The influence of Lake Żarnowiec on the efflux of ions with the Piaśnica River waters

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Efflux of ions
Lake Żarnowiec
Piaśnica River

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Abstract

An attempt has been made to estimate the influence of Lake Żarnowiec on chemical composition of waters flowing with the Piaśnica River through the Lake to the Baltic Sea. To do this, a four-year period of measurements of feeding the Lake with chemical components and of their efflux was utilized.

1. Introduction

The chemical composition of surface waters in a drainage basin is affected not only by natural processes which supply products of chemical weathering and biochemical transformations to the rivers and lakes. An important, and often decisive role in the formation of chemical composition of surface waters is played by human activities concerned with the utilization of the drainage area [1–3, 5, 6, 8–10]. The main sources of anthropogenic pollutants can be classified into the local and non-local ones. The first category can be kept under control and the amounts discharged to surface waters can be regulated. The second one derived from fertilization of agricultural regions, traditional cattle breeding and precipitation are difficult to control.

In the drainage area of Lake Żarnowiec there are both kinds of pollutants. The local one – biological waste-water treatment plant at Nadole, and those associated with land cultivation.

Waters from the drainage area and their chemical constituents are exported with the Piaśnica River across Lake Żarnowiec to the Baltic Sea. Ions transported from the drainage area into the lake can undergo chemical and biological transformations giving rise of qualitative and quantitative fluctuations. The Lake Żarnowiec waters flowing out with the Piaśnica River to the sea can thus differ markedly in their chemical composition from the inflowing waters.

The purpose of this study is to estimate, in quality as well as in quantity, variations in the chemical composition of waters flowing across the lake.

2. Field and laboratory investigations

Lake Żarnowiec is located in the Kasubian Sea-coast which occupies the north-east region of the Pomerania extending off the Słowińskie Sea-coast to the east.

The trough of the lake lies in the Piaśnica River valley about 5 km from the sea shore. The deepest site of the trough lies about 18 m under the sea level, thus creating the possibility of penetration of sea water through the ground into the lake. The sea water can be of paramount importance to the formation of chemical composition of the lake waters. To the east and west the lake is surrounded by high and steep banks covered with leafy-coniferous forests.

The Piaśnica River valley in the northern part of the lake is covered with meadows and arable grounds, and its southern part with meadows only. The watershed of the lake (249 km^2) is utilized by agriculture. There prevail arable grounds, whereas greenlands and forests cover smaller areas. As there are no bigger towns, industrial plants and cattle-breeding farms in the water-shed, the pollution of surface waters is mainly caused by mineral fertilization and traditional cattle breeding. The waste--water treatment plant at Nadole, discharging its effluents directly into the lake, is the only local pollution source in the region.

The southern part of the lake is supplied with the Piaśnica River waters (water-shed area $A=87.9$ km^2). To the northwest part of the lake, the Bychowska Struga River, being a tributary of the Piaśnica River, carries its waters ($A=122.5$ km^2). The proper watershed of the lake is bordering the area of 39.3 km^2.

The mean annual precipitation over the lake during the hydrologic years 1977–1980 was 585.1 mm, as reported by the meteorological observation point located on the north-eastern bank. Lake Żarnowiec is of the flow-through type. Waters draining from the catchment area (249 km^2) into the lake are transported through the Piaśnica River estuary into the northern part of the lake.

In the Lake Żarnowiec drainage area profiles and sampling sites were determined in which systematic hydrologic and meteorological observations were made from November '76 to October '80. The aquatic and ionic feeding sources of the lake are as follows: the Piaśnica and Bychowska Struga Rivers, direct drainage area of the lake, ground feeding and the waste-water treatment plant at Nadole. Waters of the lake flow out through the Piaśnica River estuary to the sea.

Measuring profiles were determined in the feeding and efflux sources with the exception of the ground-water feeding and the direct catchment area of the lake (Fig. 1). In the profiles Piaśnica – Kartoszyno, Piaśnica – Żarnowiec, Bychowska Struga River – Wierzchucino and Lake Żarnowiec – Nadole, daily water gauge observations and measurements of the water temperature were made. Measurements of flow rates and water sampling for chemical analyses were carried out once a month. Four measuring sites were established in the lake at a depth of 15 m, as shown in Fig. 1 (nos. 2–5). At these sites the water temperature was measured once a month at each 1 m spacing of the depth. At sites 3 and 5 water was sampled for chemical analyses. The sampling was accomplished 0.4 m below the water table, at a half

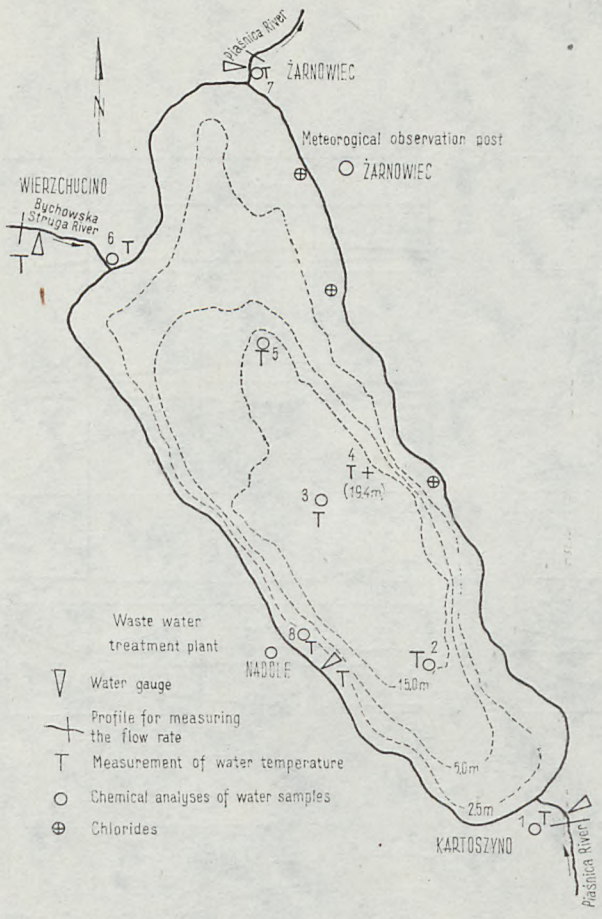
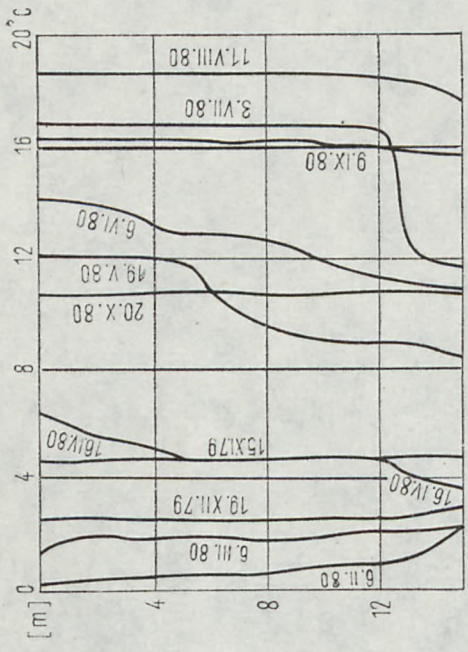


Fig. 1. Measuring sites in Lake Żarnowiec.

of the depth (7 m) and at the bottom (15 m). On the same day the municipal waste-waters discharged to the lake (from the plant at Nadole) were sampled and one water sample was taken from the lake in the vicinity of the plant (site 8). At the north-east bank of the lake, water was sampled once a month for the determination of the chloride level.

Observations of the water stages, the measurements of temperature and volume flow rates were accomplished by using the methods of the Institute of Meteorology and Water Management [7]. The temperature of water at various depths was measured with an electric thermometer. Chemical analyses of the water samples comprised the determination of turbidity, pH, dissolved oxygen, BOD_5, oxidizability, alkalinity, ammonia, nitrates, chlorides, sulphates, hydrogen carbonates, iron, manganese, magnesium and calcium. The chemical analyses were carried out according to the Polish Standards by employing the methods described in [4].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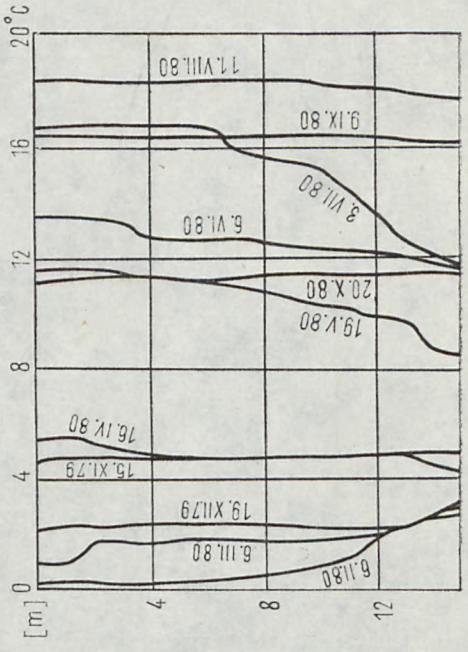
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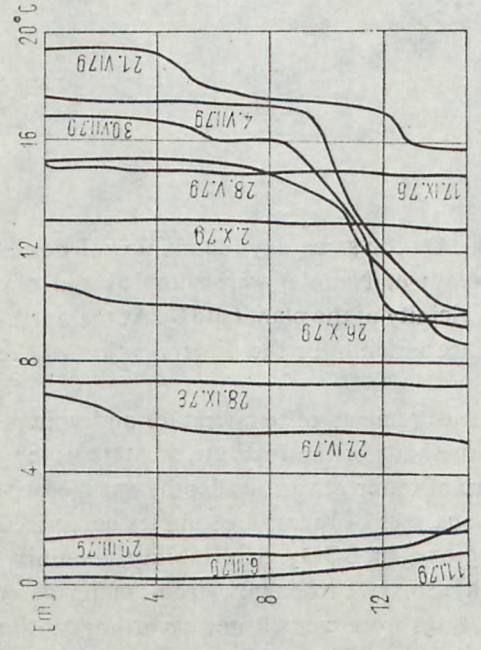
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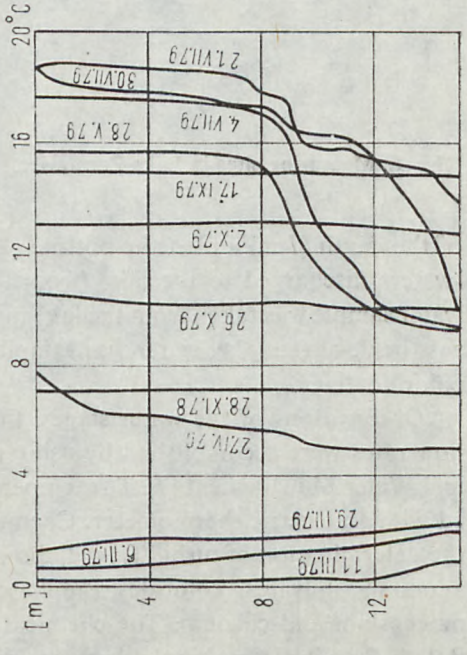
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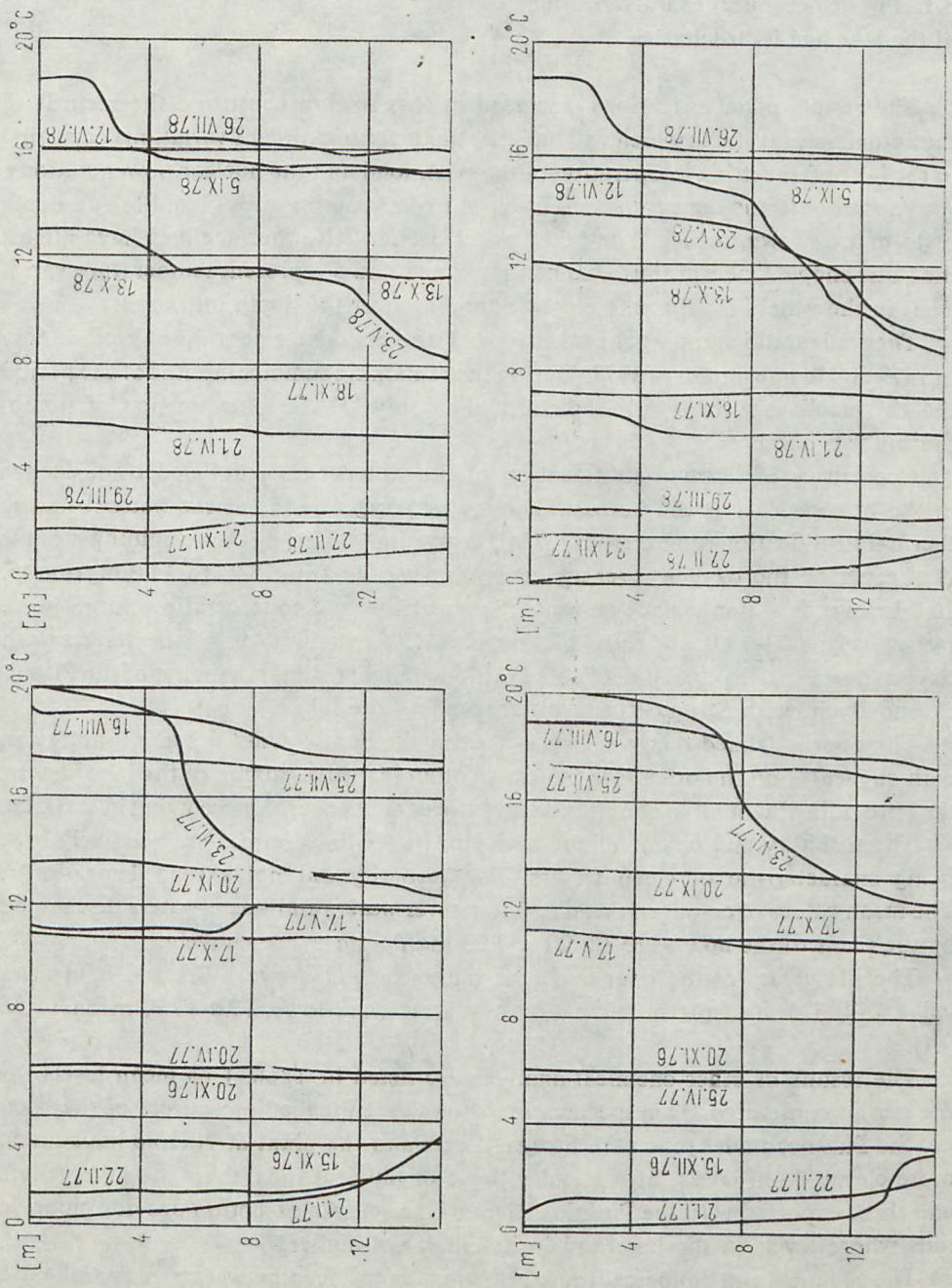

Fig. 2. Temperature variations of the Lake's water at the measuring sites.

3. Results and discussion

3.1. Physico-chemical characterization of the lake and its tributaries

The results of investigations discussed in this section constitute the records of the actual natural status which will underlie the determination of variations occurring in the lake after setting in operation of the peak-load and the nuclear power stations.

Variations in the temperature of water at two measuring sites (2 and 5) at a depth of 15 m are shown in Figs. 2 and 3. At sites 3 and 4 the thermoclines have almost the same shape. One can thus assume that sites 2 and 5 represent temperature variations in the waters for the whole area extending over the depth indicated.

Thermal stratification of the lake, typical of the summer period, took place only in 1979 and in one month of 1977. During the remaining summer months of the period the thermoclines were poorly defined and in July '77 the phenomenon of homothermy was observed.

Occurrence of thermal stratification of the waters was paralleled by a decline in the oxygen level at the bottom. The lowest oxygen levels at the bottom during thermal stratification ranged from 1.0 to 3.2 $mg \cdot dm^{-3}$. During the remaining months of the period the oxygen level at the bottom varied from 5.2. to 14.0 $mg \cdot dm^{-3}$. Just below the water surface and at a depth of 7 m the concentration ranges were respectively 8.0–18.0 and 7.0–14.0 $mg \cdot dm^{-3}$. The saturation of the waters with oxygen down to a depth of 7 m (Table 1) attained higher values than that of the Piaśnica and Bychowska Struga Rivers waters feeding the lake.

The poorly defined thermoclines – on the one hand – and the good saturation with oxygen – on the other, are indicative of an intensive mixing of the lake waters, thus providing favourable conditions for self-cleaning processes occurring in the lake.

The turbidity and colour of the lake and its feeding sources are relatively low, being characteristic of clean waters. The turbidity did not exceed 1 $mg \cdot dm^{-3}$. The mean values of colour of the lake water, river waters and waste-waters discharged by the plant to the lake were 13, 20 and 23 mg $Pt \cdot dm^{-3}$ respectively.

The pH values of the river and lake waters ranged between 7.2 and 8.0 (mean value 7.6). Those of the municipal waste-waters were lower (7.0–7.3, mean value 7.1).

The results of other chemical analyses are listed in Table 1 as mean levels for the period considered. This specification shows that the feeding sources of the lake, *i.e.* the Piaśnica and Bychowska Struga Rivers and the plant at Nadole have much more elevated ion levels, in particular those of nutrient ions, than the lake waters and those exported with the Piaśnica River to the sea. An exception provide chloride ions whose levels in the lake and in its efflux are higher.

The chemical and biological transformations of the feeding waters in the lake are favourable for the improvement of their quality. The transformations contribute to the decrease of the levels of phosphates, nitrates, ammonia, oxidizability and

Table 1. Mean annual levels of chemical components in Lake's waters during the period November '76 – October '80

Measuring sites	Mean O_2 saturation [%] vertical profile	down to 7 m	down to 15 m	Mean of BoD_5 in vertical profile [mgO_2/dm^3]	Mean of oxidizability in vertical profile [mgO_2/dm^3]	Mean of alkalinity in vertical profile [$mval/dm^3$]	Mean level of, [mg/dm^3] NH_4-N	NO_2-N	NO_3-N	PO_4^{3-}	Fe^{3+}	Mn^{2+}	Ca^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}
2	90.6	99.1	79.4	2.3	3.4	2.5	0.05	0.014	0.15	0.12	0.04	0.03	7.6	49.4	22.4	38.6
3	89.4	97.5	80.0	2.1	3.5	2.5	0.05	0.003	0.12	0.13	0.04	0.03	7.3	49.4	22.4	37.1
5	88.6	97.4	78.3	2.1-	3.4	2.5	0.05	0.004	0.14	0.13	0.04	0.03	7.1	49.0	22.4	38.4
Mean of lake	89.5	97.9	79.2	2.2	3.4	2.5	0.05	0.007	0.14	0.13	0.04	0.03	7.3	49.3	22.4	38.3

Table 2. Mean annual levels of chemical components in rivers and waste-water treatment plant at Nadole during the period November '76 – October '80

Measuring sites	Mean O_2 saturation [%] vertical profile	down to 7 m	down to 15 m	Mean of BoD_5 in vertical profile [mgO_2/dm^3]	Mean of oxidizability in vertical profile [mgO_2/dm^3]	Mean of alkalinity in vertical profile [$mval/dm^3$]	Mean level of, [mg/dm^3] NH_4-N	NO_2-N	NO_3-N	PO_4^{3-}	Fe^{3+}	Mn^{2+}	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}
8	107.4	–	–	2.5	3.6	2.5	0.06	0.003	0.14	0.11	0.07	0.06	7.3	49.2	22.4	38.4
Piaśnica R. – – Kartoszyno	94.2	–	–	2.3	4.1	3.5	0.11	0.004	0.26	0.10	0.14	0.01	8.2	66.8	11.7	48.0
Bychowska Struga R.	91.4	–	–	3.2	4.9	2.6	0.10	0.018	0.60	0.21	0.11	0.02	8.7	60.7	15.8	45.7
Plant at Nadole	40.4	–	–	13.6	7.6	3.0	1.41	0.13	1.29	6.12	0.11	0.04	13.6	62.0	56.8	64.5
Piaśnica – – Żarnowiec	109.6	–	–	2.6	3.8	2.5	0.05	0.002	0.16	0.10	0.04	0.02	7.6	48.7	22.4	38.3

BOD_5, whereas the saturation with oxygen of the Lake Żarnowiec waters increases. The lake can thus be considered as being a sort of a natural waste-water treatment plant for inflowing waters which are subsequently exported to the sea with the Piaśnica River.

The elevated chloride level in the lake (22.4 $mg \cdot dm^{-3}$) relative to those in the feeding waters of the Piaśnica and the Bychowska Struga Rivers (11.8 and 15.8 $mg \cdot dm^{-3}$ resp.) are presumably due to the ground-based feeding of the lake with waters of enhanced chloride levels. This is supported by measurements of the chloride levels at sites located at the eastern bank. Variations in the chloride levels at these sites were 21–76 $mg \cdot dm^{-3}$, the mean value being 30.6 $mg \cdot dm^{-3}$. The increase in the chloride levels at the eastern bank was noted mainly during the periods of the lowered water table. At high water stages these levels matched those of the vertical profiles studied.

3.2. Attempt at balancing the ionic composition of the lake

An attempt to establish an ionic budget of a flow-through lake, such as Lake Żarnowiec, would contribute to the assessment of the contribution of the ions making up its chemical composition and the role played by the lake chemical transformations of the feeding waters.

A simplified ionic budget of the lake for the period October '76 – October '80 was calculated from the following data:

(i) initial storage of the lake as on November 1, 1976;

(ii) water input to the lake during the period considered from the Piaśnica and Bychowska Struga Rivers, from the direct lake's drainage area and from the Nadole plant;

(iii) efflux of the waters with the Piaśnica River to the sea during the balancing;

(iv) results of chemical analyses of the lake waters, cleaned municipal waste-water, the waters of the Piaśnica and Bychowska Struga Rivers.

The initial storage of the lake was calculated on the basis of the bathometirc measurements carried out in February 1960, taking into account the water stage as on November 1, 1976. Similarly, the final storage was calculated on the basis of the water stage as on October 31, 1980. The input of the Bychowska Struga River to the lake in the Kartoszyno profile was calculated on the basis of a volume flow rate curve constructed for the Wierzchucino profile. The yearly volumes of municipal waste-waters discharged to the lake from the plant at Nadole were estimated on the basis of the twenty-four-hour data (about 300 m^3). Owing to the lack of a correlation between the water stages and volume flow rate measurements, the input of the Piaśnica River waters to the lake was calculated on the basis of average weighed runoff coefficients of the Piaśnica and Bychowska Struga Rivers catchment areas.

The efflux of the lake waters with the Piaśnica River in the Żarnowiec profile during the period November '76–November '79 was calculated on the basis of the

Table 3. Budget of ions entering Lake Żarnowiec and exported with the Piaśnica River to the Baltic Sea

Number	Source of ions	Volume $\times 10^6$ [m^3]	Mass of ions [tonnes] NH_4-N	NO_2-N	NO_3-N	PO_4^{3-}	Fe^{3+}	Mn^{2+}	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	HCO_3^-
1	Lake on Nov. 1, 1976	118.6	9.48	1.18	4.74	23.71	11.86	0.90	855	5513	3971	2490	17362
2	Piaśnica – Kartoszyno	72.3	7.64	0.29	17.99	7.17	9.66	0.98	598	4876	5386	828	15016
3	Bychowska Struga River	115.3	10.25	2.19	69.11	25.85	12.76	2.67	767	6941	5284	1792	19798
4	Lake's direct drainage area	22.0	2.24	0.26	9.31	3.55	2.71	0.51	164	1435	1027	298	4142
5	Plant at Nadole	0.44	0.59	0.048	0.55	2.90	0.056	0.018	5.8	27	28	22	80
6	Pool (1+2+3+4+5)	328.6	30.2	3.97	101.07	63.18	37.05	5.08	2390	18791	13696	5430	56397
7	Lake on Oct. 31, '80	125.0	7.50	0.00	58.37	20.75	0.00	0.00	1102	6201	500	2600	19599
8	Piaśnica R. – efflux	233.1	11.72	0.38	38.25	21.75	10.71	4.25	1752	11453	8970	5176	34309
9	>7+8<	358.0	16.22	0.38	96.62	42.50	10.71	4.25	2854	17652	14470	7775	53908
10	Net (9–6)	29.4	−13.98	−3.59	−4.45	−20.68	−26.34	−0.83	464	−1139	773	2364	−2489

volume flow curve. Due to the lack of a correlation between the water stages and the measurements of the volume flow rates in 1980, the efflux from the lake was calculated on the basis of average weighed runoff coefficients determined from the volume flow rate measurement. The amounts of waters fening the lake from the specified sources and the efflux of water to the sea with the Piaśnica River during the period considered are listed in Table 3.

The contents of particular ions in the lake at the beginning of calculations, *i.e.* on November 1, '76, were calculated by multiplying the mean levels (*i.e.* mean of three depths) of the particular ion by the volume of lake waters on the day. In a similar way, contents of particular ions were calculated at the end of the calculations, *i.e.* on October 31, '80. Annual loads of the ions entering the lake and transported away to the sea were calculated as a product of the mean annual levels of the ions and the annual outflow and inflow volumes. Similarly, the ionic runoff from the direct drainage area of the lake was calculated assuming the mean annual levels of particular ions in the Piaśnica and Bychowska Struga Rivers. The results of these calculations are shown in Table 3.

In pool of the budget in Table 3 the quantities of particular ions are shown which were supplied to the lake during the considered period. The quantities of ions delivered with the ground waters were not accounted for here.

Net results of the budget (Table 3) gave both positive and negative numerical values. It can be hypothesized that the positive values denote the volumes of water and the load of ions delivered to the lake with the terrestial runoff. The negative values denote either the quantities of the ions deposited in bottom sediments or utilized by the plant biomass in the lake. Further, the net values give information about the contribution of ions derived from surface and ground runoff. The surface runoff to the lake determines chemical composition of the nutrients, manganese, iron, calcium and hydrogen carbonates. The influx of ground water affects mostly the chloride level and only partially those of magnesium and sulphates. The function of Lake Żarnowiec as a natural waste-water treatment plant for waters from the surface runoff is best visualized by numerical values relating to the nutrients. From the total nutrient load feeding the lake with surface runoff, the Piaśnica River exports to the sea the following quantities: 56,5% of NH_4-N, 13.6% of NO_2-N, 39.4% of NO_3-N and 44.8% of phosphates. These numbers show that Lake Żarnowiec is playing important role in reducing the level of nutrients indispensable for biological life in the aquatic environment.

4. Conclusions

The results of the investigations of the Lake Żarnowiec drainage basin carried out from November '76 to October '80, allow the following conclusions to be drawn:

(i) Lake Żarnowiec is characterized by a moderate mixing of waters, relatively small vertical variations in temperature, fair aeration of the waters and satisfactory self-cleaning processes;

(ii) surface waters draining into the lake from its catchment area play a decisive role in building up its nutrient composition, in particular iron, manganese, calcium and bicarbonates. The influx of ground waters is responsible mainly for the increase in the chloride level of the lake;

(iii) the quantitative analysis of the chemical composition confirms the function of Lake Żarnowiec as a natural waste-water treatment plant for entering waters. The efflux of the lake waters with the Piaśnica River to the sea contributes to the loss of only about 45% of the nutrients derived from the lake's drainage basin. The remaining quantity of the nutrients is either deposited to bottom sediments or utilized for biological processes occurring in the lake.

References

1. Borowiec S., Skrzyczyński T., 1977, *Zmiany w stężeniach składników mineralnych w wodzie spływającej i infiltrującej przez poziomy akumulacyjne gleb różnie użytkowanych przed i po nawożeniu*, Zesz. Nauk. AR w Szczecinie, 64, 41–52.
2. Borowiec S., Skrzyczyński T., 1977, *Stężenie azotu, fosforu i potasu oraz ich udział w łącznej ilości odprowadzonego NPK przez cieki północnej części Niziny Szczecińskiej*, Zesz. Nauk. AR w Szczecinie, 64, 81–91.
3. Borowiec S., Duda L., Friedrich M., Skrzyczyński T., 1981, *Ilości składników chemicznych odprowadzone przez rzeki północnej części województwa szczecińskiego na tle użytkowania*, Zesz. Nauk. Szczec. Tow. Nauk., XLIII, 2, PWN, Warszawa–Poznań.
4. Hermanowicz W., Dożańska W., Dojlido J., Koziorowski B., 1976, *Fizyczno-chemiczne badania wody i ścieków*, Arkady.
5. Kajak Z., 1979, *Eutrofizacja jeziora*, PWN, Warszawa.
6. Korzeniewski K., 1978, *Badania sozologiczne w brzegowej strefie Bałtyku polskiego wybrzeża środkowego*, WSP Słupsk.
7. Pasławski Z., 1973, *Metody hydrometrii rzecznej*, WKiŁ, Warszawa.
8. Solski A., 1971, *Rola fosforu w eutrofizacji zbiornika Lubachowskiego*, Mater. bad. IMGW, Warszawa.
9. Wilamski J., 1970, *Erozja chemiczna zalewni Słupi*, Mater. bad. IMGW, Warszawa.
10. Wilamski J., Śliwa Z., 1978, *Spływ składników nawozowych roślin ze zlewni rzek Przymorza Zachodniego*, Mater. bad. IMGW, Warszawa.