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Hydrochemical characteristics of the Wisła-Czarne reservoir (Southern Poland) in the period 1975—1984*

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Absract — The work describes the hydrochemical characteristics of the Wisła-Czarne reservoir and its affluents. The intake of the biogenous compounds of the reservoir and the loading of the bottom nutrients were calculated. On the basis of the annual mean of some of the physico-chemical features of the reservoir water their changes during 10 years investigation period are given.

Key words: dam reservoir, hydrochemistry, nutrients, chlorophyll.

1. Introduction

The Wisła-Czarne reservoir was put into service in 1974. Before its construction, in 1969, a sozological investigation was carried out to determine the sources of pollution of its water and future catchment area (Brykowicz-Waksmundzka, Waksmundzki 1975).

From the moment of flooding, hydrochemical investigations were carried out, for the first 2 years, i.e. 1974—1975, by Magosz (1976) and since 1976 by the author. Their aim was to analyse the quality of the water in the affluents and in the reservoir, calculating the loading

* The investigation was carried out within Project No MR.II.15.

of the latter with nutrients and determining the multiannual changes of the chemical composition of the water there as well as to determine its trophic level.

2. Study area

The Wisła-Czarne reservoir was built at the confluence of the Rivers Biała and Czarna Wisełka. Its water is used by the municipal waterworks and for flood control (Table I).

Table I. Characteristics and hydrological data of the Wisła Czarne reservoir and its catchment area. F.S.L. - full supply level; x - according to Magosz (1976)

Factor	Data
Geographical location	49°36′N; 18°56′E
Catchment type	mountain, forestry, tourist
Usage of dam	water supply, flood control
Catchment area	30 km^2
Affluent rivers	Biała Wisełka, Czarna Wisełka
Dam wall completed	1974
F.S.L. volume	4.5 mln m^3
Capacity	2.0 mln m^3
F.S.L.: area	50 ha
maximum depth	30 m
mean depth	9 m
Inflow: min.[x]	0.011 m^3 sek^{-1}
annual mean[x]	0.87 m^3 sek^{-1}
max.	78 $m^3 sek^{-1}$
Water taken for water supply system	0.125 $m^3 sek^{-1}$
Biological discharge	0.06 m^3 sek^{-1}
Retention time	0.07 - 0.11 year
Water delivered from the rivers:	
Biała Wisełka	60.9 %
Czarna Wisełka	39.1 %

It is a small but deep mountain reservoir. Among Polish reservoirs it is one of the highest situated, the ordinate of its maximum damning up being 553 m above sea level. The surface inflow of water comes from the Rivers Czarna and Biała Wisełka (fig. 1). The Biała Wisełka supplies about 60% of water and the Czarna Wisełka 40% in the general water balance (Table I).

With the average capacity of 2 mln m³ the water is exchanged 9—14 times a year.

The village of Wisła-Czarne lies in the catchment area of the River Biała Wisełka whose permanent population is about 900 (Magosz 1976).

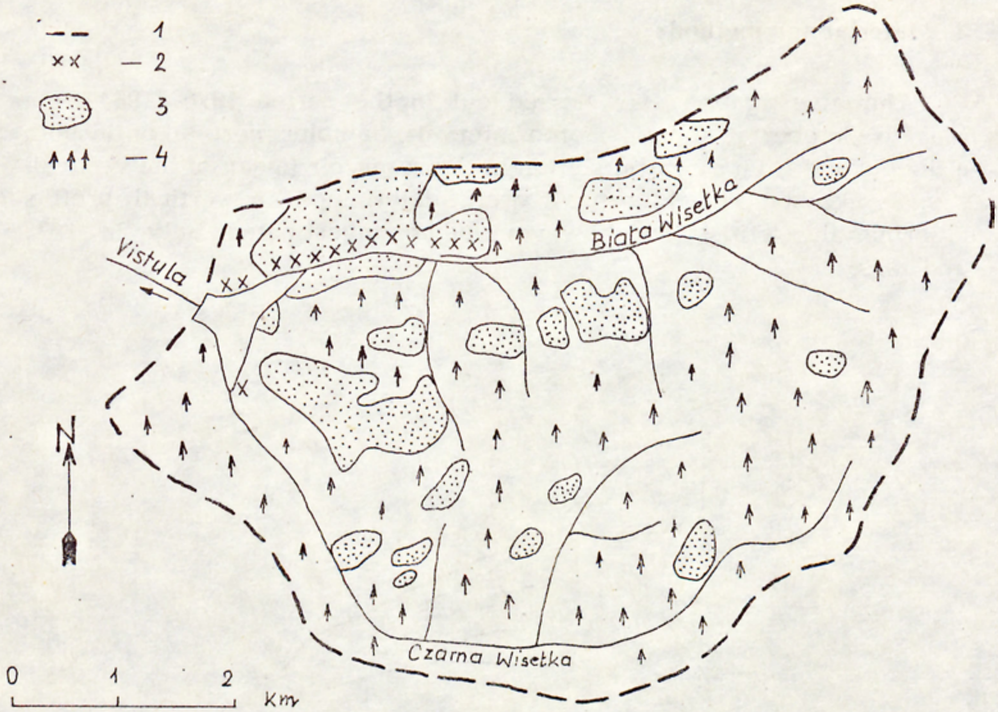

Fig. 1. Catchment area of Wisła-Czarne reservoir. 1 — boundary of catchment; 2 — buildings; 3 — farmland; 4 — forest

Land use in the catchment basin of the reservoir is dominated by forest which occupies about 80% of its area, meadows and pastures constituting 17% and arable 2% (Brykowicz-Waksmundzka, Waksmundzki 1975, Magosz 1976).

Both rivers flow through forest, the area being mountainous and sparcely populated, though a short section of the Czarna Wisełka flows through peaty terrain.

The area under discussion, with its unquestionable natural picturesque, and restorative values has been penetrated for tourist and recreational purposes. The tourist character of the place and the neighbourhood of popular trails potentially endangers the purity of both the rivers and the reservoir. Moreover, the Czarna Wisełka carries the sewage of a tourist shelter while the Biała Wisełka takes in that of the village situated in its valley. In the catchment area of the Biała Wisełka logging operations are carried out.

3. Material and methods

The investigation was carried out in the period 1976—1984 from May to October at about 1 month intervals. Samples were taken in both affluents and from a central station in the reservoir (mean of the vertical) (fig. 2). Oxygen and chlorophyll were determined in vertical profile, chlorophyll stratification, however, being investigated only in 1976 and 1979.

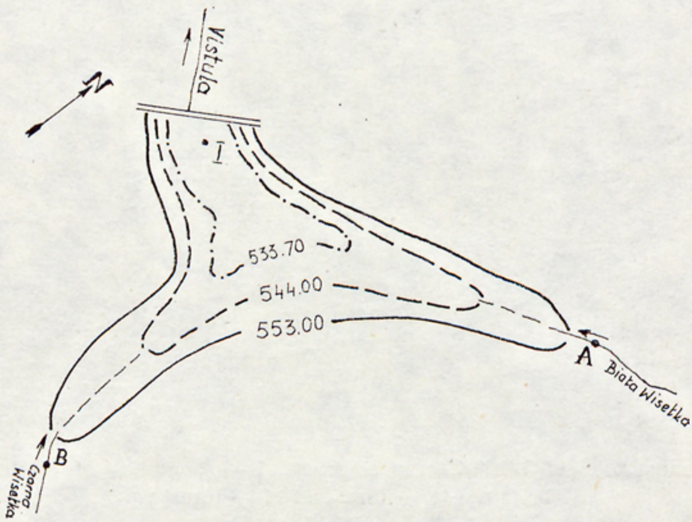

Fig. 2. Distribution of sampling places. I — reservoir; A, B — rivers

Analyses were made according to the methods given by Just and Hermanowicz (1964) and Goltermann and Clymo (1969). Chlorophyll was determined according to the method suggested by UNESCO (Ausgewählten Methoden der Wasseruntersuchung 1970).

Data concerning the hydrology of the reservoir were obtained from the dam management. Loads of nutrients flowing into the reservoir were calculated according to the formula:

$$L = \bar{x} \cdot I_a$$

where: L — total annual incoming mass of the constituent,
$\bar{x}$ — the average concentration of the constituent,
I_a — total annual inflow to the dam from the rivers.

4. Results

4.1. Chemical composition of the water

It appears from the comparison of the results of investigation of the reservoir and river water (Table II) carried out in the period 1976—1984 that neither the water from the reservoir that from the affluents shows any marks of pollution, although the range of variability of the determined parameters is relatively long (fig. 3). The Biała Wisełka has more nutrients than the Czarna Wisełka and contains more electrolytes.

Table II. Average chemical composition and range of variation of water features of affluents of the Wisła Czarne reservoir and of the reservoir in the central position from 1976-1984. x - years 1982-1984

Factor		Biała Wisełka	Czarna Wisełka	Reservoir
Transparency	m			3.3 / 1.5 - 6.0
Conductivity	$\mu S\ cm^{-2}$	105.0 / 68.4-124.5	74.3 / 51.2-120.9	91.6 / 71.2-112.7
Alkalinity	$mval\ dm^{-3}$	0.51 / 0.20-0.85	0.35 / 0.09-0.90	0.44 / 0.16-0.85
Chloride	$Cl\ mg\ dm^{-3}$	3.5 / 1.8-9.0	3.3 / 1.5-6.5	3.8 / 2.30-7.0
Calcium	$Ca\ mg\ dm^{-3}$	12.7 / 4.7-17.5	6.8 / 3.2-13.2	10.2 / 7.6-13.6
Magnesium	$Mg\ mg\ dm^{-3}$	3.8 / 2.0-9.5	4.0 / 0.4-6.9	3.8 / 2.0-8.2
Nitrate	$N\ mg\ dm^{-3}$	1.656 / 0.675-2.580	1.280 / 0.145-2.70	1.368 / 0.710-2.350
Ammonia nitrogen	$N\ mg\ dm^{-3}$	0.076 / 0.00-0.295	0.100 / 0.00-0.40	0.103 / 0.00-0.305
Mineral nitrogen	$N\ mg\ dm^{-3}$	1.734 / 0.797-2.709	1.429 / 0.298-2.808	1.505 / 0.869-2.495
Organic nitrogen^{x}	$N\ mg\ dm^{-3}$	0.277 / 0.024-0.767	0.239 / 0.020-0.750	0.336 / 0.093-0.649
Total nitrogen	$N\ mg\ dm^{-3}$	1.995 / 1.209-3.598	1.482 / 0.923-1.891	1.709 / 1.311-3.144
Phosphate	$P\ \mu g\ dm^{-3}$	8 / 0.00-31	5 / 0.0-36	6 / 0.0-20
Total phosphorus	$P\ \mu g\ dm^{-3}$	41 / 5-136	31 / 5-130	28 / 5-71
Silica	$Si\ mg\ dm^{-3}$	2.60 / 1.98-3.29	2.95 / 2.16-3.74	2.54 / 1.91-3.74
Oxygen	$O_2\ mg\ dm^{-3}$	10.0 / 7.4-13.3	9.9 / 7.4-13.1	9.4 / 5.4-12.3
Oxidability	$O_2\ mg\ dm^{-3}$	2.8 / 1.6-5.2	3.5 / 1.9-9.8	4.1 / 2.1-9.3
BOD_5	$O_2\ mg\ dm^{-3}$	2.6 / 0.2-8.8	1.8 / 0.1-6.4	2.1 / 0.4-4.0
Chlorophyll	$\mu g\ dm^{-3}$			4.5 / 1.0-13.6
N total : P total		39	38	53

In comparing the average values and variation of chemical indicators in the water of both rivers with concentrations in the reservoir water (Table II), a slight change in nutrient values is observed. The average content of the sum of mineral nitrogen is 1.51 N mg dm^{-3} and the con-

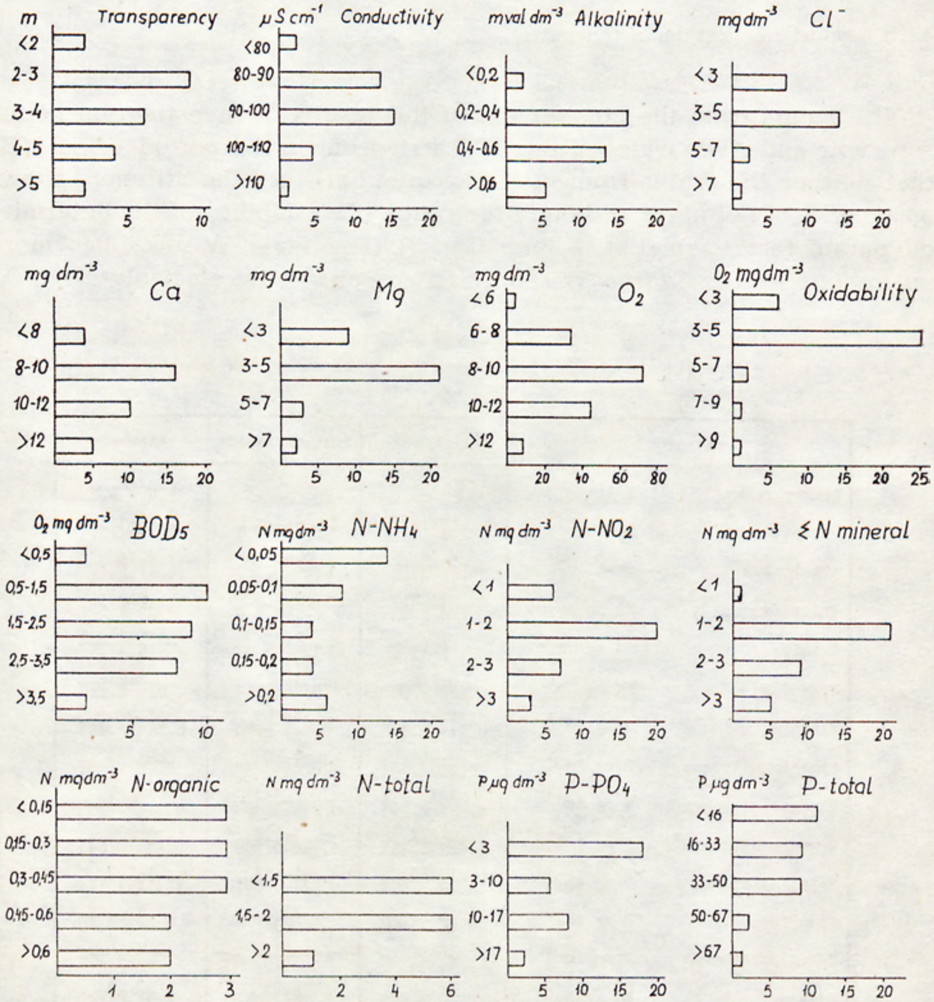

Fig. 3. Histograms of frequency of occurrence of some parameters of the chemical composition of the water (x-axis — number of measurements)

centration of total nitrogen 1.71 N mg dm^{-3}. In the water of the Wisła--Czarne reservoir the content of organic nitrogen increased in comparison with the affluents, whereas the amount of total phosphorus decreased (average concentration 28 P µg dm^{-3}). Oxidability also rose. The remaining determined parameters of chemical features of the reservoir water, similarly as in that of the Rivers Biała and Czarna Wisełka, show great variability but their average contents are close to the average concentrations of both affluents.

From the diagram of the course of temperature in vertical profile (fig. 4A) it can be seen that differences between the surface and the bottom layer of water are small, amounting to only 2°C. Only in June 1981 was a slightly greater thermal stratification found, the temperature difference between the surface and the bottom being 4.5°C.

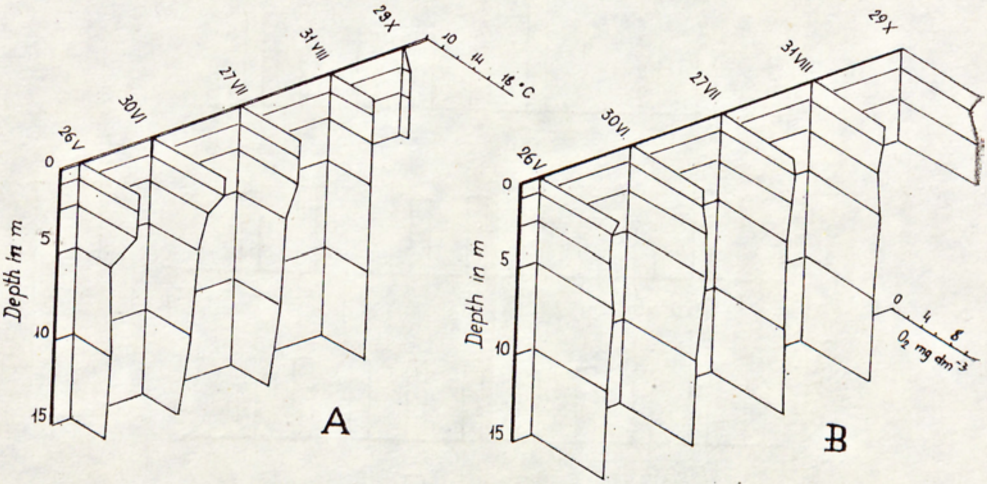

Fig. 4. Water temperature (A) and oxygen content (B) in the central zone of the reservoir in the vegetative season 1981

The investigation of oxygen content (fig. 4B) did not show any vertical differentiation of its concentration. During the 1976—1984 period the greatest difference in oxygen content found between the surface and the bottom layers of water was small (1.70 O_2 mg dm^{-3}). Usually the amount of oxygen in the water was uniform throughout the whole depth of the reservoir.

In the process of hydrochemical investigation of the Wisła-Czarne reservoir the picture of changes in the physico-chemical composition of its water was obtained for 10 years of its existence (fig. 5). Included in the characteristics of changes were the state of water mineralization (conductivity, hardness), nutrients (nitrates, total phosphorus), organic matter (oxidability), and transparency.

The detailed analysis of the degree of water mineralization in the particular years of investigation showed that mean annual values of hardness and conductivity of the reservoir water stayed at the same level for 10 years. Only in the period of catastrophic drought in 1983 did the number of electrolytes in the reservoir water slightly rise (conductivity, hardness).

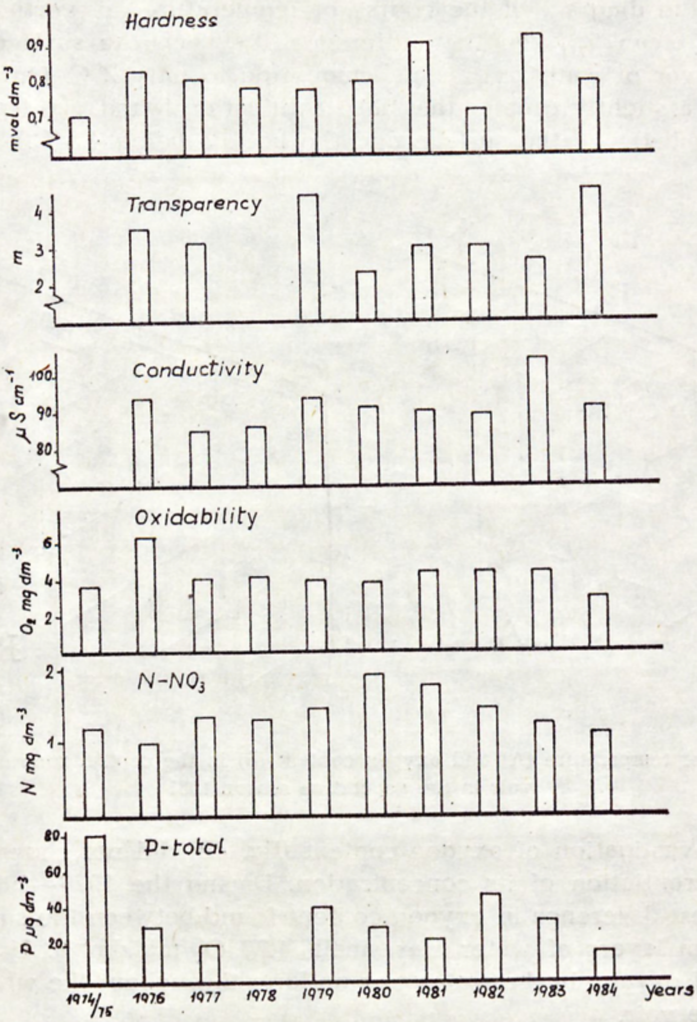

Fig. 5. Changes in the annual mean values of some parameters of the physico-chemical composition of the water in the period 1974—1984 (1974/75 acc. to Magosz 1976)

The content of nitrates during the initial 5 years of the reservoir's existence slightly rose each year, from 1981, conversely, to diminish and reach the same value after 10 years as in the first year of exploitation.

The amount of total phosphorus only in the first two years after inundation (1974—1975) was twice as high as in the remaining years, but the average amounts of total phosphorus on subsequent dates of investigation differed slightly among themselves. Nor at this time was any distinct tendency to rise nor fall observed in the content of total phosphorus.

Water oxidability, did not undergo any important changes, maintaining the same values, with the exception of 1976, throughout the whole period of investigation.

The mean annual values of transparency, similarly as the above-mentioned chemical indicators, did not change significantly and showed no tendency either to rise or fall in the subsequent years of investigation. The values of visibility of Secchi's disc varied around the multiannual average, i.e. 3.3 m. Only in 1979 and 1984 were the water transparency values 1 m higher than the average.

In generalizing the above descriptions of changes in some parameters of the physico-chemical composition of the water during the consecutive 10 years of investigation it may be said that such water features as the general value of electrolytes, the resources of trophic compounds, the content of organic matter, and transparency did not undergo any significant changes. Only the total phosphorus content during the first two years of investigation was slightly higher and during the drought the content of electrolytes in the reservoir water rose.

4.2. Loading of the reservoir with nutrients

The loading of the upper layer of the bottom of the Wisła-Czarne reservoir with nitrogen and phosphorus (Table III) was calculated according to the total of the inflowing loads from the Biała and Czarna Wisełka and the maximum area. The obtained values of loading with phosphorus, taking into account the water exchange, are low. Comparison of the bottom loading of the reservoir with nitrogen and phosphorus calculated for the periods 1974—1975 and 1982—1983 shows that the values of the inflowing N and P loads are the same order and the differences in the loading values are small.

The main source of nutrients flowing into the reservoir (Table IV) in the Biała Wisełka, for its brings in 70% of the total nitrogen compounds and 68% of total phosphorus. The Czarna Wisełka provides, respectively,

Table III. The loading of the Wisła Czarne reservoir with nitrogen and phosphorus calculated according to the magnitude of inflow (a) and taking into account the rate of water retention (b).
x - according to Magosz (1976)

Factor \ Years	a		b
	1974-1975[x]	1982-1983	1982-1983
N-mineral $g\ N\ m^{-2}\ y^{-1}$	-	64.06	6.60
N-total $g\ N\ m^{-2}\ y^{-1}$	89.8	78.2	8.06
$P\text{-}PO_4$ $g\ P\ m^{-2}\ y^{-1}$	0.17	0.26	0.03
P-total $g\ P\ m^{-2}\ y^{-1}$	3.2	2.37	0.24

30% N and 32% P. The retention of total nitrogen and phosphorus in the reservoir is small. Phosphates suffer loss, since more of them flow out through the sluice for economic purposes than flow in.

Table IV. Nitrogen and phosphorus balance calculated according to the surface discharge from 1982 and 1983 for the Wisła Czarne reservoir (N - in tons; P - in kg)

Factor	Inflow	Outflow	Retention %
N-mineral	32.03	29.68	+ 7.3
N-total	39.12	32.89	+15.9
$P-PO_4$	129.68	144.36	-11.3
P-total	1188.11	1165.67	+ 1.9

4.3. Chlorophyll content

The chlorophyll "a" content in the water of the Wisła-Czarne reservoir was small (figs 6, 7, 8, 9). For the whole investigation period 75% of the figures concerning the concentration of this assimilative pigment

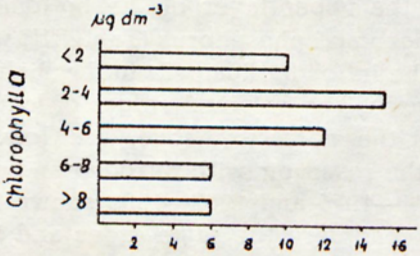

Fig. 6. Histogram of frequency of occurrence of chlorophyll "a" in the water in the period 1976—1984 (x-axis — number of measurements)

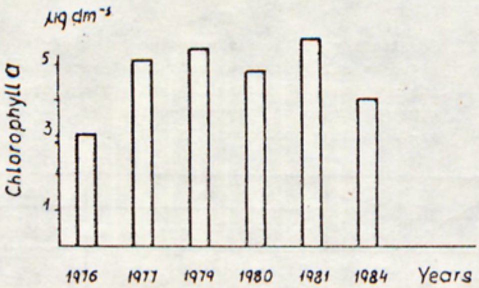

Fig. 7. Changes in the mean annual content of chlorophyll "a" in the water

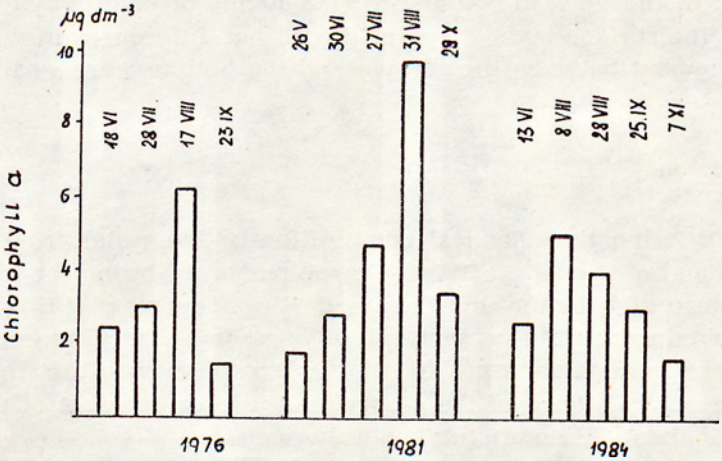

Fig. 8. Seasonal content of chlorophyll "a"

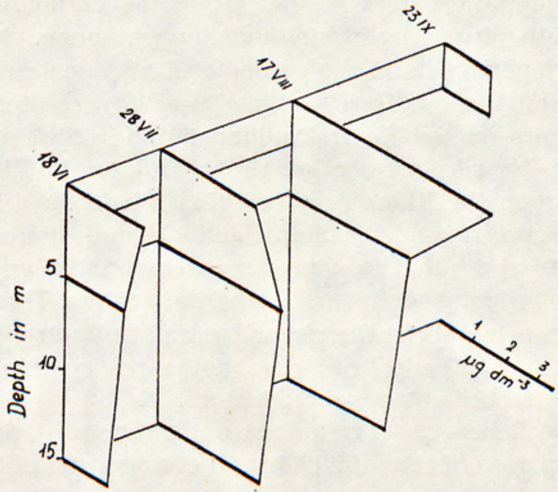

Fig. 9. Vertical distribution of chlorophyll "a" in the water in 1976

were below 6 μg dm^{-3} (fig. 6). During the 6 years of investigation the mean annual amounts of chlorophyll "a" were also low. No significant differences in the chlorophyll content of the reservoir water between the particular years were found (fig. 7).

In the vegetative season only one maximum peak of the chlorophyll value was found (fig. 8), usually occurring in August. In May, and sometimes in June, the reservoir water contained 1—2 μg of chlorophyll per litre. In the vertical profile larger amounts of chlorophyll "a" were found in the surface layer of water (fig. 9) but differences in the content of this pigment between the surface and the bottom were small.

5. Discussion

In comparing the chemical composition of the water from the two affluents and of that of the Wisła-Czarne reservoir during the 1974—1975 period, according to the analyses made by Magosz (1976), with the results obtained by the present author non-significant differences in the determined parameters were found. An exception was that in the first two years of existence of the reservoir its water and that of the rivers contained about 50% more total phosphorus.

During the investigation both just after inundation and later on, it was found that the water showed no signs of pollution but the range of variability of the indicators of particular values was wide. According to Magosz (1976), this great variation of the determined parameters is typical for mountain waters. It seems that the variability of water composition results from hydrobiological phenomena. Magosz (1976) showed this dependence on the example of nitrogen compounds.

Many years' observations of the Goczałkowice Reservoir (Kasza 1986), reservoirs on the River Dnieper (Denisova 1972, Priymachenko-Shevchenko et al. 1973, 1976), on the River Wołga (Kuzin 1972), or on the River Angara (Nikolaeva 1964), and Czechoslovakian reservoirs such as Slapy and Kličava (Prochazková et al. 1973—1976) show that in a new reservoir just after inundation there is a period of primary decomposition of the bottom. This lasts for several years, later to bring about the phenomenon of oligotrophication and then the gradual eutrophication of water if the reservoir and the basin are prone to the effect of antropogenic factors.

The Wisła-Czarne reservoir does not entirely fit this scheme. After a very short period of time the chemical composition of the water became established without showing any rise in trophy. The village of Wisła--Czarne and the tourist traffic in this region has not so far had any effect on the water fertility in the reservoir.

The loading of the bottom surface with nitrogen and phosphorus calculated in 1974—1975 and 1982—1983 (Table III) does not show any great differences, confirming at the same time the relative constancy of the chemical composition of the two inflowing rivers.

On the basis of the hydrological data and the Vollenweider equation (1976), the critical loading with phosphorus, which endangers the purity of the Wisła-Czarne reservoir may amount to 0.52 P total mg m^{-2} of the reservoir area.

The estimated inflow of phosphorus to the Wisła-Czarne reservoir after taking into account water exchange (Table III) is twice as low. This means that the development of phytoplankton should be small. The investigation of chlorophyll "a" (figs 6—9) supports the above conclusion.

A comparison of the average content of chlorophyll "a" (4.5 µg dm^{-3}), the average concentration of total phosphorus (28 µg dm^{-3}), and the transparency values (3.3 m) observed in the present study with the results obtained by Vollenweider (1979) for mesotrophic waters — 4.7 µg dm^{-3} of chlorophyll "a", 26.7 P total µg dm^{-3}, and 4.2 m of transparency — shows that the Wisła-Czarne reservoir should be included in this type of trophicity.

6. Polish summary

Hydrochemiczna charakterystyka zbiornika Wisła-Czarne (Polska Południowa) w latach 1975—1984

W nowo powstałym zbiorniku Wisła-Czarne (ryc. 1, 2, tabela I) prowadzono systematyczne badania jakości wody w dopływach i zbiorniku, od momentu zalania do chwili obecnej. Na tej podstawie przedstawiono charakterystykę fizyko-chemiczną wody zbiornika i jego dopływów (tabela II, ryc. 3—9).

Obliczono dopływ związków biogennych do zbiornika i obciążenie powierzchni jego dna nutrientami (tabele III, IV). Stwierdzono, że obciążenie fosforem, po uwzględnieniu wymiany wody według kryteriów Vollenweidera, jest niskie.

Opierając się na średnich rocznych niektórych wskaźników chemicznych wody zbiornika, przedstawiono ich zmiany w czasie (ryc. 5). Stwierdzono względną stałość składu chemicznego wody zbiornika w ciągu 10 lat. Niewielkie różnice między średnimi rocznymi są wynikiem zjawisk hydrologicznych.

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