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Environmental characteristics of affluents of the Dobczyce Reservoir (Southern Poland) in the preimpoundment period (1983—1985)*

1. Some physico-chemical indices

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A b s t r a c t — On the basis of two-year physico-chemical studies carried out on the affluents of the Dobczyce Reservoir in the preimpoundment period, these feeders were characterized and the magnitude of annual loads of mineral nitrogen and phosphorus was determined. The magnitude of voluminal loading of mineral nitrogen (2.4 g N_{min} m^{-3} year $^{-1}$) and phosphorus (0.203 g P_{min} m^{-3} $year^{-1}$) qualifies the reservoir under construction as being of eutrophic type.

K e y w o r d s: preimpoundment studies, streams, eutrophication, loading.

1. Introduction

The process of eutrophication takes place from the beginning of the existance of a water body since the outflow of waters from its catchment basin transports substances leached from the soil and arising from land use. Currently, we encounter intensified eutrophication brought about not only by the natural conditions but also by civilization-related developments.

On the basis of data from different parts of Europe, V o l l e n w e i d e r (1968) divided the areas into oligo-, meso-, and polytrophic, according to the magnitude of the export of biogenes. He also determined the range of concentrations of nitrogen and phosphorus for impoundments as depending on their hydrological parameters (V o l l e n w e i d e r 1976). Among other criteria these classifications may be used in estimating the resources of catchment basins and the magnitude of inflow of nutrients to water bodies. They are also of practical importance in decision making with regard to the protection of both catchment basins and reservoirs and their rational management.

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During the two years preceding the filling of the dam reservoir at Dobczyce, constructed for purposes up main top water supply for the city of Kraków, complex limnological studies were carried out on the affluents in the catchment basin of the impoundment. The investigation aimed at finding the prerequisites for prognoses of fishery management and exploitation of the waters of the reservoir. The author of the present elaboration examined physico-chemical properties of water, Amirowicz (1988) periphyton, Jelonek and Starmach (1988) ichthyofauna.

The aim of the present work was to describe the physico-chemical characteristics of the affluents of the future reservoir. An attempt was also made to determine the magnitude of the loads of mineral forms of nitrogen and phosphorus flowing into it and on the basis of computed indices, to determine the degree of its eutrophication.

2. Study area, material, and methods

The catchment basin of the future water supply reservoir at Dobczyce covers about 780 km² and is composed of the basin of the River Raba, the largest affluent , and of the Brzezówka, Ratanica, Trzemeśnia, Bulinka, Dębnik, Zakliczanka, and Wolnica streams (fig. 1). These affluents characterized by a poor hydrological inertia and will supply the reservoir with 3.6×10^8 m³ water annually. The River Raba will constitute 88.6% of the total inflow, other feeders 6.7%, 2.1% will be derived from the direct inflow, and 2.6% from atmospheric precipitation on the surface of the reservoir.

The catchment basin lies in the territory of the Gorce, Beskid Wyspowy, and Beskid Średni ranges and the Wieliczka Foothills. Almost the entire area of the Raba basin is composed of sandstone shale formations of the magura series and of submagura beds. The substratum of the sub-montane part of the basin, beginning from Myślenice, is built of Silesian flysh formations of various age and of varied mosaic distribution (Pasternak 1969).

Most of the montane part of the basin is composed of loam soil with a small or medium content of skeleton grain in its upper horizon. Starting from Myślenice a considerable part of the basin is covered by fine sands soils originated from flysh rocks.

The catchment basin of the River Raba, which constitutes the basin of the reservoir, lies in the region of a moderately warm climate with no amplitude of average annual temperatures from 18.8—21.1°C, in the zone of annual precipitation of 1200—800 mm (Punzet 1969).

The Dobczyce Reservoir is 10 km in length, has the shore line of 43 km, and lies in the middle course of the River Raba. The earth dam with surface outflows, a bottom sluice, a Borland fish pass, and an electric

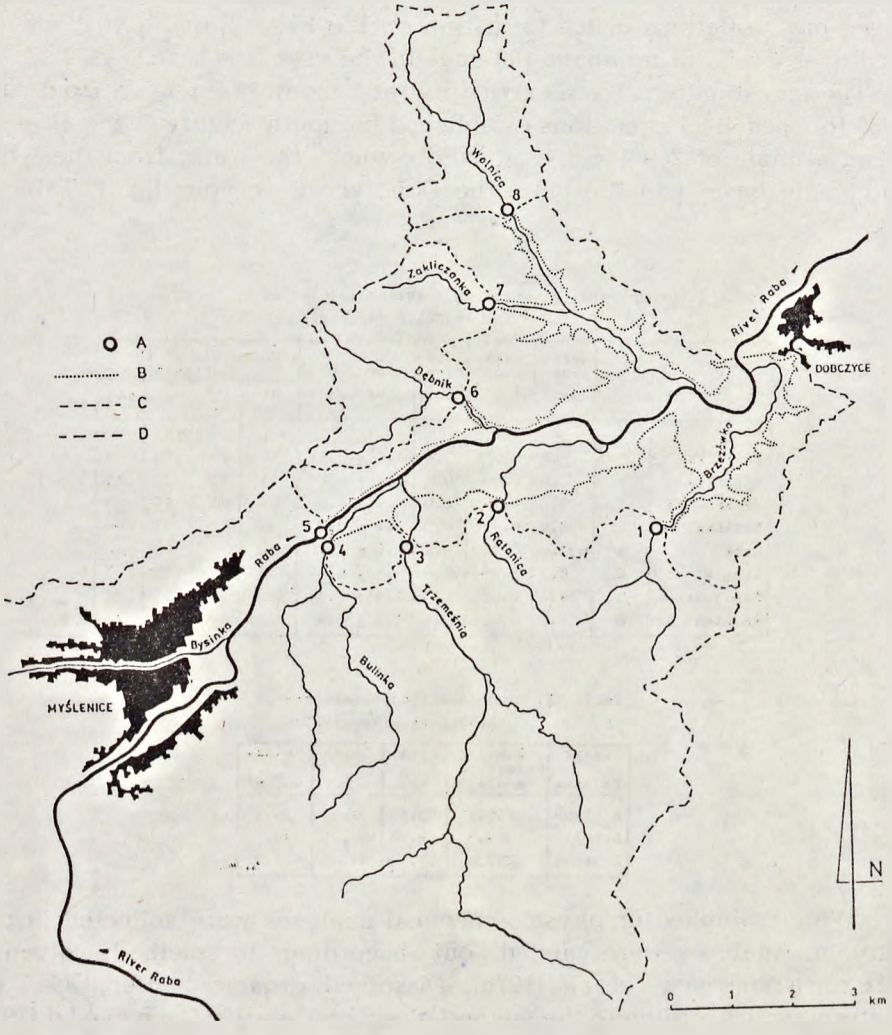

Fig. 1. Catchment basin of the Dobczyce Reservoir. A — sampling stations; B — range of the reservoir; C — borderline of direct catchment basin of the reservoir; D — borderline of the catchment basin

power plant is situated at the village of Dobczyce between Wzgórze Zamkowe and Góra Jałowcowa in the 60.1 km of the Raba.

The average frequency of water exchange will be 3.6 times a year. The projected mean final uptake by the water supply plant is 3.5 $m^3 s^{-1}$ with a biological flow of 1.25 $m^3 s^{-1}$.

The bowl of the reservoir is built of sandstone shale rocks of Carpathian flysh covered with acid fine sand formations, loams, and clays

of pH 4.9—7.4. The location of the reservoir in a cool sub-montane region of abundant precipitation (850 mm on the average) allows the prognosis, based on the pattern of ice formation on the River Raba, that it may be iced over even during about 100 days in the year (P u n z e t 1969).

The investigations were carried out at 1 monthly intervals from April 1983 to April 1985 at stations established in mouth sectors of the affluents at an altitude of 269.9 m, i.e. at points where the water from the whole catchment basin will flow into the Dobczyce Reservoir (fig. 1, Tables I, II).

Table I. Description of sampling stations located on the affluents of the Dobczyce Reservoir

Affluents	Stations	Basin area km^2	Mean flow $m^3 s^{-1}$	Gradient ‰	Width of riverbed	Character of the bottom %			
						stones	gravel	sand	mud
Brzezówka	1	6.8	0.070	13.4	1.4 ± 0.6	50	40	10	0
Ratanica	2	2.8	0.035	19.2	0.7 ± 0.2	15	35	35	15
Trzemeśnia	3	29.0	0.360	8.0	4.9 ± 1.0	65	20	10	5
Bulinka	4	8.0	0.100	8.5	1.2 ± 0.2	30	45	15	10
Raba	5	691.0	10.000	4.2	24.0 ± 10.0	70	25	5	0
Dębnik	6	4.1	0.054	10.4	1.5 ± 0.3	35	45	15	5
Zakliczanka	7	4.2	0.045	8.3	1.1 ± 0.3	20	35	25	20
Wolnica	8	8.5	0.090	7.7	1.8 ± 0.4	5	20	40	35

Table II. Hydrotechnical parameters of the Dobczyce Reservoir

Level of filling	Damming ordinate m a.s.l.	Area km^2	Depth m	Volume $10^6 m^3$
Minimum	256.7	3.35	4.55	14.5
Normal	269.9	9.70	10.25	99.5
Maximum	272.6	11.10	11.40	127.0

Water samples for physico-chemical analyses were collected in midstream. Analyses were carried out according to methods given by H e r m a n o w i c z et al. (1976). Dissolved organic matter (DOC) was determined according to the method given by L e w i s, C a n f i e l d (1977).

Data concerning the loads of nutrients from the direct catchment basin, whose share amounted to 2.1%, were given as means from the investigated streams flowing into the reservoir. According to S t a c h o w i c z (1986), data concerning the loads of nutrients from atmospheric precipitation were given as means from experimental catchment basins of the Brzezówka and Wolnica streams. The loads brought in by the feeders were calculated on the basis of an interaction between the flow and the concentration of the investigated forms of biogene salts.

Data concerning the hydrology of affluents of the Dobczyce Reservoir were obtained from the Institute of Meteorology and Water Economy in Kraków.

3. Results

Some physico-chemical indices of the tributaries are given in Table III. In the period of the investigation the temperature of waters in the catchment basin of the Dobczyce Reservoir varied from 0.1—21.5°C. From spring to late autumn the water temperature in the River Raba was higher than in the streams, in August and September the difference reaching 4.0°C in relation to the Brzezówka (Station 1) where the lowest temperatures were usually noted.

Table III. Average physico-chemical composition and range of variation of water of affluents of the Dodczyce Reservoir from the period 1983 - 1985

Affluents / Stations		Temperature °C	pH	Dissolved oxygen mg O_2 dm^{-3}	Oxygen saturation % O_2	BOD_5 mg O_2 dm^{-3}	DOC mg C dm^{-3}	Total hardness °g	Total residue mg dm^{-3}
Brzezówka	1	0.1 - 17.1	7.2 6.5 - 8.4	9.7 2.9 - 14.4	81 20 - 180	2.9 0.4 - 6.2	1.93 1.34 - 3.05	9.6 7 - 12	99 19 - 248
Ratanica	2	0.2 - 17.1	7.6 7.0 - 7.9	10.3 6.8 - 13.9	88 70 - 111	4.2 0.8 - 6.8	1.74 1.44 - 2.45	9.9 7 - 12	127 10 - 352
Trzemesnia	3	0.2 - 21.0	8.1 6.6 - 9.0	9.9 2.9 - 14.4	88 20 - 129	3.9 0.7 - 7.5	1.75 1.29 - 3.05	9.3 7 - 14	192 5 - 744
Bulinka	4	0.1 - 19.0	8.0 7.3 - 8.5	10.8 7.4 - 14.5	92 63 - 116	4.9 1.4 - 9.5	1.95 1.44 - 2.60	9.0 7 - 11	128 5 - 516
Raba	5	0.3 - 21.5	8.3 7.0 - 9.3	10.8 2.7 - 15.0	95 19 - 126	4.5 0.5 - 9.6	1.37 1.24 - 2.20	10.6 8 - 15	205 5 - 800
Dębnik	6	0.2 - 17.5	7.7 6.6 - 8.4	9.0 3.0 - 12.0	71 21 - 119	1.9 0.8 - 3.5	1.51 1.24 - 2.15	9.0 8 - 10	92 12 - 225
Zakliczanka	7	0.2 - 17.8	7.9 7.3 - 8.6	8.0 3.7 - 12.1	67 36 - 97	3.9 2.2 - 9.0	2.04 1.59 - 2.60	16 13 - 18	178 12 - 1005
Wolnica	8	0.1 - 19.5	7.8 6.7 - 8.4	9.9 2.8 - 15.2	77 19 - 108	3.6 0.4 - 8.3	2.01 1.34 - 3.15	9.9 8 - 11	170 42 - 700

In the River Raba the pH of the water varied from 7.0—9.3 and in the streams from 6.5—9.0. The lowest average pH was found in the Ratanica (Station 2), Brzezówka (Station 1), and Dębnik (Station 6) streams.

Water hardness in the streams and in the River Raba (Station 5) varied fairly strongly, from 7—18°g; the mean water hardness of the affluents approximated to 10°g (soft waters) with the exception of the Zakliczanka stream (Station 6) which was characterized by waters of marked hardness.

In the water of the streams the content of dissolved oxygen varied 2.8—15.2 mg O_2 dm^{-3}, and in the Raba (Station 5) from 2.7—15.0 mg O_2 dm^{-3}. The lowest values of oxygenation were noted in periods when there was ice on the Raba and its tributaries. Oxygenation of the water was high from spring to autumn when supersaturation was also observed.

Biochemical oxygen demand (BOD_5) varied in the range 0.4—9.6 mg O_2 dm^{-3}. In the streams the highest values of this parameter were found in the Bulinka (Station 4) and Ratanica (Station 2) and the lowest in the Dębnik (Station 6) and Brzezówka (Station 1), while intermediate values appeared in the River Raba.

The content of dissolved organic carbon (DOC) varied from 1.24 mg C dm^{-3} in the water of the Dębnik stream (Station 6) and in the Raba (Station 5) to 3.15 mg C dm^{-3} in the Wolnica (Station 8). Summer months were characterized by increased values of DOC. The largest feeders of the Dobczyce Reservoir, the River Raba, (Station 5) manifested the lowest value of the DOC index.

The Raba (Station 5) and the Trzemeśnia (Station 3), Bulinka (Station 4), Zakliczanka (Station 7), and Wolnica (Station 8) streams showed the most advanced mineralization of the water and also the highest concentrations of mineral forms of nitrogen and phosphorus (Tables III, IV).

Table IV. Average concentrations of mineral forms of nitrogen and phosphorus in the affluents of the Dobczyce Reservoir (mg dm^{-3}). σ - standard deviation; V - coefficient of variation; x - data according to Stuchowicz (1986)

Affluent / Stations		NH_4			NO_2			NO_3			PO_4		
			σ	V		σ	V		σ	V		σ	V
Brzezówka	1	0.569	0.279	0.49	0.008	0.005	0.62	1.593	0.557	0.35	0.099	0.202	2.00
Rutanica	2	0.355	0.151	0.42	0.006	0.004	0.67	1.443	0.619	0.43	0.042	0.047	1.12
Trzemeśnia	3	0.355	0.237	0.67	0.009	0.009	1.00	1.123	0.367	0.33	0.046	0.053	1.15
Bulinka	4	0.482	0.289	0.59	0.013	0.009	0.69	1.403	0.509	0.36	0.094	0.086	0.91
Raba	5	0.631	0.844	1.34	0.055	0.043	0.78	1.542	0.849	0.55	0.187	0.125	0.67
Dębnik	6	0.340	0.184	0.54	0.006	0.004	0.67	0.989	0.347	0.35	0.032	0.025	0.78
Zakliczanka	7	0.975	0.797	0.82	0.009	0.007	0.78	1.878	0.921	0.49	0.079	0.068	0.86
Wolnica	8	0.874	0.535	0.61	0.026	0.010	0.38	1.968	0.906	0.46	0.125	0.203	1.62
Direct catchment basin		0.622	-	-	0.011	-	-	1.574	-	-	0.075	-	-
Atmospheric precipitation		1.28	-	-	-	-	-	0.652	-	-	0.094	-	-

In the period of the investigation the concentrations of mineral forms of nitrogen were within the ranges: NH_4 0.100—4.200 mg dm^{-3}, NO_2 0.0015—0.180 mg dm^{-3}, NO_3 0.520—4.210 mg dm^{-3}. The Zakliczanka (Station 7), and Wolnica (Station 8) streams and the River Raba (Station 5) were characterized by the highest concentrations of these forms of nitrogen. Of the remaining affluents, an increased content of mineral nitrogen was found in the Brzezówka (Station 1) and Bulinka (Station 4). The highest concentrations of ammonia and nitrate forms appeared in the River Raba (Station 5), Zakliczanka (Station 7), and Wolnica (Station 8) streams in periods of spring run-off and in the remaining streams in the summer. In most of the affluents nitrites reaches the highest values in spring and summer. The greatest variability was found in the concentration of ammonia and nitrite forms of nitrogen. For NH_4 the coefficient of variability was within the range 0.42—1.34, for NO_2 from 0.38—1.00, while for nitrates it did not exceed 0.55.

The content of mineral phosphorus changed from analytical zero to 0.815 mg PO_4 dm^{-3}. A periodical saturation of orthophosphates occurred in all the affluents with the exception of the River Raba (Station 5) in the period May—July, the largest amounts being observed in autumn. The

greatest variation in the concentration of phosphates appeared in the Brzezówka (Station 1) and Wolnica (Station 8) streams. In the catchment basin of the Dobczyce Reservoir the mean concentrations of PO_4 varied from 0.032 mg PO_4 dm^{-3} in the Dębnik stream (Station 6) to 0.187 mg PO_4 dm^{-3} in the Raba (Station 5).

In order to determine the role of particular affluents in the formation of water quality in the reservoir the annual loading of inorganic nitrogen and phosphorus compounds fed by eight affluents, the direct catchment basin, and atmospheric precipitation was computed (Table V).

Table V. Annual loads of mineral nitrogen and phosphorus brought in by the affluents of the Dobczyce Reservoir in kg N_{min} and P_{min} in the period 1983 – 1985

Affluents / Stations		Inflow %	N_{min}	Nitrogen load %	P_{min}	Phosphorus load %
Brzezówka	1	0.62	1793.9	0.75	71.3	0.35
Ratanica	2	0.31	673.9	0.28	15.1	0.07
Trzemeśnia	3	3.19	6106.7	2.55	170.4	0.84
Bulinka	4	0.89	2215.5	0.93	96.7	0.48
Raba	5	88.63	205847.3	86.00	19243.6	95.10
Dębnik	6	0.48	842.1	0.35	17.8	0.09
Zakliczanka	7	0.40	1693.7	0.71	36.6	0.18
Wolnica	8	0.80	3241.7	1.35	115.8	0.57
Direct inflow		2.12	6410.2	2.68	184.5	0.91
Atmospheric precipitation		2.57	10466.4	4.37	281.7	1.39
Total		100	239291.4	100	20233.5	100

The quantities of nutrients result not only from the different content of these elements in the water of the affluents but also from different hydrological relations. These two variables being taken into consideration, it was calculated that the annual inflow of mineral nitrogen and mineral phosphorus would amount to about 239 t and 20 t, respectively.

The dominant form of mineral nitrogen is nitrate nitrogen, which constitutes 51.6% of its total inflow. In the particular affluents the share of nitrates differed, reaching 36% in the Zakliczanka stream (Station 7) to 54% in the River Raba (Station 5) and in the Ratanica stream (Station 8). The smallest NO_3 content (13%) was found in the atmospheric precipitation. In relation to the total loading, the percentage share of ammonia nitrogen reached 46.2% in the water of the affluents. Nitrite nitrogen had the least share (2.2%) in the total mineral nitrogen carried into the reservoir.

The River Raba will feed about 206 t of mineral nitrogen annually, including 112 t of nitrates, 89 t in ammonia form, and 5 t in nitrite form. This constitutes 86% of the total inflow of mineral nitrogen in the reservoir.

About 20 t of mineral phosphorus will flow into the reservoir from the catchment basin and, as in the case of nitrogen, the River Raba will be its chief source (about 19 t annually, i.e. 95% of the total inflow).

4. Discussion

The mean values and variation of physico-chemical indices being taken into consideration, the affluents of the future Dobczyce Reservoir may be divided into two groups: „pure" affluents, i.e. the Brzezówka (Station 1), Ratanica (Station 2), Trzemeśnia (Station 3), and Dębnik (Station 6) streams and those with a large content of biogens, i.e. Bulinka stream (Station 4), the River Raba (Station 5), and the Zakliczanka (Station 7) and Wolnica (Station 8) streams. The current resources of nutrients in waters of the catchment basin of the reservoir indicate a progressive increase in their fertility in comparison with earlier studies (B o m b ó w n a 1969, W r ó b e l 1980).

The high concentrations and the values of coefficients of variation in the content of mineral nitrogen and phosphorus forms show a strong pressure of anthropogenic factors on the basin (inappropriate structure of land use, improper agrotechnical measures, point discharge of pollution, and atmospheric pollution). This is particulary manifested at Station 5 on the River Raba, which is strongly affected by municipal sewage from Myślenice.

Evaluation of the effect of nutrients flowing into the reservoir on its fertility can naturally be only approximate. Nevertheless, on this basis general rules concerning its loading with mineral nitrogen and phosphorus may be derived and used in determining the role of the catchment basin and in forecasting the biological transformations occurring there.

The presented data show the waters of the River Raba will significantly affect the level of mineral nitrogen, and particularly of mineral phosphorus in the reservoir. Other feeders will modify the quality of the water to a small degree, being only more important in the mouth sectors. Only in the case of the bay of the Wolnica stream, on account of its position, will the loads of mineral nitrogen and phosphorus brought in by the Zakliczanka and Wolnica streams not affect the quality of water in the bay.

The data concerning the total load of mineral nitrogen and phosphorus brought into the reservoir suggest that the surface loading of the water of the reservoir with mineral nitrogen will amount to 24.7 g N_{min} m^{-2} $year^{-1}$, and with phosphorus to 2.1 g P_{min} m^{-2} $year^{-1}$ (Table VI).

Table VI. Expected loading of mineral nitrogen and phosphorus in the Dobczyce Reservoir, calculated according to Vollenweider (1976)

Loading parameters		N_{min}	P_{min}
Total inflow	t $year^{-1}$	239.3	20.2
Average inflow concentration	g m^{-3}	0.862	0.057
Specific surface loading	g m^{-2} $year^{-1}$	24.7	2.1
Specific voluminal loading	g m^{-3} $year^{-1}$	2.4	0.203

On the basis of empirical data, Vollenweider (1968) determined the magnitude of loads of nutrients which did not distinctly increase the rate of eutrophication, and quoted the amounts of nutrients endangering the purity of water in a reservoir. Taking into account the frequency of water exchange in the Dobczyce Reservoir, the following values were determined according to Vollenweider's criteria (1976): as the safe loading of the reservoir 0.565 g P_{tot} m^{-2} $year^{-1}$ and as the critical one 1.129 g P_{tot} m^{-2} $year^{-1}$. The currently computed surface loading of the reservoir exceeds 4 times the safe level and 2 times the critical one. Also the computations carried out according to the Uhlmann and Albrecht method (1968) determining the capacity of phosphorus elimination (0.544 g P_{tot} m^{-2} $year^{-1}$) gave results below the current loading of the Dobczyce Reservoir.

With the voluminal loading of nitrogen and phosphorus maintained at the level of 0.203 g P_{min} m^{-3} $year^{-1}$ and 2.4 g N_{min} m^{-3} $year^{-1}$ according to Vollenweider and Kerekes (1980), the Dobczyce Reservoir will represent the eutrophic type of water body. It should be stressed that the above calculations included only mineral forms of nitrogen and phosphorus.

5. Polish summary

Środowiskowa charakterystyka dopływów zbiornika dobczyckiego (Polska Południowa) w okresie poprzedzającym jego zalanie (1983—1985)

1. Wybrane wskaźniki fizykochemiczne

Na podstawie dwuletnich badań fizykochemicznych dopływów zbiornika dobczyckiego, wykonanych przed jego zalaniem, sporządzono charakterystykę dopływów oraz określono wielkość dopływających rocznych ładunków azotu i fosforu mineralnego (ryc. 1, tabele I—V).

Dopływy przyszłego zbiornika można podzielić na dwie grupy: dopływy „czyste" (Brzezówka — st. 1, Ratanica — st. 2, Trzemeśnia — st. 3, Dębnik — st. 6) oraz dopływy o znacznej koncentracji biogenów (Bulinka — st. 4, Raba — st. 5, Zakliczanka — st. 7, Wolnica — st. 8). Wody rzeki Raby będą miały istotny wpływ na poziom w wodzie zbiornika azotu mineralnego (86% całkowitego dopływu), a w szczególności fosforu mineralnego (95%).

Z danych dotyczących całkowitego ładunku azotu i fosforu mineralnego wnoszonego na teren zbiornika wynika, że powierzchniowe obciążenie wód zbiornika azotem mineralnym wyniesie 24,7 g N_{min} m^{-2} rok^{-1}, a fosforem 2,1 g P_{min} m^{-2} rok^{-1} (tabela VI). Przy utrzymującym się objętościowym obciążeniu fosforem mineralnym na poziomie 0,203 g P_{min} m^{-3} rok^{-1} i azotem 2,4 g N_{min} m^{-3} rok^{-1} zbiornik dobczycki będzie stanowił typ zbiornika eutroficznego. Należy podkreślić, że do powyższych obliczeń wzięto pod uwagę tylko formy mineralne azotu i fosforu.

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