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ECOLOGICAL CHARACTERISTICS OF LAKES IN NORTH-EASTERN POLAND VERSUS THEIR TROPHIC GRADIENT

II. LAKE CATCHMENT AREAS - PHYSICO-GEOGRAPHICAL ENVIRONMENT. DESCRIPTION OF THE REGION AND 43 LAKES *

ABSTRACT: The paper contains a general physical geographic description of the study area, as well as a more detailed hydrographic description of 43 lakes and their catchment areas. The possible improving effect of the drainage area on the trophic conditions of a lake has been assessed against the physico-geographical conditions of the entities analysed, and the parameters favouring the transport of matter from the catchment area have been indicated.
KEY WORDS: Hydrography of lake catchment areas, limnology, protection of waters against pollution.

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1. GENERAL PHYSICAL GEOGRAPHIC DESCRIPTION OF THE REGION

The boundary between western Europe and eastern Europe runs across north-eastern Poland (K o n d r a c k i 1978), more precisely, between the South Baltic Coastland (313) and South Baltic Lake District (314-315) (the Middle European lowland province), and the East Baltic Coastland (831) and East Baltic Lake District (832) (East Baltic Lowland) (Fig. 1). The lake catchment areas chosen for the investigations are located in the following macroregions: the East Pomeranian Lake District (314.5) (mainly the Iława Lake District 314.53) and the Chełmińsko-Dobrzyńskie Lake District (315.3) (mainly the Lubawa Upland 315.35) belonging to the South Baltic Lake District subprovince, and in the Masurian Lake District macroregion (832.1) (mainly the lake districts of Olsztyn 832.11, Mrągowo 832.12, Ełk 832.16, and the Masurian Great Lake Country 832.13) belonging to the East Baltic Lake District subprovince (Table I).

The relief of north-eastern Poland is the result of the action of the ice sheet, and it formed ultimately during the Baltic glaciation which left huge masses of material consisting of clays, gravels, stones and sands. The geomorphological landscape of the Chełmińsko-Dobrzyńskie Lake District is associated with phases of the last glaciation older than the Pomeranian phase, which is in contrast to the landscape of the East Pomeranian and Masurian lake districts. These areas are characterized by a young glacial landscape, that is to say, a landscape of plains and morainic hills, a hilly, lakeland landscape, and an outwash-plain lakeland landscape (K o n d r a c k i 1978). It is distinct for the presence of hill-like forms, a large number of drainageless depressions partially filled with lake waters or peat-bogs, a poorly developed natural drainage and a large number of lakes. Dominating among the glacial forms are marginal forms (terminal moraines) and dead ice forms (eskers, kames and crevice fillings). Crevice forms sometimes show

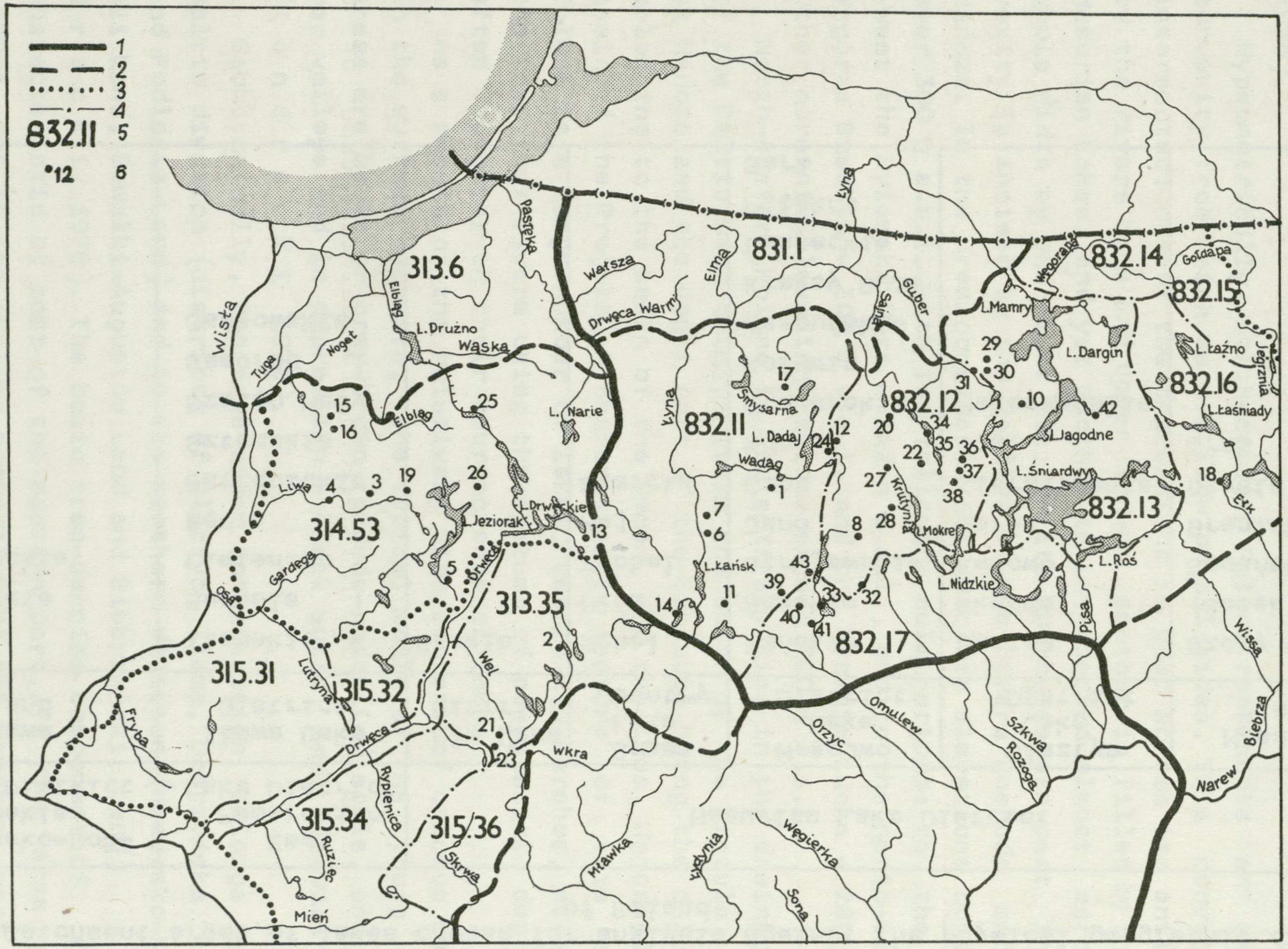

Fig. 1. Location map

1 - province boundary, 2 - subprovince boundary, 3 - macroregion boundary, 4 - mesoregion boundary, 5 - mesoregions according to the list in the text, 6 - lakes in the same sequence as in the Tables

Table I. Catchment areas of lakes chosen for analysis against the physical geographic division of Poland

Chełmińsko-Dobrzyńskie Lake District	East Pomeranian Lake District	Masurian Lake District				
Lubawa Upland	Iława Lake District	Ełk Lake District	Great Lake Country	Mrągowo Lake District	Olsztyn Lake District	Masurian Plain
Rumian	Iławskie	Ełckie	Wobel	Rańskie	Bartąg	Szoby Małe
Lidzbarskie	Burgale		Ołów	Rzeckie	Skanda	(Sasek Mały)
Hartowieckie	Liwieniec		Tuchel	Stryjewskie	Kokowo	Sędańskie
	Bądze		Mój	Juno	Maróz	Branickie
	Barlewickie		Siercze	Czos	Kierzlińskie	Długie
	Sztumskie			Kuc	Gim	Grom
	Szeląg Mały			Probarskie	Małaszewskie	
	Sambród			Kołowin		
	Jaśkowskie			Warpuńskie		
				Kraksy Duże		
				Lampackie		
				Piłakno		
				Sarż		

a direct transition into extramarginal outwash plains. The surface of the alluvial deposits appears to have been strongly deformed everywhere, due to the decay of dead ice blocks (K o n d r a c k i 1978).

Hypsometrically, north-eastern Poland represents an elongated convexity from which waters flow on all sides. This convexity is intersected: one of the depressions is used across its entire width by the rivers Łyna and upper Omulwia, another is filled by the Great Masurian Lakes, and yet another is intersected almost across its whole width by the river Ełk; in its north-eastern part the convexity is incised by the valleys of the rivers Rospuda and Czarna Hańcza. In the area considered the absolute elevations come up to over 300 m a.s.l. with the following culminations: to the south-west the Dylewska Góra - 312 m a.s.l., and to the north-east the Wzgórza Szeskie - 309 m a.s.l. and the Krzemieniucha - 289 m a.s.l. Other morainic elevations seldom exceed 200 m a.s.l.

North-eastern Poland in its entirety lies in the drainage area of the Baltic sea, mainly within the basin of the Vistula, the Czarna Hańcza and the upper part of the Szeszupa being the only rivers belonging to the basin of the Nemen, and the Łyna, Węgorapa to the basin of the Pregoła. A characteristic feature of this part of Poland is a large number of lakes, swamps and marshes, as well as the fact that rivers using the systems of postglacial depressions often encounter on their courses several lakes.

As a result of the relatively high content of calcium carbonate in the surface deposits, the typical soils of the young glacial areas are brown or gray-brown (pseudo-podzolic) soils, and in river valleys and in depression - black soils and alluvial soils (K o n d r a c k i 1978).

Geobotanically, the area under consideration belongs to the Baltic division (districts of Olsztyn, Iława, Dobrzyńska Plateau and Podlasie Land) and to the northern division (Mazursko-Kurpiowski Land, Suwałki-Augustów Land and Biebrzański Land) (K o n d r a c k i 1978). The basic tree-species component of forests, characteristic of most of the eastern part of the area is the spruce, and of the smaller proportion of the western part - the beech. The spruce is often found in pine-spruce of spruce-pine forests, and where its geographic range overlaps that of the beech, it is found in mixed forests.

At present the natural environment is utilized in the following way: in areas with rich soils on boulder clay agriculture predominates, on outwash-plain sands forests prevail, in drainageless depressions and on valley floors meadows are found, whereas lakes are used for fish-farming.

2. CLIMATE OF THE REGION

The main factors affecting the climate of the north-eastern part of Poland are the following:

a. position in temperate latitudes between 52° and $54^{\circ}20'$ φ N and longitude between $19^{\circ}50'$ and $24^{\circ}10'$ λ E,

b. proximity of the Baltic and of the centre of the land of Asia,

c. relief.

The latitudes determine a specific inflow of solar energy: the region in question receives the smallest radiation totals in December - about 142 $J \cdot cm^{-2} \cdot day^{-1}$, and the highest in June - 2010 to 2093 $J \cdot cm^{-2} \cdot day^{-1}$. The annual average sum of total radiation in the northern part of the area amounts to 1005 $J \cdot cm^{-2} \cdot day^{-1}$, and in its southern part - 1130 $J \cdot cm^{-2} \cdot day^{-1}$.

The annual average air temperature in this area ranges from 6.5 to $7.5^{\circ}C$. The warmest month is July (average temperature 17 to $18^{\circ}C$), and the coldest is January (average temperature -3.3 to $-5.5^{\circ}C$). Due to this, the yearly temperature amplitude is $20-23^{\circ}C$.

Annual precipitation totals almost throughout the north-eastern part of Poland range from 500 to 600 mm, except the morainic hills for which higher values are recorded: from 600 to 700 mm. In wet years the annual precipitation totals exceed 900 mm, except the Masurian Great Lake Country where they come up to 800 mm; at some meteorological stations (e.g., Nidzica) precipitation totals for such years may even exceed 1100 mm. In years poor in precipitation annual totals vary between 300 and 400 mm.. Thus the difference between the annual precipitation totals of the extreme years ranges from 350 mm (Kętrzyn) to 800 mm (Nidzica). The summer season receives about 60% of the annual precipitation, this being due to a higher intensity of rainfall from convective clouds. During a year (Table II) the highest precipitation totals are recorded for July: 80-100 mm (Ełk is the only locality that receives 60-80 mm),

Table II. Precipitation totals (1951-1970) in mm (acc. to C h o m i c z 1977)

Pluviometric station	Months												Year
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Mikołajki	26	26	25	40	51	72	77	73	49	41	50	35	565
Prabuty	34	30	27	35	57	57	92	85	58	38	44	41	598
Elbląg	32	31	24	39	55	62	91	85	80	50	52	47	648
Olsztyn	33	31	28	39	55	67	92	76	58	47	51	43	620
Lidzbark	34	29	26	40	53	64	87	83	62	49	53	42	622
Kętrzyn	24	23	24	40	51	62	86	77	58	46	46	32	569
Ełk	32	35	25	37	48	64	73	67	55	42	48	40	566
Szczytno	36	34	28	43	51	72	85	77	47	38	54	45	610
Nidzica	40	42	33	41	56	63	84	72	51	40	53	52	627
Ostróda	32	28	26	37	50	55	90	78	55	44	50	43	588
Iława	42	34	30	40	58	57	82	79	55	39	53	47	616
Lidzbark Działdowski	29	24	26	35	55	57	88	70	45	35	48	40	552
Malbork	28	24	21	33	51	61	86	76	54	37	46	35	552

and the lowest for February (20-40 mm) and March (20-30 mm) (Ch o m i c z 1977, R a s i ń s k i 1978).

Important for the assessment of the effect of precipitation on the transport of matter is, apart from the magnitude of precipitation (its annual total), its intensity, and especially the seasonal distribution of high-intensity precipitation. In north-eastern Poland there are on an average 10-20 days with a downpour (≥10 mm) a year, this number growing in the south-western direction. Downpour rainfalls are typical of the summer months: June, July and August (about 5-6 days with downpour rainfalls).

The total number of days with a ≥ 0.1 mm precipitation in the study area is from 150 (Lidzbark) to 170 (Olsztyn). A precipitation ≥ 0.1 mm is characteristic of the autumn-winter months during which the number of days with a ≥ 0.1 mm precipitation ranges from 13 to 17. Another peak falls on the summer months (July) when the number of days with a ≥ 0.1 mm rainfall varies between 13 and 15.

Another element of the climate, in addition to precipitation, affecting the transport of nutrient matter is the wind. In general, taking into account the division of winds from eight directions, in north-eastern Poland westerly winds (W, SW, NW) prevail during the year, this being particularly evident in the winter half-year (from 15 to 30%). Over the yearly scale the smallest is the percentage of N and NE winds. Small, too, is the percentage of easterly (E and SE) winds. The latter become more frequent in the spring months (March) and autumn months (November). The frequency of wind directions varies with the seasons: in winter (December-February) westerly and south-westerly winds predominate; in spring (March-May) there is no clear dominance of any one direction, but this period is characterized by an increased percentage of easterly winds; in summer (June-August) a prevalence of winds from the western sector can be seen, while the proportion of easterly winds decreases markedly; in autumn (September-November) westerly and south-westerly winds predominate (K o n d r a c i u k 1978).

In the yearly course of average wind velocities the highest velocities occur in winter months (February), and the lowest in summer months (August). The average wind velocity for the region under study is from 3.1 m per s (Lidzbark Warmiński) to 3.9 m per s (Elbląg). Monthly average wind velocities for the winter half-year range from 3.5 to 4.6 m per s, whereas for the summer months values below 1 m per s are obtained. The average number of days with strong winds ($V > 10$ m per s) per year is about 20, and only in the Elbląg region - 43 (K o n d r a c i u k 1977, S i e n k i e w i c z 1978).

3. HYDROGRAPHIC DESCRIPTION OF LAKES AND THEIR CATCHMENT AREAS

The lake catchment areas considered in this paper belong to the Vistula basin (25 cases) and to the drainage area of the Lagoon of Vistula (18 cases) (Table III). Most of the lake catchment areas under study (as many as 16) are found in the basin of the Łyna (thereof 5 in the basin of the Guber river); nine of the catchment areas belong to the basin of the Pisa (thereof 4 to the basin of the Krutynia); the basins of the Omulwia and Drwęca include six catchment areas each, three catchment areas are found in the basin of the Liwa, two in the basin of the Nogat, and one in the basin of the Ełk river. The lake catchment areas vary in size, ranging from several to several hundred km^2 (Table IV). The largest are the catchment areas of the lakes Lidzbarskie (563 km^2) and Ełckie (967 km^2), the smallest are those of the lakes: Siercze (2.12 km^2), Ołów (3.19 km^2), Sarż (3.86 km^2), Bartąg (4.19 km^2) and Sztumskie (4.60 km^2). The number of lakes with a catchment-area size up to 100 km^2 is 38; the most numerous is the group of lakes with catchment areas of 10-20 km^2.

According to Bogosławski's criteria for lake size assessment (P a s ł a w s k i 1975), the lakes considered belong to the classes of small lakes (of 20-50 ha) - five cases, medium-sized (of 50-100 ha) - seventeen cases, and of large lakes (of 100-500 ha) - twenty-two cases, the largest lake not exceeding 500 ha in area (Table IV). Seven of them are shallow (maximum depth up to 5 m), twelve - medium-deep (maximum depth from 5 to 10 m), ten - deep (maximum depth from 10 to 20 m), and fourteen - very deep (maximum depth above 20 m); the depth of the deepest lake does not exceed 60 m.

As regards the water balance, the lakes under study represent three types: transit lakes, outflow lakes, enclosed lakes. It seems that the greatest potential of nutrient delivery into the lake exists in transit lakes, a smaller one in enclosed lakes, and the smallest in outflow lakes.

Table III. Catchment areas of lakes chosen for analysis against the hydrographic division of Poland (P o d z i a ł h y d r o g r a f i c z n y P o l s k i 1980)

Vistula basin therein basins of the rivers:					Vistula Lagoon drainage area therein basins of the rivers:	
Ełk	Pisa	Omulwia	Drwęca	Liwa	Nogat	Łyna
Ełckie	Wobel	Długie	Rumian	Burgale	Barlewickie	Stryjewskie
	Ołów	Gim	Lidzbarskie	Liwiec	Sztumskie	Kierzlińskie Duże
	Szeląg Mały	Grom	Hartowiec	Bądze		Bartąg
	Piłakno	Branickie	Iławskie			Skanda
	Lampackie	Sędańskie	Sambród			Rzeckie
	Sarż	Szoby Małe	Jaśkowskie			Małaszewskie
	Rańskie	(Sasek Mały)				Czos
	Warpuńskie					Juno
	Kołowin					Maróz
						Kokowo
						Kuc
						Probarskie
						Mój
						Siercze
						Tuchel
						Kraksy Duże

In the assessment of the effect of a catchment area on the cycling of water and matter in a lake the important values to be considered are the indices relating the surface area and volume of lakes to the size of their catchment areas. These are: the lake ratio (Ohle's index) and Schindler's index. The former is the catchment-area-size to lake-surface-area ratio, and defines the hydrological type of the lake (P a s ł a w s k i 1975). Obviously, the higher the ratio the greater (assuming the same type of catchment area) the potential of nutrient supply into the lake and threat to the cleanness of its waters. In the cases considered in the paper the value of the ratio shows a considerable variation, ranging from 4 to 463 (Table V). According to P a s ł a w s k i 's (1975) criteria, water bodies for which the lake ratio values are below 40 are characterized by a passive hydrological type (a low water-exchange rate, below 1, a small amplitude of water-state oscillations - an annual average of about 50 cm); with values of the ratio ranging from 40 to 150 the respective lakes show a moderate type (an average water-exchange rate of 1-5, an annual average water-state amplitude of 50-100 cm); when the value of the ratio is above 150, the respective lakes are characterized by an active hydrological type (a high water-exchange rate, over 5, annual average water-state oscillation amplitudes of over 100 cm). A passive type is found in 29 of the lakes under study, a moderate type - in 8, and an active one in 6. Particularly passive (a lake-ratio value up to 5) are the following lakes: Ołów, Sarż, Jaśkowskie, Piłakno, Siercze, Grom, Probarskie, while the following appear to be very active (a lake-ratio of over 400): Liwieniec and Lidzbarskie.

Another measure indicating the nature of a lake is the ratio of the size of the drainage area, catching the matter which subsequently gets into the lake (the total surface area of the drainage basin plus the lake surface area), to the volume of the water in the lake, that is to say, the amount of water diluting the matter. This ratio is called Schindler's index (Table V). The higher the value of this index, the greater the dependence of a lake on the catchment area. In the lakes under study it takes the values from 0.3 to 274; in 25 lakes it was found to be below 5, therein in 9 cases it was less than 1. In 11 cases Schindler's index values were between 5 and 30, in 4 cases between 30 and 100, and in 3 cases above 100.

Table IV. Total surface area of lake catchment areas, and selected morphometric features of the lakes (acc. to Chojnowski 1975)

Lake	Area of total lake basin (km²)	Lake area (km²)	Lake volume (mlln. m³)	Lake depth (m)	
				maximum	average
Kierzlińskie Duże	16.6	0.928	10.861	44.5	11.7
Rumian	251.2	3.058	19.955	14.4	6.5
Burgale	12.6	0.790	3.645	7.4	4.6
Liwieniec	342.2	0.812	1.250	2.4	1.2
Iławskie	362.7	1.545	1.774	2.6	1.1
Bartąg	4.19	0.723	4.695	15.2	6.4
Skanda	10.8	0.511	2.964	12.0	5.8
Rańskie	31.3	2.913	11.209	7.8	3.8
Rzeckie	17.1	0.561	3.930	29.0	7.0
Ołów	3.19	0.614	7.980	40.1	12.9
Gim	11.1	1.759	13.456	25.8	7.6
Stryjewskie	22.6	0.675	1.741	6.2	2.6
Szeląg Mały	14.4	0.838	4.781	15.2	5.7
Maróz	216.8	3.325	39.566	41.0	11.9
Barlewickie	9.28	0.637	2.695	8.5	4.2
Sztumskie	4.60	0.501	3.442	24.6	6.8
Kokowo	89.0	0.372	1.257	11.75	3.3
Ełckie	966.9	3.824	57.420	55.8	15.0
Bądze	12.1	1.499	4.288	6.7	2.8
Warpuńskie	23.0	0.490	1.270	6.9	2.6

Lidzbarskie	562.4	1.218	12.292	25.5	10.0
Sarż	3.86	0.767	4.541	15.0	5.0
Hartowieckie	12.2	0.696	1.955	5.2	2.8
Kraksy Duże	87.6	0.442	0.493	4.0	1.1
Sambród	59.3	1.284	2.427	4.3	1.9
Jaśkowskie	7.49	1.525	11.238	16.5	7.3
Lampackie	87.2	1.986	22.135	38.5	11.1
Piłakno	10.8	2.590	33.785	56.6	13.0
Mój	9.98	1.165	2.877	4.1	2.4
Siercze	2.12	0.554	0.593	2.0	1.0
Tuchel	17.6	0.427	1.163	5.1	2.7
Długie	17.0	0.621	1.750	5.4	2.8
Sędańskie	219.1	1.685	4.329	6.1	2.5
Juno	233.2	3.807	45.476	33.0	11.9
Czos	98.6	2.791	31.012	42.6	11.1
Kuc	8.78	0.980	*	28.0	8.0
Probarskie	8.60	2.014	18.572	31.0	9.2
Kołowin	20.8	0.782	3.138	7.2	4.0
Małaszewskie	38.1	2.022	12.857	16.9	6.3
Branickie	32.7	1.863	5.024	5.2	2.7
Szoby Małe	357.7	3.191	5.269	3.7	1.6
Wobel	5.82	0.237	0.982	15.0	4.2
Grom	11.1	2.400	13.996	15.8	5.8

* No data available.

Table V. Hydrological characteristics of lakes

Lake	Basin of river	Annual average unit outflow in basin $l \cdot s^{-1} \cdot km^{-2}$	Water exchange rate* $\frac{Hw}{Vj}$	Ohle's index** $\frac{Azl}{Aj}$	Schindler's index $\frac{Azl}{Vj}$
Kierzlińskie Duże	Łyna	6.9	0.33	17	1.5
Rumian	Wel	5.8	2.31	82	12.6
Burgale	Liwa	4.5	0.49	16	3.4
Liwieniec	Liwa	3.9	33.7	421	274.0
Iławskie	Drwęca	5.7	36.9	235	204.0
Bartąg	Łyna	6.9	B***	6	0.9
Skanda	Łyna	6.9	B	21	3.6
Rańskie	Krutynia	6.2	0.50	11	2.8
Rzeckie	Dymer	6.0	0.82	30	4.4
Ołów	Pisa	4.5	B	5	0.4
Gim	Omulew	4.6	B	6	0.8
Stryjewskie	Czerwonka	6.0	2.50	34	13.0
Szeląg Mały	Drwęca	6.9	0.65	17	3.0
Maróz	Łyna	6.9	1.19	65	5.5
Barlewickie	Nogat	4.5	B	15	3.4
Sztumskie	Nogat	4.5	0.19	9	1.3
Kokowo	Symsarna	6.0	13.4	239	71.0
Ełckie	Ełk	5.8	3.05	253	16.8
Bądze	Liwa	4.5	0.40	8	2.8
Warpuńskie	Krutynia	6.2	3.50	47	18.1
Lidzbarskie	Wel	5.8	8.41	463	46.0

Sarż	Krutynia	6.2	B	5	0.8
Hartowiec	Wel	5.8	1.14	18	6.2
Kraksy Duże	Dymer	6.0	33.7	198	178.0
Sambród	Drwęca	6.9	5.3	46	24.0
Jaśkowskie	Drwęca	6.9	0.14	5	0.7
Lampackie	Pisa	6.2	0.77	44	3.9
Piłakno	Pisa	6.2	0.06	4	0.3
Mój	Guber	6.0	B	9	3.5
Siercze	Guber	6.0	0.67	4	3.6
Tuchel	Guber	6.0	2.84	41	15.0
Długie	Omulew	4.6	B	27	9.7
Sędańskie	Omulew	4.6	7.40	8	51.0
Juno	Łyna	6.0	0.97	61	5.0
Czos	Łyna	6.0	0.60	35	3.0
Kuc	Dajna	6.2	B	9	
Probarskie	Dajna	6.2	B	4	0.5
Kołowin	Krutynia	6.2	1.30	27	3.0
Małaszewskie	Łyna	6.9	0.64	19	2.0
Branickie	Omulew	4.6	0.92	18	6.0
Szoby Małe	Omulew	4.6	9.90	112	68.0
Wobel	Pisa	4.5	0.84	25	6.0
Grom	Omulew	4.6	0.12	5	0.8

*$\frac{Hw}{Vj}$ where: Hw - value of river outflow from lake, Vj - total lake volume. **$\frac{Azl}{Aj}$ and $\frac{Azl}{Vj}$ where: Azl - area of total lake basin, Aj - lake area, Vj - lake volume. ***B - outflowless lake.

The hydrological type of a lake is indicated by, apart from Ohle's index, the rate of water exchange (P a s ł a w s k i 1975). The intensity of water exchange in a lake is a factor which has a considerable influence on the cycling of matter in it. In general, the faster the rate of water exchange in a lake, the shorter the retention of water in it and thereby the faster the renewal of its waters. The adopted measure of the rate of water exchange in a lake was the quotient obtained by dividing the water flowing out of the lake (H_w) by the volume of the lake (V_j) (M i k u l s k i 1967, D y n u s - A n g i e l 1979). The value of the outflow from a lake was estimated on the basis of the mean unit outflow in the catchment area (Table V), evaluated on the basis of data on the rate of flow in the years 1960-1975 of the main rivers, in the basins of which the catchment areas under study are found. The rate of water exchange in the study lakes is as follows: enclosed lakes and some of the outflow lakes located mainly in a watershed zone are characterized by a very low water exchange rate - up to 1 (27 cases); a water exchange rate of 1 to 5 is found for 8 of the lakes under study, a water exchange rate of 5 to 10 for 4 lakes, and a rate of above 10 also for 4 lakes. The most active are the following lakes: Liwieniec (I = 34), Kraksy Duże (I = 34) and Iławskie (I = 37).

4. PHYSICAL GEOGRAPHIC DESCRIPTION OF LAKE CATCHMENT AREAS

The description of the physico-geographical environment of the lake catchment areas was made from the point of view of an assessment of the possibility of the amount of matter contained in an area getting removed and transported to the lake. It has been decided that the constant features of the physico-geographical environment affecting the supply of matter to a lake include: the size of the catchment area (conditions the action of the catchment area on the lake), the morphometry of the catchment area (determines the runoff and the magnitude of water-caused erosion), river-network density (the way of transport of matter to a lake), the geological structure and soil conditions (affecting the transport of nutrients to groundwaters). A feature varying with time is the use of land, which influences the rate of a possible supply of nutrient matter to a water body.

The values of the physico-geographical parameters of the lake drainage areas were estimated on the basis of 1 : 25000 maps, that is, a topographical map and agricultural soil maps, prepared by the Voivodship Offices of Geodesy and Land Use.

Data relating to the basic physico-geographical characteristics concern only those catchment areas which directly affect the supply of nutrients to water bodies. In the case of transit lakes it is a partial basin understood as the remaining lake basin after the subtraction of the catchment area of the main stream. In this case the supply by a transit stream is understood as a point--source of pollution which is overlapped by the effect of areal pollution.

The characteristic feature of a young glacial landscape is the presence of large areas excluded from the surface runoff, known as areas without drainage. Their presence in a drainage area reduces the surface supply of nutrients to lakes. If they are depressions with a good infiltration (with permeable deposits present in the substrate), there is a possibility of enriching the underground water with chemical compounds. In the case of water-retaining depressions considerable amounts of nutrients are retained on the surface. In general, the greater the proportion of a basin occupied by drainageless depressions, the lesser the likelihood of matter getting to the lake over the surface. The proportion of drainageless depressions in the total catchment area of the lakes under study ranges from 0 to 75%. In eight lake catchment areas depressions without surface drainage occupy 20% of the area, in twenty catchment areas drainagelessness amounts to 20-45%, ten catchment areas are characterized by a drainagelessness of 45-60%, and five by a drainagelessness of over 60% (Table VI).

The slope of the terrain has been described by the land slope index (J), understood as $J = \Delta H \cdot A^{-\frac{1}{2}}$‰, where ΔH = Hmaks - Hmin m a.s.l., A - the surface area of a catchment basin in km^2. It has been found that in the case of lake districts this measure diversifies catchment areas much better than does the longitudinal gradient of a river. Three of the lake catchment areas considered have an average slope of 5‰, fifteen have a slope of the order of 6-10‰, twenty-one catchment areas have a slope of 10-20‰, and four have a slope of above 20‰ (Table VI).

Table VI. Selected physico-geographical parameters of lake catchment areas

Catchment area of lake	Area of immediate lake basin (km^2)	Percentage of area occupied by outflowless depressions (%)	River network density ($km \cdot km^{-2}$)	Terrain slope (‰)	Type of land use (%)					
					woods	arable land	meadows pastures	water	buildings	others
Kierzlińskie Duże	16.61	39	0.95	9	16	62	14	6	1	1
Rumian	22.70	50	0.12	14	5	77	3	13	1	1
Burgale	12.60	18	1.42	10	17	66	11	6	-	-
Liwieniec	14.83	50	1.66	12	25	47	15	6	4	3
Iławskie	7.17	26	0.87	7	11	58	9	19	3	-
Bartąg	4.19	33	0.12	20	14	51	15	17	2	1
Skanda	10.81	49	0.65	9	4	45	14	5	27	5
Rańskie	31.30	21	1.02	7	18	64	7	9	1	1
Rzeckie	17.10	28	1.23	13	5	78	12	5	-	-
Ołów	3.19	32	0.00	30	26	46	3	20	4	1
Gim	11.07	51	0.32	7	64	14	5	16	1	-
Stryjewskie	22.63	29	0.14	18	34	38	2	26	-	-
Szeląg Mały	14.40	51	0.57	18	79	6	5	8	2	-
Maróz	20.90	35	0.31	12	66	16	2	16	-	-
Barlewickie	9.28	54	1.08	12	4	72	11	7	4	2
Sztumskie	4.60	67	0.49	11	0	73	7	12	8	-
Kokowo	7.62	25	1.60	20	9	73	13	5	-	-
Ełckie	40.90	5	1.00	9	16	53	11	15	4	1

Bądze	12.10	75	0.00	10	83	2	3	12	0	0
Warpuńskie	23.00	30	1.02	14	15	74	9	2	0	0
Lidzbarskie	17.40	51	0.43	13	51	35	4	8	2	0
Sarż	3.86	45	0.49	14	26	55	2	17	-	-
Hartowiec	12.20	72	0.55	10	6	79	5	6	2	2
Kraksy Duże	7.56	36	0.96	8	6	59	22	4	8	1
Sambród	25.51	39	1.17	11	23	58	11	5	3	-
Jaśkowskie	7.49	14	0.63	13	5	70	4	18	2	1
Lampackie	13.85	9	1.04	15	16	55	13	14	1	1
Piłakno	10.80	35	0.51	10	40	30	4	24	-	-
Mój	9.98	10	0.96	4	62	22	4	12	-	-
Siercze	2.12	9	0.47	22	9	63	2	26	-	-
Tuchel	17.60	7	1.72	10	26	54	15	4	-	1
Długie	17.00	46	0.18	11	33	32	1	6	27	1
Sędańskie	12.90	61	0.33	7	79	6	2	13	-	-
Juno	36.80	0	0.00	26	10	46	3	38	3	-
Czos	18.40	36	0.36	16	18	53	8	9	12	-
Kuc	8.78	38	0.73	22	24	56	8	11	-	1
Probarskie	8.60	54	0.17	14	31	41	1	24	3	-
Kołowin	20.80	63	0.22	11	77	13	6	4	-	-
Małaszewskie	38.10	39	0.88	8	33	47	12	7	1	-
Branickie	32.70	36	1.02	5	9	70	8	10	1	2
Szoby Małe	26.80	40	0.35	8	78	2	3	16	1	-
Wobel	5.82	53	2.20	14	1	79	10	5	4	1
Grom	11.08	37	0.24	5	24	42	11	20	2	1

The river-network density was calculated by using Neumann's formula, where $D = \Sigma l \cdot A^{-1}$ km $\cdot$ km^{2} (Σl - length of all streams, A - the area of the basin drained by these streams). This parameter depends primarily on the climate, relief and substrate permeability (D o b i j a and D y n o w s k a 1975). If the former two factors are similar (as in the case of the catchment areas discussed), the river-network density depends exclusively on the permeability of the substrate (the anthropogenic factor excluded). The denser the river network, the better the conditions of runoff to the lake, and the greater the probability of nutrient matter reaching the lake. The river-network density in the study catchment areas varies between 0 and 2.20 km per km^2. River-network densities up to 0.5 km per km^2 were found in nineteen catchment areas, 0.5-1.0 km per km^2 in twelve catchment areas, 1.0--1.5 km per km^2 in eight catchment areas, and over 1.5 km per km^2 in four lake catchment areas (Table VI).

The geological structure of the substratum and the soil type have a fundamental effect on the chemical composition of the waters, and on the way waters are fed to lakes. In permeable soils underground feeding predominates, in less permeable soils feeding by underground waters is less intense, but where the relief is favourable, surface runoff may dominate. As the amount of nutrients removed from a soil profile depends on the amount of infiltrated water (K a j a k 1979), the lake catchment areas have been grouped according to the nature of the surface deposits making up the soil cover, using the appropriate criteria after B a j k i e w i c z - G r a b o w s k a (in press). The following catchment basin types have been identified:

1. A sandy basin - one in which sandy deposits dominate (gravel and loose sandy soils), covering over 50% of the area of the basin; there are not in essence any loamy deposits (loams, clays and very fine sand fractions). In such a basin underground export of nutrients is easy.

2. A loamy basin - one in which less permeable deposits (loams, clays and very fine sand fractions) occupy over 30% of the area, and gravels and loose sandy soils are in essence absent. In catchment basins of this type the underground supply of matter is limited.

3. A loam-sandy basin - one in which loams, very fine sand

fractions, clays and gravels and loose sandy soils occupy up to 10% of the surface area, whereas over 90% of the area is occupied by loamy sands and sandy loams.

4. Finally, a sand-loamy basin is a basin in which soils made up of loams, clays and very fine sand fractions cover from 10 to 30% of the area, whereas loose sandy soils and gravels - up to 10%. The remainder of the area of the catchment basin is made up of soils that have formed on loamy-sands and on sandy loams (Table VII).

The type of land use determines the quantity of nutrients removed from the catchment area and carried to the lake (K a j a k 1979). Bearing this in mind, B a j k i e w i c z - G r a b o w s k a (in press) distinguished, on the basis of the type of land use in areas in the immediate vicinity of a lake, the following catchment-basin groups.

A forest basin in which forests cover over 70% of the area, meadows up to 10% and buildings up to 10% of the area; if meadows occupy over 10% of the area, the respective basin changes its name by becoming a pasture-forest basin, and where built up areas occupy over 10% of the surface area - it becomes a forest basin with buildings. An agricultural-forest catchment basin is a basin in which 30 up to 70% of the area is occupied by woods and arable land (areas covered by woods being larger); meadows occupy up to 10% of the area of the catchment basin and buildings up to 10%; if meadows occupy over 10% of the area, the basin changes its name by becoming a pasture-agricultural-forest basin, and if buildings occupy over 10% of the area of the basin, the respective basin is called an agriculture-forest basin with built up areas. A forest-agricultural basin is a basin in which 30 to 70% of the area is occupied by woods and arable land, the area occupied by arable land being greater; meadows occupy up to 10% of the area and buildings up to 10%. If meadows occupy over 10% of the area of a drainage basin, it has been classified to be a pasture-forest-agricultural basin, but if buildings exceed 10% of the area - a forest-agricultural basin with built up areas. The last types are represented by the agricultural catchment basin in which arable lands occupy over 70% of the area, meadows and compact buildings up to 10%; if meadows occupy over 10% of the area of a catchment basin, the class has been altered to a pasture-agricultural basin,

Table VII. Catchment areas of the lakes under analysis, according to the kind of surface deposits making up the soil cover (I), and type of land use (II)
Catchment area: S - sandy, L-S - loam-sandy, S-L - sand-loamy, L - loamy, A - peats occupy up to 10% of immediate lake catchment area, B - peats occupy over 10% of immediate lake catchment area, Fo - forest, Ag-Fo - agriculture-forest, Fo-Ag - forest-agricultural, Pa-Fo-Ag - pasture-forest-agricultural, Pa-Fo-Ag(b) - pasture-forest-agricultural with built up areas, Fo-Ag(b) - forest-agricultural with built up areas, Ag - agricultural, Pa-Ag - pasture-agricultural, Pa-Ag(b) - pasture-agricultural with built up areas. Rules of classification in the text

Catchment areas of lake	I							II								
	S	L-S		S-L		L		Fo	Ag-Fo	Fo-Ag	Pa-Fo-Ag	Pa-Fo-Ag (b)	Fo-Ag (b)	Ag	Pa-Ag	Pa-Ag (b)
		A	B	A	B	A	B									
Kierzlińskie Duże						+					+					
Rumian		+												+		
Burgale			+												+	
Liwieniec			+								+					
Iławskie		+													+	
Bartąg						+					+					
Skanda			+													+
Rańskie		+												+		
Rzeckie			+												+	
Ołów		+								+						
Gim		+						+								
Stryjewskie		+								+						
Szeląg Mały		+						+								
Maróz		+						+								
Barlewickie															+	
Sztumskie		+														+
Kokowo		+													+	

Ełckie		+											+			
Będze		+						+								
Warpuńskie		+												+		
Lidzbarskie		+							+							
Sarż		+								+						
Hartowiec		+												+		
Kraksy Duże			+									+				
Sambród		+									+					
Jaśkowskie		+												+		
Lampackie					+						+					
Piłakno		+							+							
Mój		+						+								
Siercze		+												+		
Tuchel			+								+					
Długie		+											+			
Sędańskie		+						+								
Juno		+												+		
Czos		+											+			
Kuc		+								+						
Probarskie		+								+						
Kołowin		+						+								
Małaszewskie			+								+					
Branickie			+												+	
Szoby Małe		+						+								
Wobel					+											+
Grom			+								+					

and if buildings occupy over 10% of the area, the basin is called an agricultural basin with built up areas (Table VII).

5. SUMMING UP

The magnitude of surface runoff into rivers and lakes no doubt depends on the physico-geographical environment of a catchment area. By classifying selected characteristics of the physico-geographical environment and hydrological properties of the water bodies themselves (B a j k i e w i c z - G r a b o w s k a - in press) it is possible to group the lake catchment areas chosen for study into classes according to the possibility of moving the amount of matter contained it the area and transporting in to lakes (Table VIII).

The group of catchment areas with limited possibilities of supplying matter to a lake (class I) includes the basins of the following lakes: Będze, Kołowin, Grom, Bartąg, Kierzlińskie Duże, Gim, Maróz, Piłakno and Sędańskie. These are lakes with a passive hydrological regime, where the catchment area does not exert a significant effect on the lake itself (Ohle's index up to 10); the water exchange rate does not exceed 0.5, which means that a total exchange of water in a lake occurs less often than every other year. An exception is the following lakes: Sędańskie and Kołowin, which show a higher hydrological activity associated, in the case of the former, with the transit nature of the lake. The land use does not favour the transport of nutrients to the lakes (they are as a rule forest catchment areas), even though the lithological structure of the areas is not favourable, and in the case of the following lakes: Bartąg, Kierzlińskie Duże and Piłakno, even the morphometry of the catchment areas is not favourable.

The group of lakes poorly supplied by the basin with nutrient matter (class II) includes nineteen of the lakes chosen for the analysis. These, too, are lakes with a passive hydrological regime, resulting primarily from the fact that they are water bodies without surface outflow. Nutrient transportation to a lake is favoured by the lithology of surface deposits, the morphometric conditions - fairly often very unfavourable - of the catchment areas, and in the case of lakes: Sztumskie, Hartowiec, Jaśkowskie and Siercze also an improper land use. Only lakes: Szoby Małe (or Sasek Mały), Sambród and Maróz are characterized by a considerable hydrological activity. However, due to a considerable dependence of the lakes on the catchment areas (Ohle's index above 45), as well as to the fact that they are fairly shallow, there exist favourable conditions for the growth of nutrient content in them. The supply of matter from the drainage area is partially limited by a favourable morphology of the drainage area, as well as by a favourable land use.

Moderate conditions for nutrient supply from the catchment basin (class III) are found in ten lakes. They are mainly transit lakes (except Lake Wobel), characterized by a passive or medium hydrological regime. In these lakes water exchange rate comes up to 5. Lake Liwiec and Lidzbarskie Lake to a large extent depend on their catchment areas (there are over 400 km^2 of the catchment area per each km^2 of the lake). The remaining lakes of this group are either located in a watershed zone (Ohle's index up to 20), or dependent to a madium extent on their catchment areas (Ohle's index ranging from 40 to 150). The catchment areas are mostly agricultural, and only in the case of lakes: Długie, Miłki and Skanda are they forest- or pasture-agricultural with built up areas. The transport of nutrient matter to the lakes is favoured also by the lithology of the surface deposits, and by the morphology, in some cases unfavourable, of the catchment area.

The greatest potential of nutrient matter supply from the catchment areas (class IV) exists in the following lakes: Kokowo, Czos, Juno, Iławskie, Ełckie and Kraksy Duże. They are transit lakes, highly dependent on their drainage areas (Ohle's index as a rule above 200, Schindler's index above 70), with an active hydrological regime (a passive regime is only found in Lake Czos and Lake Juno). The corresponding basins are agricultural, and compact buildings occupy in them a considerable surface area. Nutrient matter supply from the catchment areas is favoured by the lithology of surface deposits and unfavourable morphometry of the drainage areas (absence of areas without surface drainage in the basin, a considerable density of river network, and often also considerable terrain gradients).

Table VIII. Classification of lake catchment areas according to their potentials of matter supply to water bodies

+ – medium effect of the parameter on matter supply, ++ – great effect of the parameter on matter supply

Classes	Catchment areas of lakes	Parameters affecting the rate of matter supply to a lake						
		morphometry	geological structure	land use	Ohle's index	Schindler's index	balance of outflow from lake	water exchange rate
I Limited potential of matter supply from catchment area	Będze		+					++
	Kołowin		+					+
	Grom		+					++
	Bartąg	+					+	++
	Kierzlińskie	+						++
	Gim		+				+	++
	Piłakno	+	+					++
	Sędańskie		+			+	++	
II Low potential of matter supply to lake	Kuc	+	+				+	++
	Szeląg Mały		+					++
	Mój	+	+				+	++
	Sarż		+				+	++
	Probarskie		+				+	++
	Małaszewskie	+	+					++
	Ołów	+	+				+	++
	Sztumskie		+	++				++
	Barlewickie	+					+	++
	Rzeckie	+	+					++
	Lampackie	++			+			++

	Burgale	++	+					++
	Hartowiec		+	+				++
	Jaśkowskie	++	+	+				++
	Siercze	++	+	+				++
	Tuchel	++	+		+			+
	Szoby Małe		+		+	+	++	
	Sambród	+			+		++	
	Maróz	+	+		+	+		
III Medium potential of matter supply to lake	Rańskie	+	+	+				++
	Stryjewskie	+	+				++	+
	Branickie	+	+				++	++
	Liwieniec	+	+		++	++	++	
	Warpuńskie	+	+	+	+			+
	Długie		+	++			+	++
	Rumian		+	+	+		++	+
	Skanda		+	++			+	++
	Lidzbarskie		+		++	+	++	
	Wobel			++				++
IV High potential of matter supply to lake	Kokowo	++	+		++	+	++	
	Czos	+	+	++			++	++
	Juno	++	+	+	+		++	++
	Iławskie	+	+		++	++	++	
	Kraksy Duże	+	+	+	++	++	++	
	Ełckie	+	+	++	++		++	+

6. SUMMARY

The lake drainage areas chosen for the assessment of the effect of physico-geographical parameters on the removal and supply of nutrient matter to lakes are located in north-eastern Poland (Fig. 1), mainly in the Masurian Lake District (Table I).

In this part of Poland the annual precipitation totals range from 500 to 600 mm, and only in the morainic-hill zone 600-700 mm (Table II). The catchment areas chosen for analysis belong to the basin of the Vistula and the catchment area of the Vistula Lagoon (Table III). The lake catchment areas vary in size, ranging from several to several hundred km^2 (Table IV); the morphometric parameters of the lakes themselves also vary considerably (Table IV).

In the assessment of the effect of the catchment areas on the potential of nutrient matter supply to the lake several physico-geographical parameters of the catchment area were taken into account. These included some morphometric parameters such as the size of the catchment area directly included in the outflow (specifically, the percentage of the area without surface drainage), the average gradient of the catchment area, the river-network density, as well as the lithology, soil type and land use (Table VI, VII). Taken into account were also parameters relating the catchment area size to the size of the water body itself, and to its water volume, that is to say, Ohle's index and Schindler's index, and also the parameter indicating the rate of water exchange in a lake (Table V). The aggregate total of the characteristics combined according to B a j k i e w i c z - G r a b o w s k a's (in press) suggestion made it possible to group the catchment areas into four classes (Table VIII). The classes differ in their possibilities of removing matter, and in the rate of its supply to the water body. The classification indicates the parameters which to a medium an high degree affect the potential of nutrient matter supply.

7. POLISH SUMMARY

Zlewnie jeziorne wybrane do oceny wpływu parametrów fizyczno-geograficznych na możliwość uruchomienia i dostarczenia materii do jezior, zlokalizowane są w północno-wschodniej Polsce (rys. 1), głównie na Pojezierzu Mazurskim (tab. I).

Roczne sumy opadu w tej części Polski wynoszą 500-600 mm, tylko w strefie wzgórz morenowych 600-700 mm (tab. II). Wytypowane do analizy zlewnie należą do dorzecza Wisły i do zlewiska Zalewu Wiślanego (tab. III). Powierzchnia zlewni jeziornych jest zróżnicowana i wynosi od kilku do kilkuset km^2 (tab. IV); znaczne jest też zróżnicowanie parametrów morfometrycznych samych zbiorników (tab. IV).

Oceniając wpływ zlewni na możliwość dostarczania materii do jeziora uwzględniono kilka parametrów fizyczno-geograficznych zlewni. Były nimi parametry morfometryczne zlewni, takie jak wielkość zlewni bezpośrednio włączonej w odpływ (konkretnie procent powierzchni powierzchniowo bezodpływowej), średni spadek zlewni i gęstość sieci rzecznej, a także litologia i typ gleb oraz sposób użytkowania terenu (tab. VI, VII). Uwzględniono także parametry wiążące wielkość zlewni z wielkością samego zbiornika i z jego pojemnością, tj. wskaźnik Ohlego i wskaźnik Schindlera, a także parametr informujący o tempie wymiany wody w jeziorze (tab. V). Łączna suma cech przeprowadzona wg propozycji Bajkiewicz-Grabowskiej (w druku), pozwoliła pogrupować zlewnie w 4 klasy (tab. VIII). Każda klasa ma inne możliwości uruchamiania materii i inne tempo jej dostarczania do zbiornika. W podziale tym wskazano na parametry w średnim i w dużym stopniu decydujące o możliwościach dostawy materii.

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