, 1992. The samples were collected at 9 stations at monthly intervals.

The content of biogenic compounds was determined using the methods of J u s t and H e r m a n o w i c z (1955, 1964) and those of G o l t e r m a n and C l y m o (1969). The loads of biogenic compounds carried into the reservoir with the river waters and through the pumping stations and those leaving it were calculated by multiplying the mean concentration of the particular nutrient by the annual inflow (outflow) of the water. The practical and theoretical problems of calculating the loads can be found in a study by N e s m e r a k (1986), and a description of the four basic methods of calculating the inflow of nutrients together with references to literature has been supplied by K r u m m e n a c h e r (1976). The content of nitrogen and phosphorus in atmospheric precipitation is quoted according to the results of the author's own investigations (K a s z a 1979). On the basis of the literature data, after H i l l b r i c h t - I l k o w s k a, Ł a w a c z (1983), it has been assumed that the dry and wet fallout on the reservoir surface supplies 1.5 g N m^{-2} $year^{-1}$ and 0.07 g P m^{-2} $year^{-1}$. The amount of nutrients flowing into it from its direct drainage basin was calculated on the basis of data concerning the surface runoff from the left-bank tributary of the Vistula (the River Knajka), which joins the Vistula above the reservoir and which has a similar structure of drainage basin management (K a s z a, W i n o h r a d n i k 1986). Because of the lack of data about the volume of the ground runoff this source of biogen inflow has not been taken into account when preparing the balance.

The amount of nutrients collected together with fish was calculated on the basis of the volume of net catches (data supplied by the Upper Silesian Water Company) and the mean contents of N and P in the fish (P e n c z a k et al. 1985). The hydrological balance of the reservoir was prepared according to data obtained from the Upper Silesian Water Company and on the basis of the author's own investigations from the period 1973-1975. In preparing the hydrological balance it was assumed that the amount of water evaporated from the reservoir is equal to the amount of rainfall, similarly as for Lake Szczytno Małe (T r o j a n o w s k i 1985).

4. Results

The concentrations of total nitrogen and phosphorus in the waters flowing into the reservoir are very high (Table II). Those recorded in the course of the present investigations in the waters of the Vistula reveal its very fertile character. A similar concentration range for both occurring nutrients characterized the Bajerka stream.

Waters discharged through the intermediate pumping stations directly into the reservoir contained more nitrogen and phosphorus compounds than the waters of the two tributary rivers. Especially fertile were the waters from the pumping stations Va, Vb, and Ve. The concentrations of nitrogen compounds ($N_{tot.}$) in the water pumped by the 3 pumping stations were 1.5 times higher than those in the Vistula water and the concentrations of total phosphorus were on the average 3 times higher.

In the reservoir the concentrations of both nutrients were reduced, this being manifested by considerably lower mean concentrations of total nitrogen and phosphorus as well as by a narrower range of their quantitative occurrence (Table II). In spite of the reduced content of both biogens, the N and P concentrations in the reservoir water were high.

Table II. Range of variation and mean content of total nitrogen (mg N dm^{-3}) and total phosphorus (μg P dm^{-3}) in water of the Goczałkowice Reservoir, in the inflowing water and in the water from the pumping stations

Station	$N_{tot.}$		$P_{tot.}$	
	range of variation	mean	range of variation	mean
I	1.41 - 6.66	3.35	33 - 240	103
II	1.60 - 6.01	2.69	49 - 178	113
III	0.85 - 2.66	1.96	19 - 230	78
IV	0.85 - 2.54	1.79	38 - 230	76
Va	4.82 - 9.25	6.37	74 - 2100	347
Vb	1.63 - 13.05	4.01	190 - 290	226
Vc	1.81 - 9.77	3.45	105 - 320	171
Vd	1.66 - 7.95	4.60	50 - 335	136
Ve	1.80 - 9.07	3.98	74 - 700	332

In the balance of the biogens inflow to the reservoir (Table III) it was demonstrated that the latter received 652 tons of total nitrogen and about 23 tons of total phosphorus. From the above finding it follows that in spite of a negative hydrological balance (the weather in the year of the investigations was exceptionally dry) there took place a cumulation of the biogenic compounds. 33.7% of the nitrogen compounds and 22.1% of phosphorus compounds remained in the reservoir.

Table III Load of biogens flowing into and out of Goczałkowice Reservoir in the period 1.XI.1991 - 31.X.1992 (in tons)

Source of N and P	$N_{min.}$	$N_{tot.}$	$P\text{-}PO_4$	$P_{tot.}$
Inflow				
Vistula	329.6	511.1	3.12	15.72
Bajerka stream	12.8	19.9	0.20	0.84
Pumping stations	66.4	79.0	3.01	4.12
Fallout	33.3	37.5	0.50	1.75
Surface runoff	3.6	4.7	0.22	0.44
Total inflow	445.7	652.2	7.05	22.87
Outflow				
Bottom outlet	52.5	101.7	0.48	4.14
Intake of weirs	170.0	329.3	1.57	13.40
Fish capture	–	1.2	–	0.28
Total outflow	222.5	432.2	2.05	17.82
Result of budget				
Retention	+223.2	220.0	+5.0	+5.05
Retention %	50.1	33.7	70.9	22.1

The main source of the inflow of biogenic compounds was the River Vistula, which brought 78% of the compounds of total nitrogen, 44% of phosphates, and 69% of total phosphorus. The other important source of nutrients were the intermediate pumping stations, which altogether supplied 12.2% of total nitrogen and 18% of total phosphorus. The dry and wet fallout on the reservoir surface together with those of the direct drainage basin supplied 5.8% and 0.7% of $N_{tot.}$ and 7.7% and 1.9% of $P_{tot.}$, respectively.

In a calculation of the outflow of nutrients from the reservoir the amount of biogenic substances carried out together with the caught fish amounted only to 0.3% of $N_{tot.}$ and 1.6% of $P_{tot.}$.

5. Discussion

High concentrations of nitrogen and phosphorus compounds in the waters flowing into the reservoir (Table II) and in the those pumped by the intermediate pumping stations from the drainage ditches may be ascribed to the absence of proper waste-water disposal in the drainage basin and to a low water flow because 1992 was an exceptionally dry and warm year.

In investigations on the balance of matter in water bodies (T u r n e r et al. 1983, G a l i c k a, P e n c z a k 1989, G a l i c k a 1990, 1992, K a j a k 1990) it was demonstrated that the input of matter through the main rivers is so dominant that other sources (such as inflows from the atmosphere, recreation, aquatic birds, etc., and even small point sources of wastes discharged directly to the water body) are of little importance and do not exceed a few per cent of the total load. The rainfall directly on the reservoir surface, and taken into account in the present study, occupies a relatively high position in the inflow of nutrients (Table II). This may be due to the morphometric characteristics of the reservoir as it is large and shallow. Moreover, the frequency of water exchange in the examined period was 1.1 times a year (Table I), which shows that the inflow of water was small. As a rule, the water in this reservoir is exchanged 2-3 times in a year.

On the basis of empirical data, V o l l e n w e i d e r (1968, 1976) determined the volume of the load of nutrients which do not yet induce a distinct acceleration of eutrophication and which can be neutralized by the ecosystem, and the load of nutrients which threatens acceleration the eutrophication of the reservoir. In the case of the Goczałkowice Reservoir, according to the author's own calculations, this threshold value amounts to 0.15 g P m^{-2} $year^{-1}$. The load of phosphorus carried into the reservoir, with consideration given to the frequency of water exchange, was 0.65 g P m^{-2} $year^{-1}$, exceeding 4 times the admissible values. When taking into account the loads of phosphorus entering this reservoir a relation was found to exist between the load of phosphorus on the bottom and its mean annual concentration in the water (fig. 2A). The positive correlation which was demonstrated between the two variables can be interpreted as indicating that an increase in the annual quota of inflowing phosphorus results in an increase in the mean content of phosphorus in the water of the reservoir.

The result of excessive loading of the reservoir with nutrients is the intensified development of phytoplankton in its waters. In 1992 there appeared large water blooms caused by algae (K r z y ż a n e k

et al. in press). In spring the diatoms occurred in masses, the most frequently occurring species being *Synedra acus, Asterionella formosa, Cyclotella planctonica, and Melosira granulata*. In summer water bloom was caused by the blue-green algae which accounted for 88-99% of the numbers and biomass of algae. The principal species among the blue-green algae occurring in summer were *Aphanizomenon flos-aquae, Gomphosphaeria naegeliana, and Anabena flos-aquae* (P a j ą k unpubl. data). During the summer blooms the content of chlorophyll *a* in certain zones of the reservoir was 234 μg dm^{-3} (K a s z a unpubl. data).

The established positive correlation between the mean amount of chlorophyll *a* in a vegetation season and the annual load of phosphorus brought from external sources (fig. 2B) is evidence that an increase in the amount of phosphorus flowing into the reservoir causes an increase in the concentration of chlorophyll (condensation of the biomass of the algae). In order to restore the original purity of the reservoir water and to obtain positive results in improving its quality, as described, among others, by F o r s b e r g et al. (1978), A h l g r e n G. (1978), A h l g r e n I. (1978) the inflow of phosphorus to the Goczałkowice Reservoir must be reduced.

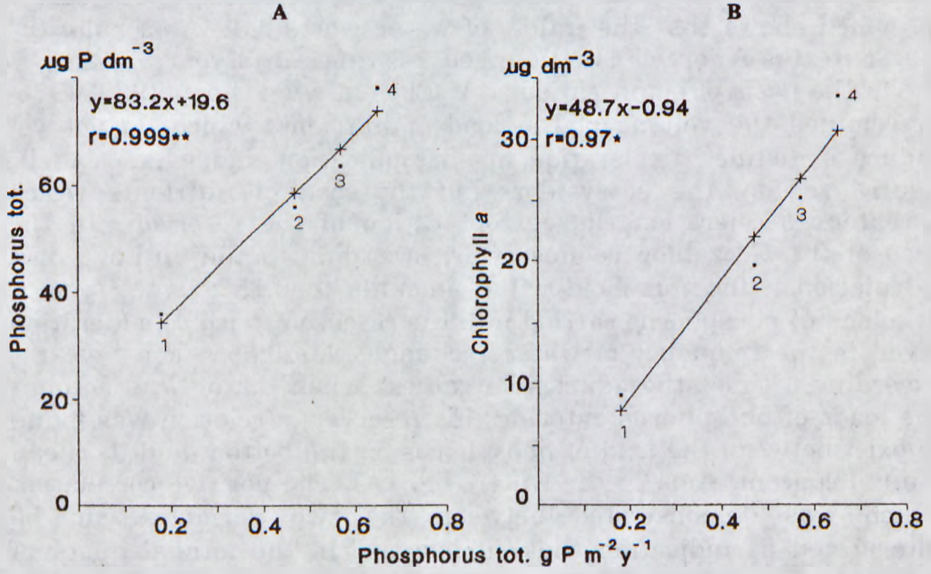

Fig. 2. Mean annual content of total phosphorus (A) and chlorophyll *a* during the vegetation season (B) in the water of the Goczałkowice Reservoir depending on the load of the inflowing phosphorus. 1 - data for the years 1973-1975; 2 - 1982-1983; 3 - 1987 (after K a s z a 1992); 4 - 1992 (data from the present study). ** - p = 0.001; * - p = 0.01

It should be mentioned here that in the presented balance of phosphorus its internal inflow - such as its release in the course of decomposition of organic matter in the sediments (A n d e r s e n, J e n s e n 1992, B a r b a n t i et al. 1992) or during their resuspension (S o n d e r g a a r d et al. 1992, K r i s t e n s e n et al. 992) - was not taken into account, while bearing in mind that the reservoir water is exposed to frequent and through mixing (W i ś n i e w s k i, P a c h n i k 1959). Although in the period immediately following a drop in the spread of water blooming 2 mg O_2 dm^{-3} was recorded in the water volume (K a s z a unpubl. data). However, owing to the progressing eutrophication, conditions may be created which will favour a rapid release of phosphorus from the sediments under oxygen-free conditions, especially since the sediments are fairly rich in this nutrient (0.07-0.16% P in 1 g d.w. of the sediment) (K a s z a unpubl. data).

6. Polish summary

Ładunki biogenów dopływających i opuszczających Zbiornik Goczałkowicki (Polska południowa)

W Zbiorniku Goczałkowickim, którego cechy morfologiczne i hydrologiczne scharakteryzowano w tabeli I, przeprowadzono na 9 stanowiskach (ryc. 1) badania mające na celu określenie ładunku biogenów dopływających do niego ze źródeł zewnętrznych oraz opuszczających zbiornik. Badania obejmowały okres od 1 listopada 1991 r. do 31 października 1992 r.

Dane o koncentracjach ogólnego azotu i fosforu (tabela II) w wodach dopływających do zbiornika wskazują na wysoką zawartość obu nutrientów we wszystkich źródłach ich zewnętrznego dopływu. Wprawdzie w zbiorniku zachodził proces redukcji stężenia obu nutrientów, ale stężenia związków N i P były wysokie, nadając wodzie żyzny charakter.

W sporządzonym bilansie dopływu biogenów do zbiornika (tabela III) wykazano, że głównym źródłem pochodzenia nutrientów była rzeka Wisła (78% $N_{ogól.}$, 69% $P_{ogól.}$). Drugim ważnym źródłem dostawania się związków pokarmowych do zbiornika były przepompownie odwadniające tereny leżące w depresji zbiornika (12% $N_{ogól.}$, 18% $P_{ogól.}$). Opady suche i mokre na powierzchnię zbiornika oraz z bezpośredniej zlewni dostarczały odpowiednio: 5.8% i 0.7% $N_{ogól.}$ oraz 7.7% i 1.9% $P_{ogól.}$

W rozliczeniu odpływu nutrientów ze zbiornika wynoszenie substancji biogennych wraz z odłowionymi rybami stanowiło 0.3% $N_{ogól.}$ i 1.6% $P_{ogól.}$

Stwierdzono zależność średniej rocznej zawartości fosforu ogólnego (ryc. 2A) i chlorofilu *a* za sezon wegetacyjny (ryc. 2B) od ładunku dopływającego fosforu.

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