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Abstract
Lake Miedwie is a eutrophic reservoir characterized by strong oxygen deficiencies in the hypolimnion, as well as high concentrations of nutrients (particularly phosphorus) and a significant recent increase in algae biomass. The water quality in the lake depends on pollutant inflow from the watershed, rate of biological activities, and accumulations of pollutants in bottom sediments.

The lake has very good natural conditions, described by class I of vulnerability for degradation. Decreasing the level of anthropogenic stress should allow the natural self-purification of lake water. Thus changes in the type of land and waste management in the watershed should improve the water quality in Lake Miedwie.

Disciplines
Agriculture | Water Resource Management

Water Quality in Lake Miedwie, 1992 to 1994: An Analysis of Basic Monitoring Data

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WATER QUALITY IN LAKE MIEDWIE

Lake Characteristics

Lake Location

Lake Miedwie is the fifth largest lake in Poland and the second largest in the Szczecin voivodship. It is located in the central part of the voivodship, between Szczecin and Stargard Szczecinski.

Geographic region:	Southern-Baltic littoral
Macroregion:	Baltic Littoral
Mesoregion:	Pyrzycko-Stargradzka plain

Watershed

The Lake Miedwie watershed originally included a basin of approximately 1032.9 square kilometers. The immediate watershed covers 57.8 square kilometers. The lake is fed by an eastern tributary of the Odra River, the Plonia River. The water outlet is regulated by a weir in Zelewo village. The Plonia River basin in the estuary section of Lake Miedwie includes 478.8 square kilometers.

Major tributaries discharging into Lake Miedwie include Ostrawica, Miedwianka, and Gowienica Miedwianska (Figure 1). About 73 percent of the water in the lake is supplied by surface runofft, 16 percent by underground flow, and 11 percent from precipitation.

There are two other large lakes in the Lake Miedwie watershed: Plon, 7.9 km^2, flow lake for Ploni River, and Bedgoszcz, 2.6 km^2 , flow lake for Ostrowica River.

Table 1. Political organization of the Lake Miedwie watershed

Voivodship	Gminas
Szczecin	Pyrzce, Stare Czarnowo, Warnice, Stargard Szczecinski, Kobylanka, Kozielice, Bielice, Przelewice, Dolice
Gorzow	Barlinek

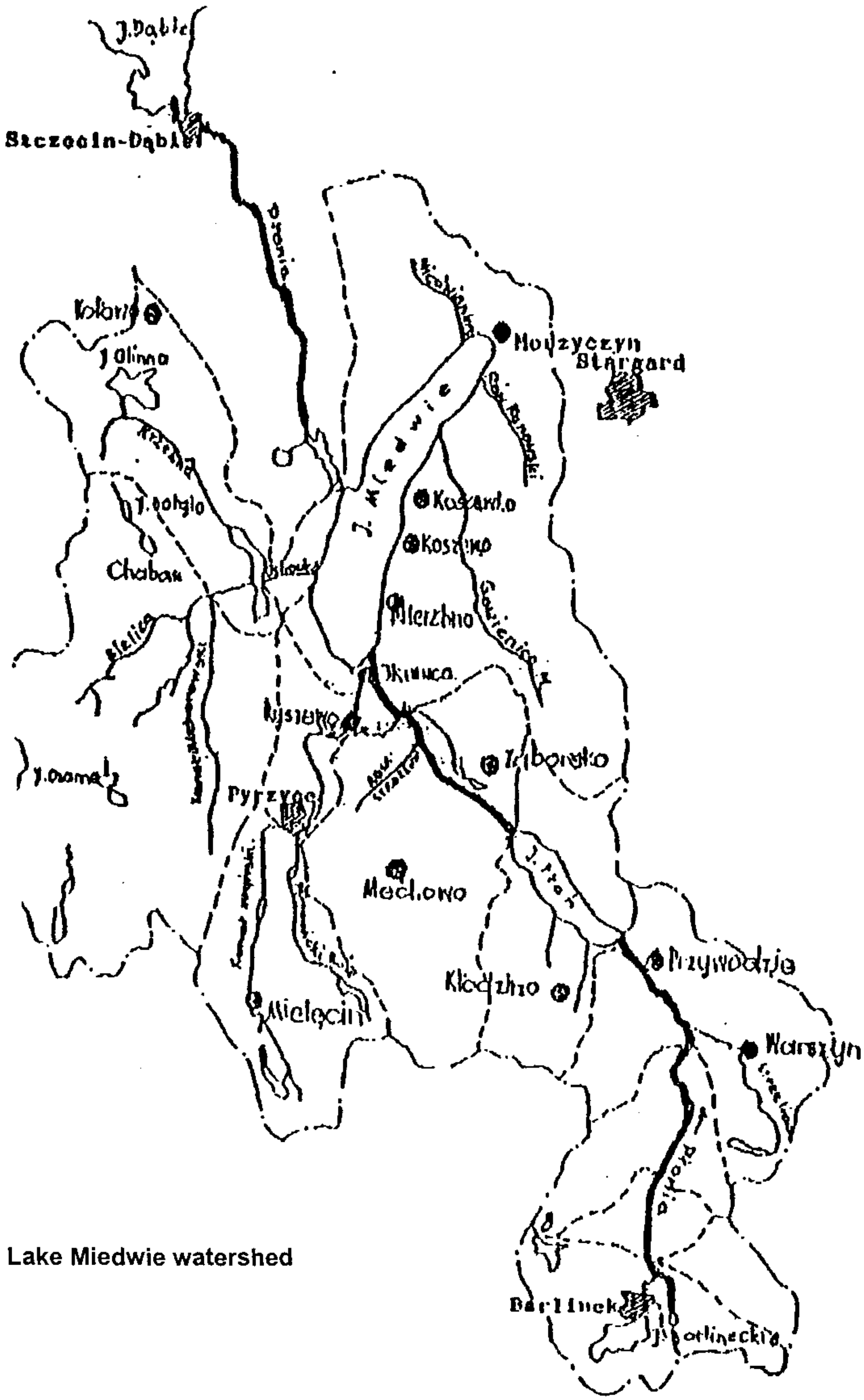


Figure 1. Lake Miedwie watershed

Basic Morphometric Data	
Area	35.27 km^2
Maximum depth	43.8 m
Average depth	19.3 m
Length of shoreline	38.8 km
Length of longest axis	16.2 km
Average width	3.2 km
Water volume	681.7 mln m

The bottom configuration is shown in Figure 2. Miedwie is a tunnel-valley lake from the glaciation epoch and its shape is strongly elongated. About 60 percent of the total bottom area is a crypto-depression in the tunnel-valley spread out along the main lake axis. The deepest point is 29.8 meters below sea level. The water surface is, on the average, 14.1 meters above sea level. A littoral zone (near shore zone) approximately 2 meters deep runs along the lake shore and is characterized by a sandy bottom and frequent reed beds. The width of the reed strip is between 5 and 25 meters. There are stonewort meadows in the riparian zone of the lake.

The lake shore is rather inaccessible (low and swampy with drainage ditches). The convenient entrances to the lake are in Morzyczyno, Wierzchlad, Koszewek, Koszewo, Wierzbno, and Zelew.

Lake Miedwie stratifies thermally, meaning that during the summer, temperature differences cause the water to form layers of different densities. There are three layers of varying thickness:

- epilimnion, surface layer to about 10-12 m deep;
- metalimnion, 5 to 7 m thickness, characterized by decreasing temperature at a rate greater than 1^0C per m; and
- hypolimnion, abyssal layer with cold water and a temperature difference compared to the epilimnion of about 10^0 to 13^0C colder.

Water Quality Research Work in Lake Miedwie and the Tributaries

The Provincial Environmental Protection Inspectorate in Szczecin (WIOS) has been conducting systematic lake monitoring since 1992. The monitoring program is designed to evaluate both the lake's vulnerability to degradation and the current state of water contamination.

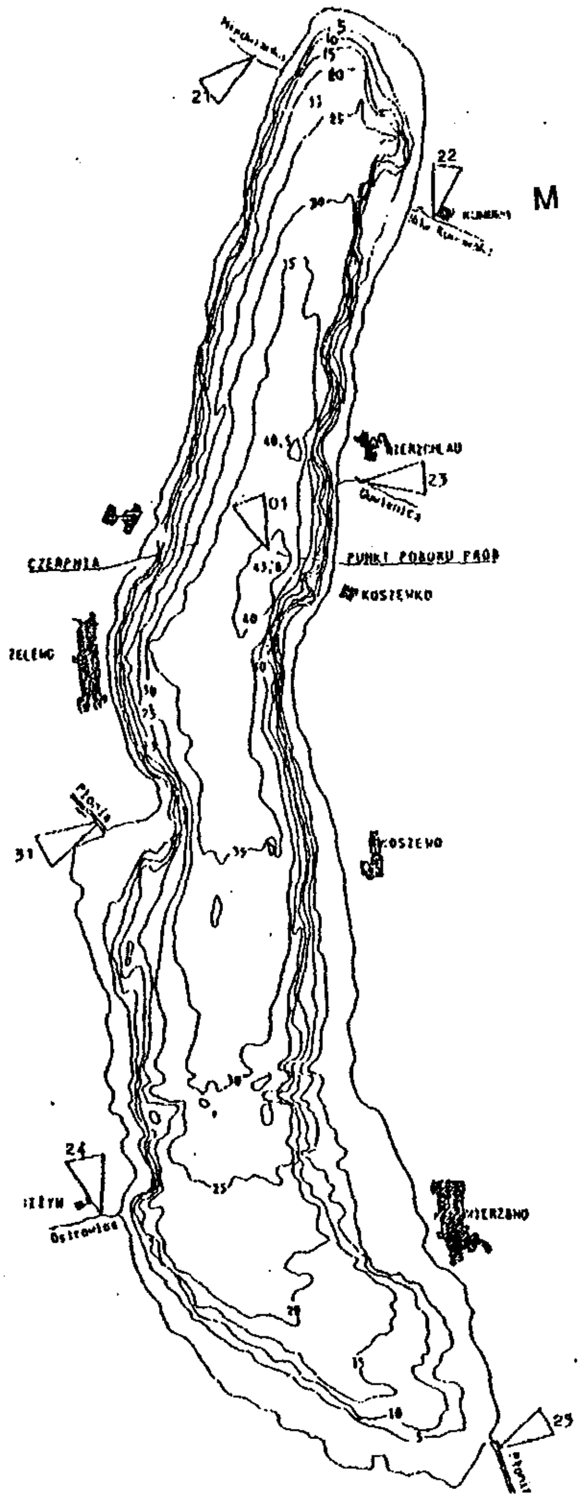


Figure 2. Lake Miedwie

The lake's vulnerability to degradation is calculated on the basis of morphological, hydrological, and watershed (lake shape, water rotation, watershed management) characteristics. The vulnerability indices are assigned numeric values according to these characteristics and normal tabular values, and their average is compared with values in Table 2.

Table 2. Classification of lake water based on vulnerability index scores

Score	Class	Category
Less than 1.50	I	I
1.51 - 2.50	II	II
2.51 - 3.25	III	III
Greater than 3.25	Out of class	Out of category

The water quality evaluation is made on the basis of physiochemical and biological factors analyzed in water samples gathered from both surface and bottom layers (concentration of dissolved oxygen, organic matter content, nitrogen and phosphorus concentrations, chlorophyll pigment concentration, seston dry matter, and conductivity). The samples were taken two times per year—in early spring and during the summer. The water temperature, oxygen concentration in the water profile, and visibility by Secchi disk were measured.

The results were compared with the normal values for lake water from the tables. A number designating purity class is assigned to each indicator. The arithmetic average of these numbers for the basic indicators is used as an argument to the scoring system presented in Table 3.

The basic classification is further refined by health limits determined from measuring pesticides, heavy metals, and coliform bacteria concentrations. This means that, for example, if the heavy metal or pesticide content is over the limit for that element, the water is downgraded no matter what the basic indicators score is. When the coliform count is in the worst class, the quality of lake water is automatically reduced to the same class.

Quality measurements of water flowing into Lake Miedwie are conducted in connection with regional monitoring once per month. The sample points are marked on Figure 2. The water classification is conducted in response to the Ministry of Environmental Protection, Natural Resources and Forestry Act of 5 November 1991 (DZ.U.116 no 503).

Table 3. Vulnerability classification for Lake Miedwie

Indicator	Indicator Value	Score
Average depth	19.3	1
V/L	17.57	1
Percent of water stratification	27.4	2
Pe/Ve	0.04	1
Percent of water replacement/year	20.0	1
Watershed agricultural land	30.4%	2
Schindler coefficient	1.5	1
Result	Category I	1.28 (average score)

Estimation of Vulnerability to Degradation

The morphometric, hydrographic, and watershed factor characteristic of Lake Miedwie qualify it in the first category of vulnerability to degradation. This means that the lake is significantly resistant to anthropogenic influences. This condition could, of course, be changed by contaminant overloads.

The seven indicators of vulnerability to degradation and types of calculations are presented in Table 3. The calculated result, 1.28, falls in the first category because the limit for this class is 1.5. The indicators determined from standard morphometric values, such as the lake water volume (V), length of shoreline (L), lake area (Pj), and watershed area (Pz) have constant values for describing the water region and category I classification. The value of the average lake depth (V/Pj) indicates a relatively slow eutrophication rate. The quotient V/L indicates the potential for dilution of the pollutants inflowing from the lake shore zone and surrounding area.

The Schindler coefficient, (Pj + Pz)/V, is positively correlated with some water quality indicators such as dissolved oxygen concentration, chlorophyll a concentration, and concentration of organic compounds in the bottom sediment. A value for this indicator, < 2, suggests the possibility of dilution of nonpoint pollutant input from the total watershed.

The percent of water rotation per year is an estimated value calculated from measurements of average runoff from the total watershed, taken over a period of several years. Estimated values are also used for the next indicator, the type of watershed management, which is based on the percentages of land devoted to agriculture and forest in the immediate watershed. For Lake Miedwie this indicator falls in category II. The reduction of the proportion of cultivated land can be an important factor in improving the water quality in Lake Miedwie.

The two remaining indicators vary in relation to epilimnion thickness and matalimnion thickness. Deep, stratified lakes usually have lower productivity as a result of a limited eutrophication zone and decreasing rates of material cycling. The thicknesses of these zones depend on meteorological conditions, particularly during the stratification period and summer stagnation period.

The biotic component recirculation from bottom sediment increases the productivity in the water column. The ratio of the active bottom area (which has contact with warm epilimnion water, Pe) to the epilimnion water volume (Ve) is an indicator of the intensity of the nutrient cycling in the lake. A low value of this ratio indicates a positive environmental situation.

The percentage of water stratification is defined as the ratio of the hypolimnion volume to the total volume of lake water. The thickness of the hypolimnion indicates a significant oxygen reserve in the tropholitic zone and a decrease in the volume of the trophic zone.

Lake Water Contamination

From 1962 to 1973, Lake Miedwie water was of class I; in the period 1977 to 1978, class II; and from 1979 to 1992, the water had degraded to class III. The most recent classifications of Lake Miedwie water are shown in Table 4. The scoring system for all basic indicators for water samples gathered in Lake Miedwie is presented. The verification indicators had no influence on the classification results.

For heavy metals and pesticides, the concentrations were below the health standards. Only trace amounts were found. In 1992 and 1993, no water polluted by fecal types of bacteria was found. In 1994, in the sample collected during summer from the bottom layer, the value of coliform count was 0.04, a value that falls into class II. Other samples were in quality class I.

Table 4. Water quality determinations for Lake Miedwie, 1992 to 1994

Indicator	Unit	Date of Sample	1992	1993	1994
Surface Water					
Mineral N	mg-N/dm^3	Spring	1	1	3
Phosphates	mg-P/dm^3	Spring	4	3	3
Conductivity	µS/cm	Spring		4	4
ChOD	mg-O_2/dm^3	Summer	2	2	2
BOD	mg-O_2/dm^3	Summer	2	1	3
Total phosphorus	mg-P/ dm^3	Spring/Summer	4	3	3
Total nitrogen	mg-N/ dm^3	Spring/Summer	2	3	2
Chlorophyll	mg/m^3	Spring/Summer	3	3	2
Seston dry mass	mg/dm^3	Spring/Summer	2	2	1
Visibility	m	Spring/Summer	2	2	1
Bottom Water					
Mean hypolimnion saturation	%	Summer	4	3	3
BOD5	mg-O_2/dm^3	Summer	2	1	2
Phosphates	mg-P/ dm^3	Summer	4	4	4
Total phosphorus	mg-P/ dm^3	Summer	4	3	4
Ammonium	mg-N/ dm^3	Summer	2	1	1
Result			2.71	2.40	2.53
Verification coliform count			I	I	II
Verified Purity Class			III	II	III

The differences in water quality in the lake are connected with anthropogenic influences and the variation of climatic and hydrologic conditions, which together act to change the material cycles in the lake ecosystem. The summers of 1992 and 1994 were very dry. The average temperature was about 30° C. A significant lowering of the water table in the lake was observed, concentrating a number of contaminants. However, in 1993 after a warm period in April and May, the summer was cold and rainy. This caused a significant improvement in the oxygenation of hypolimnion water, but resulted in ammonium, phosphorus, and BOD5 concentrating in the bottom layer.

The concentration of some indicators regarding average oxygenation of hypolimnion water (the arithmetic average from all measurements taken in the hypolimnion) are presented in Figure 3. The biological oxygen demand (BOD5) was also decreased in the surface layer and phosphorus content in comparison with 1992. The thermo-oxygen profiles made in the "gleboczek" part of the lake during the summer stagnation in 1992 to 1994 are shown in Figure 4. The oxygen content in the bottom layer was measurable only in one year, 1993. The oxygen concentration in the water from the zone near the bottom was 1.4 mg O_2/l. A similar oxygen content in the hypolimnion was also found in 1971, when the lake was ranked in the first quality class. These results indicate that autopurification processes occur in the lake.

The oxygen decrease in the stagnating layer above the bottom results from oxygen when organic matter decomposes and falls to the lake bottom. The higher concentration of biogenic compounds supplied from the watershed and accumulated in the bottom sediments stimulates the rate of biological processes. The increased organic matter content causes intensification of oxygen deficiency in the layer near the bottom. The oxygen insufficiency in hypolimnion water occurs during autumn homothermy when the water is mixed to the bottom and the oxygen deficiency becomes limited. The study conducted during spring homothermy indicated a constant level of oxygen concentration from surface to the bottom.

Lake Miedwie has very good water conditions due to wind mixing. In case of a specific climatic condition (lack of a cold winter), an extended period of water circulation during the winter is observed. Recently, the central part of the lake was without ice.

Phosphorus contributes significantly to lake eutrophication. Excess phosphorus contributes to the algal blooming and has an important influence on the water quality described by the indicators seston DM, Secchi disk, and chlorophyll a content. Changes in values of water quality indicators are presented in Figure 5.

A higher concentration of total phosphorus and orthophosphate in surface and bottom layers was found in 1992. In 1993, the P content decreased to the purity class III. The highest P concentration during the study period was observed at 1.7 mgP/l in 1994. Higher values were obtained in the last decade (1986, 2.43; 1988, 2.94 mgP/l), but even a concentration of 1.7 mg P/l is evidence of intensive eutrophication.

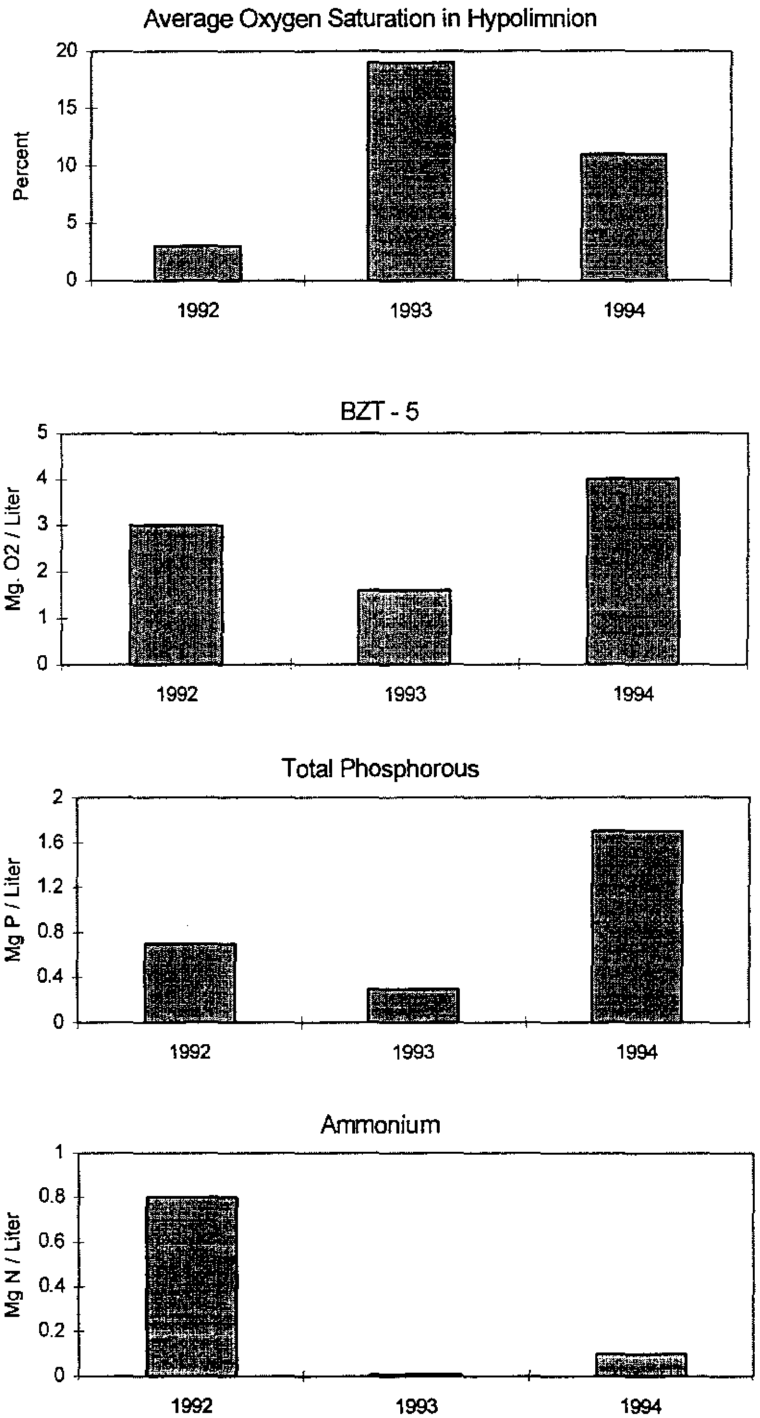


Figure 3. Changes of water quality indicators in the bottom layer, summer 1993

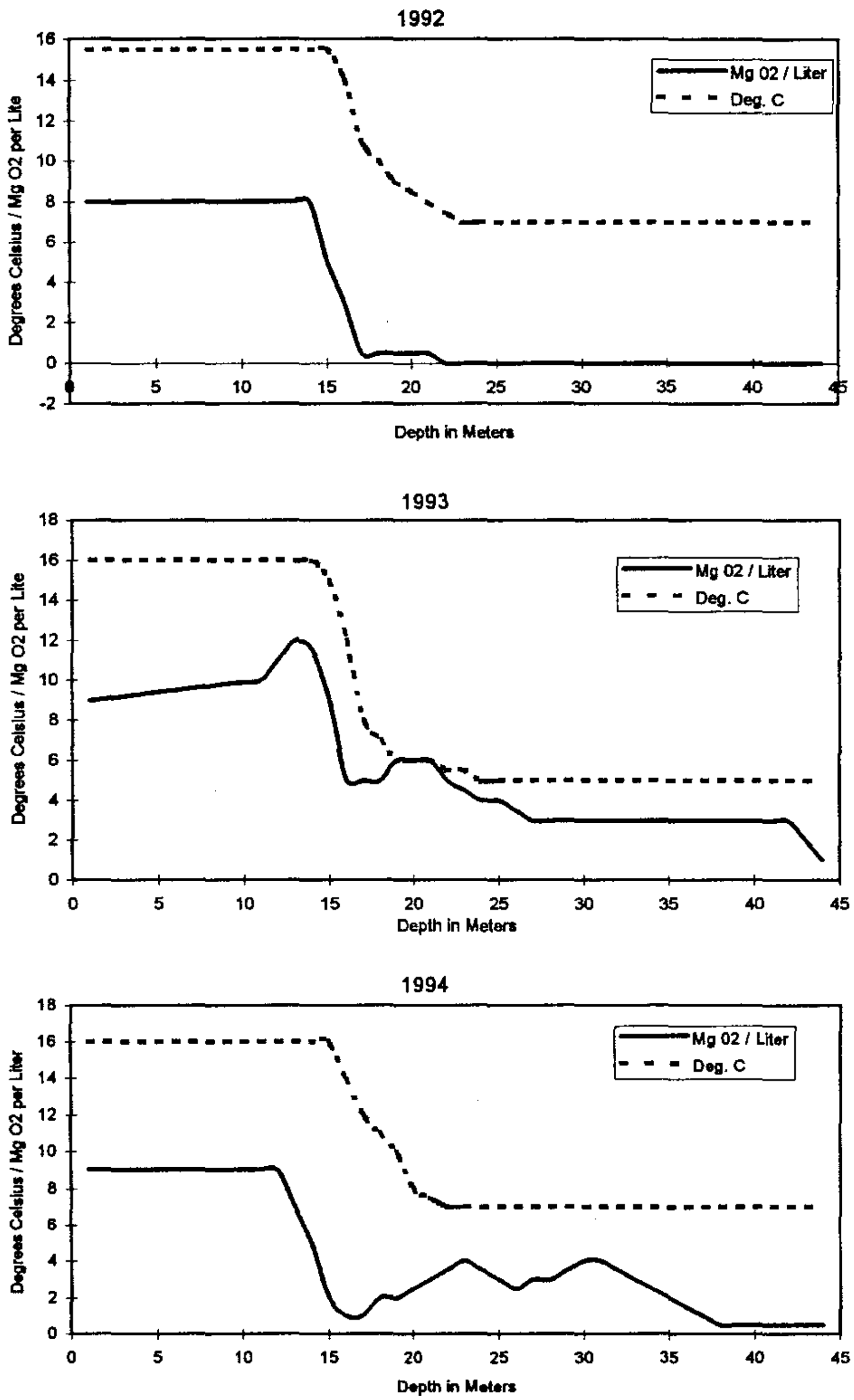


Figure 4. Profile of Lake Miedwie, temperature and O_2 levels, 1992–94

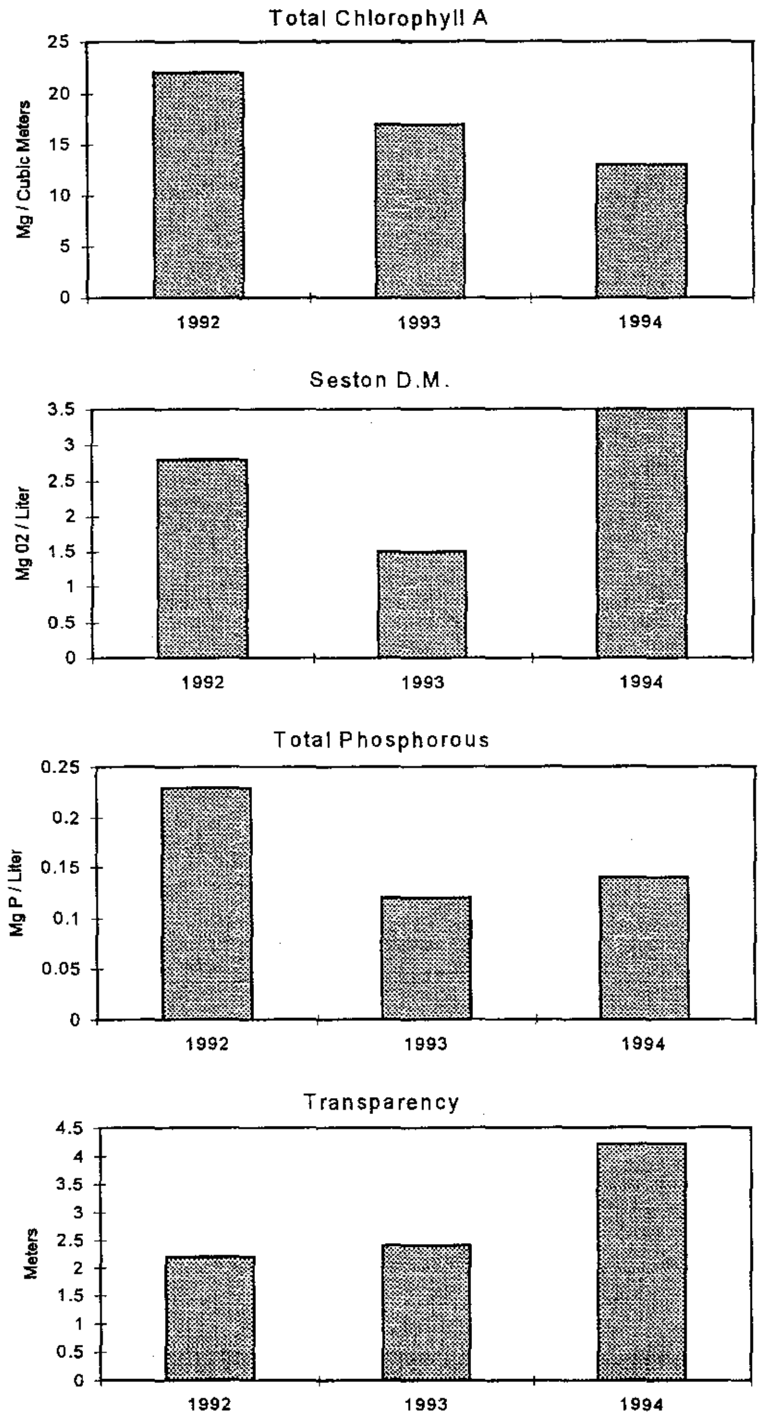


Figure 5. Water quality indicator changes in the surface layer, average summer and spring

Changes in the orthophosphate concentration in the layer near the bottom of Lake Miedwie for 1971 to1994 are shown in Figure 6. The concentrations of these very important biogenic compounds are several times more than the standard for purity class III.

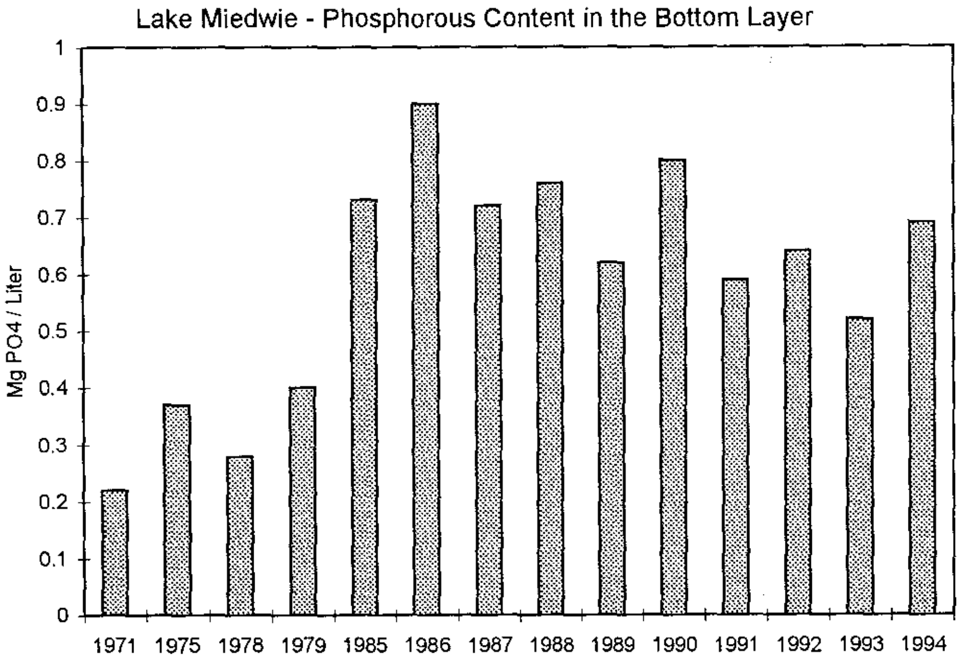


Figure 6. Lake Miedwie 1971 to 1994 phosphorous content in the bottom layer

One result of eutrophication is the appearance of the filiform algae such as *Cladophora sp.* There currently is intensive development of these algae in the shallow water. The underwater "ramienice" meadows are degraded, and large amounts of green algae migrate with the wind on the lake surface. This phenomenon was particularly observed in 1994 when the accumulated algae caused a specific smell. Only Kobylanka gmina removed it.

The spring water blooms are dominated by the diatoms *Asterionella formosa* and *A. gracillima.* The intensity of the blooms is related to oxygen supersaturation in the lake water (120 to130 percent). During summers, the dominant algae groups are green algae, diatoms, and blue-green algae.

Management of the Lake and Its Tributaries

The lake is also used as a recreation area for inhabitants of Szczecin and Stargard, as well as a vacation place for others.

The Fish Farm (AWRSP) in Insk is also located near Lake Miedwie. Desirable fish species are caught, such as eel, pike, whitefish, and tench and, in 1985, a relict species was found, powan. Szczecin began to take its drinking water from the lake in 1976. The water is taken from an 18-meter depth and is carried to Szczecin by a 27-km water main. The drinking water is analyzed by the local laboratory.

The Lake Miedwie watershed is highly agricultural. Industrial crops and feed crops predominate. From 1972 to 1978, commercial fertilizer use was above the national average. The eutrophication of Lake Miedwie in part results from surface runoff from agricultural land. Mismanagement of animal waste disposal and poor sanitation in the farm buildings are the important sources of the soil, river, and lake contamination.

Political and economic changes in Poland have had the following results in the Lake Miedwie region:

- The closing of a cattle breeding operation in Koszew (1100 head); the slurry from this operation was used for agricultural production. This farm was located about 150 meters from the lake.
- The Russian Army left the airport in Kluczew in autumn 1992 and the sources of household waste flowing into Gowienica Miedwianska through the sewage system were closed.
- Decrease of mineral fertilizer application in the watershed area was caused by problems in agricultural management.

There are 21 wastewater treatment plants in the Miedwie watershed, with only two having to pay a penalty for improper management or lack of an operating permit in 1992 to 1993. Very often, the need for a permit is connected with modernization or reconstruction of the same installation. Most wastewater treatment plants do not have any measuring equipment.

The facilities around the reservoir that have a significant influence on the water quality in Lake Miedwie are presented in Table 5.

Table 5. Wastewater treatment plants

Wastewater treatment facility	Receiving water body
Koszewo	Miedwie
Skalin	Row Kunowski
Rensko	Gowienica Miedwienska
Baranim	Gowienica Miedwienska
Pyrzyce	Mlynski Channel

Of the wastewater treatment plants, only one, constructed in 1989 in Pyrzyce, has been able to limit pollution as recommended. However, activities in all of these treatment facilities are in agreement with water laws.

The Miedwie tributaries supply a lot of pollutants. The water quality in Lake Miedwie is from characteristic concentrations (arithmetic average of the two worst results). The data collected from the last three years are presented in Table 6.

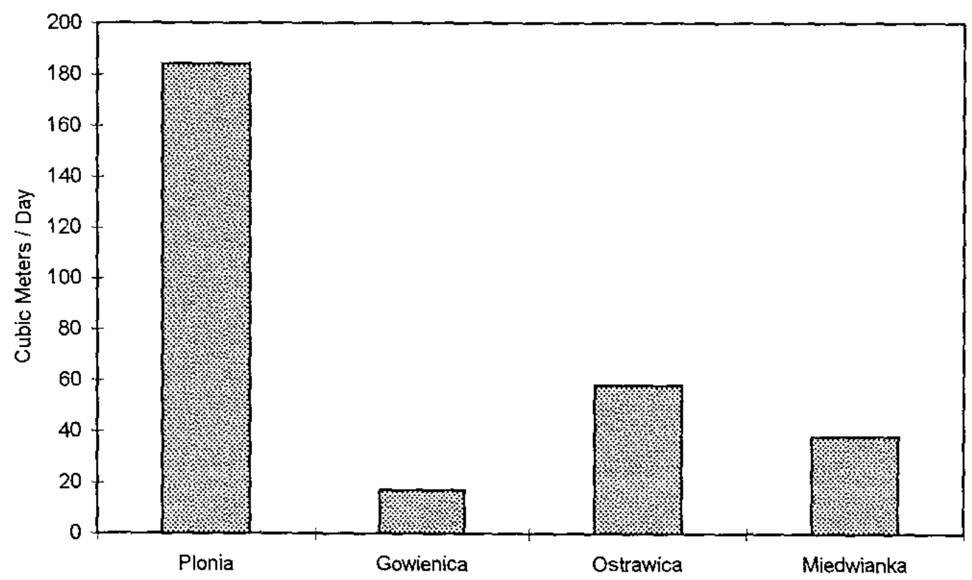


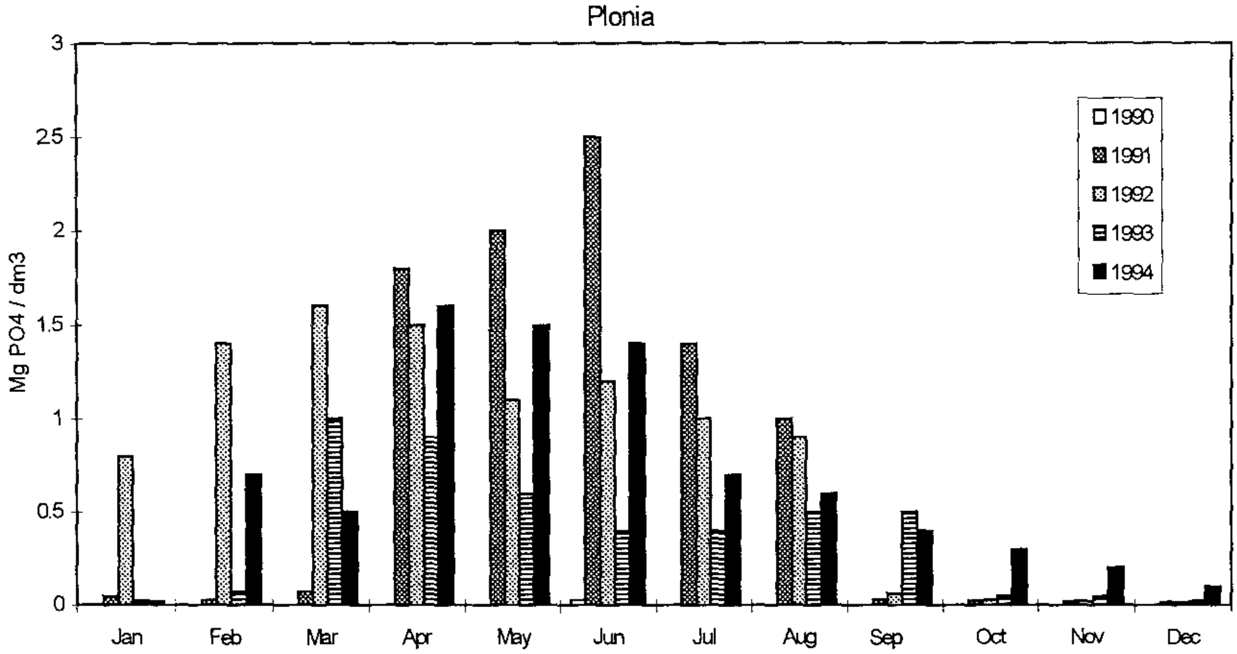
Figure 7. Average phosphorous content in the stream tributaries of Lake Miedwie

Table 6. Water quality of tributaries to Lake Miedwie

Tributary	Year	Class	Indicators exceeding standards
Gowienica	1991	Out	Phosphates, Coliforms
	1992	Out	BOD5, DO, P, Coliform
	1993	Out	Suspended matter, Total P, N-NO_2
	1994	Out	Suspended matter, Total P, N-NO_2
Miedwianka	1991	III	O_2 consumption, pH, Coliforms
	1992	III	O_2 consumption, NO_2, Total P, Coliforms
	1993	Out	Coliforms
	1994	Out	O_2 consumption
Ostrowica	1991	III	Total P, pH, Coliforms
	1992	Out	Total P, Chlorophyll a
	1993	Out	Chlorophyll a
	1994	Out	O_2 consumption
Row Kunowski	1991	Out	O_2 consumption, Suspended matter, Phosphate, Coliforms
	1992	Out	BOD5, Oxygen, Nitrogen, Phosphorus, Coliforms
	1993	Out	BOD5, O_2 consumption, Nitrogen, Phosphorus, Oxygen, Conductivity
	1994	Out	BOD5, Nitrogen, Phosphorus, Coliforms, Oxygen, Conductivity
Plonia	1991	Out	Phosphates, Coliforms
	1992	Out	Total P, Phosphates, Chlorophyll a
	1993	Out	Chlorophyll a, Phosphorus, pH
	1994	Out	Chlorophyll a, Phosphorus, Coliforms

Currently, all water in Miedwie tributaries is below class III. Very often the result is affected by the high concentration of biogenic compounds. The information about the amount supplied by particular tributaries is presented in Figure 7. The streams Plonia, Ostrawica, and Gowienica Miedwianska contributed significantly to the contamination of the lake water by biogenic compounds.

Thirty years ago the water from Lake Miedwie was in class II. Figure 8 presents the concentration of orthophosphate collected during the WIOS lab monitoring program for 1990 to 1994.



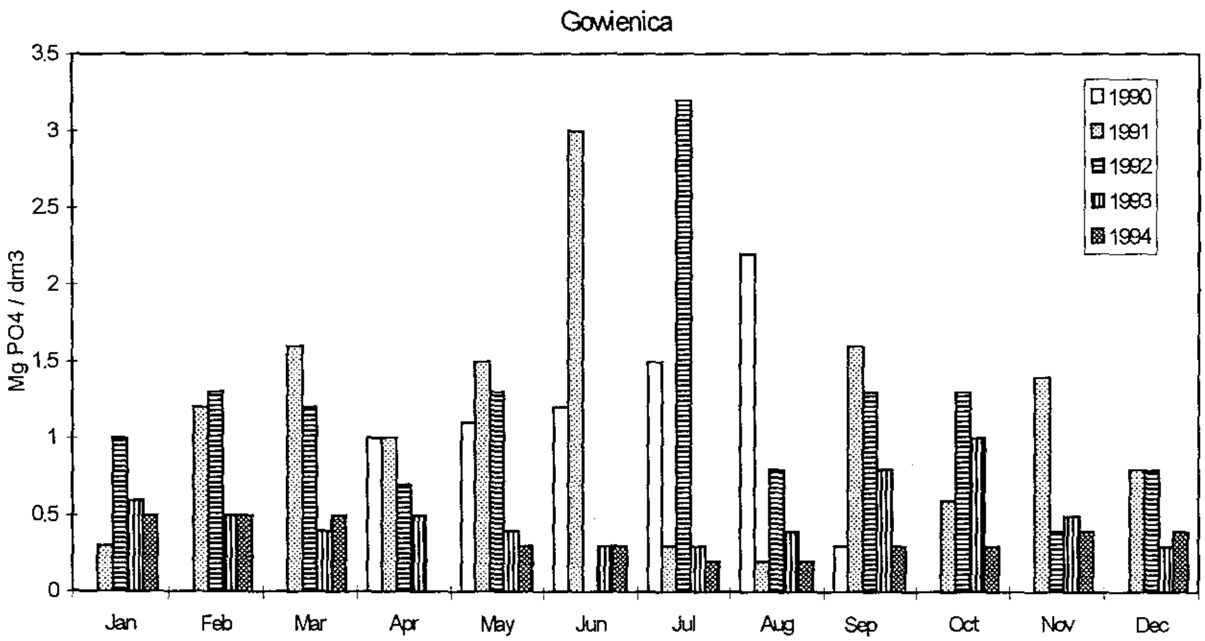
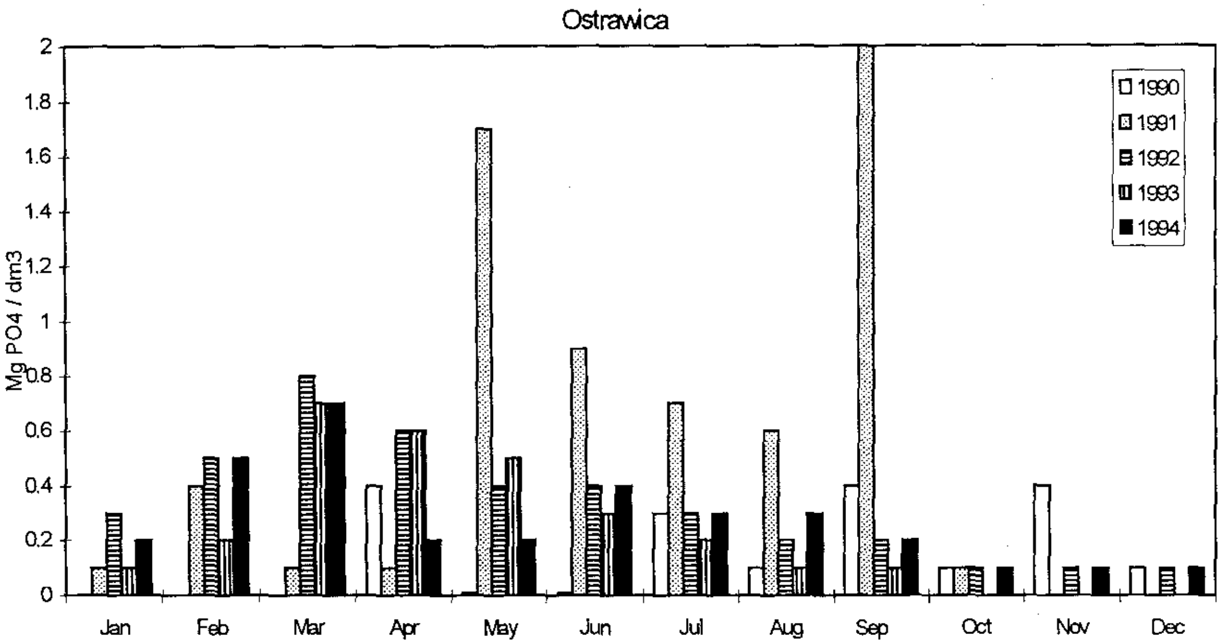


Figure 8. Orthophosphoran concentration in Lake Miedwie tributaries (Mg PO_4/dm^3)



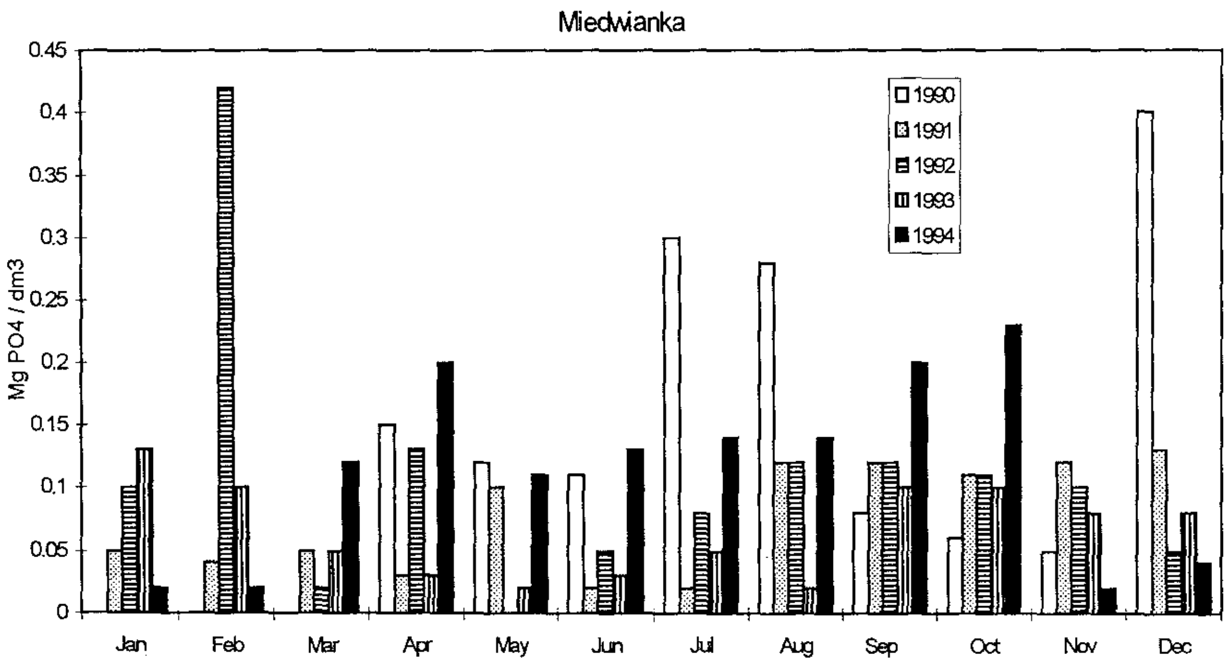


Figure 8. continued

Plonia

The water quality in Plonia is significantly influenced by eutrophic lake water and pollutants from the Mlynski Channel. When wastewater treatment in Pyrzyce began, the water quality in this stream was improved.

The concentration of chlorophyll a in the Plon lake water is 147 mg/m^3, nearly five times more than standard for class III. The sewage from six wastewater treatment facilities are input by irrigation ditches to Plon Lake.

Ostrowica

The water quality in Ostrowica is significantly influenced by eutrophic water from Lake Bedgoszcz. The water in this region receives pollutants from the Nieborowski and Krzekne Channels.

Gowienica Miedwianska

This tributary receives sewage from the wastewater treatment plants at Rensko and Barnim. Neverless, the class III water quality in these stream reduces the amount of pollutants supplied to Lake Miedwie from this stream.

Summary

Lake Miedwie is a eutrophic reservoir characterized by strong oxygen deficiencies in the hypolimnion, as well as high concentrations of nutrients (particularly phosphorus) and a significant recent increase in algae biomass. The water quality in the lake depends on pollutant inflow from the watershed, rate of biological activities, and accumulations of pollutants in bottom sediments.

The lake has very good natural conditions, described by class I of vulnerability for degradation. Decreasing the level of anthropogenic stress should allow the natural self-purification of lake water. Thus changes in the type of land and waste management in the watershed should improve the water quality in Lake Miedwie.

Future activities should be based on the following conditions:

- Regulation of sewage management in the immediate watershed, particularly in Wierzbno, Wierzchlad, Obryta, and Warnice villages.

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Future activities should be based on the following conditions:

- Regulation of sewage management in the immediate watershed, particularly in Wierzbno, Wierzchlad, Obryta, and Warnice villages.

- Support of existing wastewater treatment (modernization and reconstruction) activities to limit the pollutants inflowing to Plon and Bedgoszcz Lakes.