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FACTORS AFFECTING NUTRIENT BUDGET IN LAKES OF THE R. JORKA WATERSHED (MASURIAN LAKELAND, POLAND) I. GEOGRAPHICAL DESCRIPTION, HYDROGRAPHIC COMPONENTS AND MAN'S IMPACT*

ABSTRACT: Physical-geographic conditions are presented of the watershed of the river Jorka with particular emphasis placed on those factors of the geographic environment which affect the water and nutrient cycles in the watershed and the habitat features of the lakes. The description covers morphometric conditions of the watershed, as well as lithological, climatic and hydrographic conditions. At this background the potential is shown of the surface run-off to watercourses and lakes. On the basis of a number of indices the possible effect of the watershed on the particular water bodies has been determined.

KEY WORDS: Lakes, watershed, land use, man's impact.

Contents

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1. INTRODUCTION, LOCALIZATION OF THE STUDY AREA

The aim of this paper is to describe the basic physical-geographic conditions of the river Jorka watershed with particular attention given to those components of the geographic environment which affect the water and nutrient cycle in the watershed and the habitat features of the lakes. Taken into account is also the effect of the anthropogenic factors — the main source of transformation of the natural conditions of the watershed.

Hydrographically, the watershed selected for traverse studies (geographic co-ordinates: 53°45′ N to 53°53′ N, and 21°25′ E to 21°33′ E) as an order-III watershed belongs to the watershed of the Pisa river representing part of the right-bank watershed of the Vistula river. It is drained by a small watercourse, the river Jorka, which on its course passes through five lakes, finally carrying its waters to Lake Tałty, one of the Great Masurian Lakes (Fig. 1). In the physical-geographic classification of Europe and Poland the area under study belongs, according to K o n d r a c k i (1972), to mesoregion 832.12, the Mrągowo Lake District, of macroregion 832.1, the Masurian Lake District, of subprovince 832, the Eastern-Baltic Lakelands, of province 83, the Eastern-Baltic Lowland, the Eastern European region. Along with the whole mesoregion it constitutes a typical lakeland landscape area corresponding, geomorphologically, to the range of the Masurian lobe of the Baltic glaciation (K o n d r a c k i 1972). The glacier activity of this period resulted in the formation of

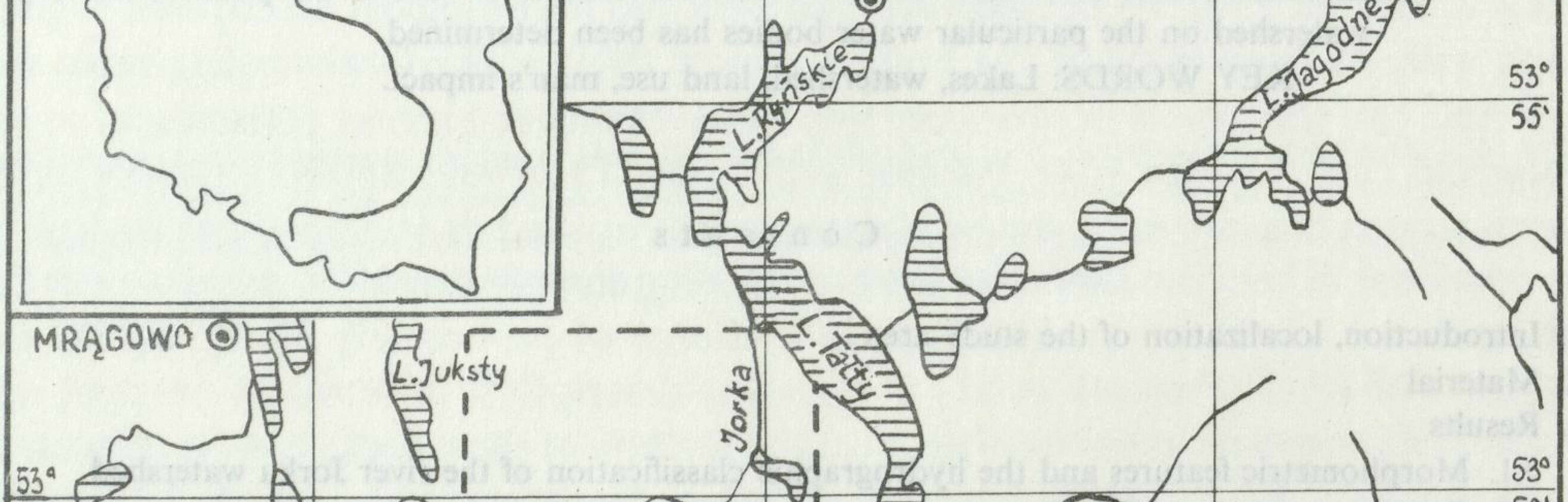

Fig. 1. A location map of the river Jorka watershed (encircled with dashed line) within part of the Masurian Lakeland

specific relief features. Due to an "oscillatory lobal" nature of the deglaciation, typical of this macroregion and characteristic for the presence of traces of small lobes probably determined by the relief of the period preceding the last glaciation (K o n d r a c k i 1972), the relief is characterized by numerous moraine ramparts and a considerable number of hollows where there had been dead ice. A characteristic feature of the relief of this mesoregion is also its "lattice-like" appearance resulting from the fact that the glacial-drainage channels there run evenly with the meridian, and the terminal moraines – with the parallel of latitude.

2. MATERIAL

The physical-geographic conditions in the river Jorka watershed were identified in the years 1977–1979 on the basis of field work (connected with hydrographic and geomorphological mapping supplemented with a lot of earth work), aerial photographs and cartographic materials and documentation prepared by people of the reclamation, forest, hydrogeological and agricultural services. The result of this complex work was subject maps, drawn on topographical charts in the 1:25000 scale, of the different components of the geographic environment, such as: a geomorphological map, a map of potential morphological processes, a terrain sloping map, a surface deposits map, a hydrographic map and a soil type map. Data have also been collected for a land use map, with a particular attention given to forms of management and economy which lead to an excessive pollution of the water.

3. RESULTS

3.1. MORPHOMETRIC FEATURES AND THE HYDROGRAPHIC CLASSIFICATION OF THE RIVER JORKA WATERSHED

The basic parameters characterizing the morphometry of the watershed are as follows: (1) area within the topographic divide $A = 63.3$ km^2, (2) basin length (along the river Jorka valley) $L = 12.1$ km, (3) mean basin width $B = 5.2$ km, (4) basin form factor $K = B/L = 0.43$, (5) divide compactness coefficient defined by the ratio of the basin perimeter (P) to the perimeter of a circle, the area of which is equal to the area of the watershed (A) – $W_w = 0.28\ P/\sqrt{A} = 1.62$, (6) maximum height in the area $H_{max} = 206.4$ m a.s.l., (7) minimum height in the watershed $H_{min} = 116.0$ m a.s.l., (8) average slope of the basin $\psi = (H_{max} - H_{min}) : A = 11‰$, (9) average relief ratio of the Jorka valley $J = 0.8‰$.

There are seven lakes of different origin and morphometry[1] in the watershed area.

[1] A detailed description of lakes and watercourses is given in Subsection 3.5. Characteristics of the hydrographic entities.

These are: Lake Majcz Wielki and Lake Majcz Mały located in the divide zone of the basin (Fig. 2), L. Inulec, Głębokie L. together with L. Płociczno and L. Zełwążek situated in the central part of the watershed, and L. Jorzec located on the lower course of the river Jorka. The surface area of the lakes represents 8% of the basin area. The main permanent watercourses of the watershed are: river Jorka (12.1 km long), Baranowska Struga river (7.7 km long) opening into L. Jorzec, and Struga Cudnochy river (4.12 km long) directly discharging into the Jorka river near its opening into L. Tałty (Fig. 2).

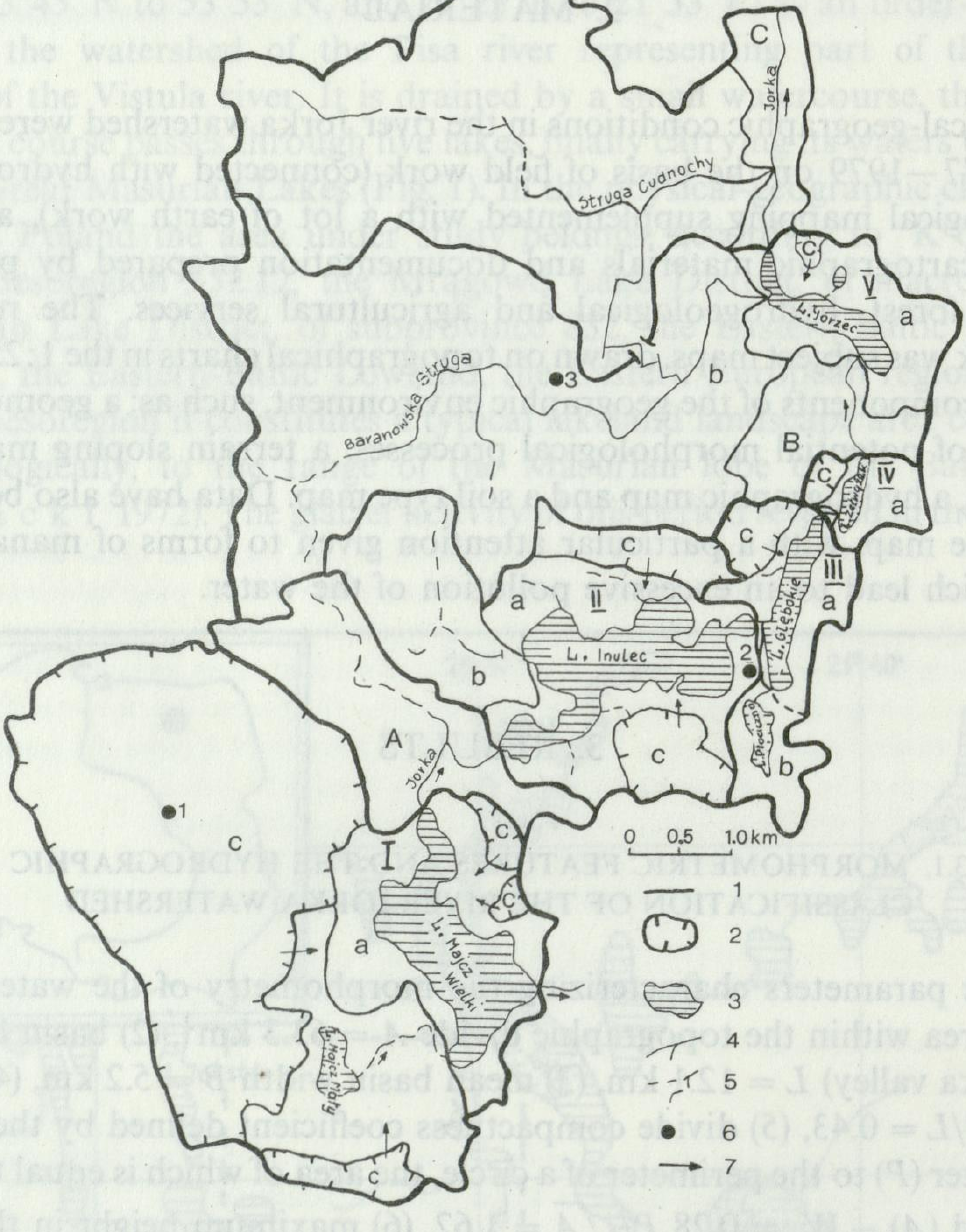

Fig. 2. Hydrographic division of the river Jorka watershed
1 – divides, 2 – divides of larger outflow-less areas, 3 – lakes, 4 – permanent streams, 5 – seasonal streams, 6 – precipitation stations, 7 – water flow directions, I – V – lake basins, a – direct lake basin, b – basin of the main tributary of the lake, c – basins of larger outflow-less areas, A, B, C – areas between rivers

In the river Jorka watershed five main partial basins have been identified (Fig. 2), and within each of these several smaller basins have been distinguished, that is to say, immediate lake basins (Fig. 2a), basins of the main tributaries of the lakes (Fig. 2b) and basins of areas without surface run-off (Fig. 2c). The area of the partial basins identified varies between 13.28 km^2 (Baranowska Struga river) and 0.09 km^2 (an outflow-less area in the basin of L. Zełwążek). Immediate basin represents from 21% (L. Majcz Wielki) and 13% (L. Inulec) to 4–5% (other lakes) of the total lake basin.

Table I. Hydrographical division of the river Jorka watershed

Partial basins	Field designations according to Fig. 2	Field area (km^2)	Basin area (km^2)	Jorka river watershed area (km^2)	Areas without surface outflow in percentage of area	
					of lake basin	of Jorka river watershed
I. Basin of Lake Majcz Wielki	a	4.05				
	b	3.01				
	c	11.85	18.91	18.91	78	78
Area between rivers	A	3.63	3.63	22.54	–	–
II. Basin of Lake Inulec	a	4.32				
	b	2.33				
	c	2.04	8.69	31.23	63	54
III. Basin of Głębokie Lake	a	1.35				
	b	0.89	2.24	33.47	0	50
IV. Basin of Lake Zełwążek	a	0.67				
	c	0.09	0.76	34.23	12	50
Area between rivers	B	1.54	1.54	35.77	–	–
V. Basin of Lake Jorzec	a	1.64				
	b	13.28				
	c	0.41	15.33	51.10	3	34
Area between rivers	C	12.16	12.16	63.26	–	–
River Jorka watershed	–	–	–	63.26	–	28

Areas without surface run-off of two kinds constitute about 28% of the total area of the watershed (Table I). They are receptive areas without surface run-off, where precipitation is balanced by sinking, and thereby groundwater outflow (thanks to a good permeability of the substrate), and areas without surface run-off, where precipitation is balanced by surface retention and evaporation. During high states of underground waters some of the latter areas seasonally contribute to the surface outflow. The proportion of areas without surface outflow in the partial watersheds identified in the Jorka river watershed varies (Table I). They appear to be most numerous in the southern part of the watershed, where they occupy more than half the area in the basins of L. Majcz Wielki and L. Inulec. Such areas are not practically found in the northern part of the river Jorka watershed.

3.2. RELIEF AND LITHOLOGY OF SURFACE DEPOSITS. CONDITIONS FOR INFILTRATION

In the river Jorka watershed two types can be distinguished of youthful glacial landscape connected with the range of the Masurian lobe of the Baltic glaciation: a hilly lakeland landscape, characteristic of the study area, and an outwash-plain lakeland landscape that can only be found in the south-eastern part of the basin of L. Majcz Wielki (Fig. 3).

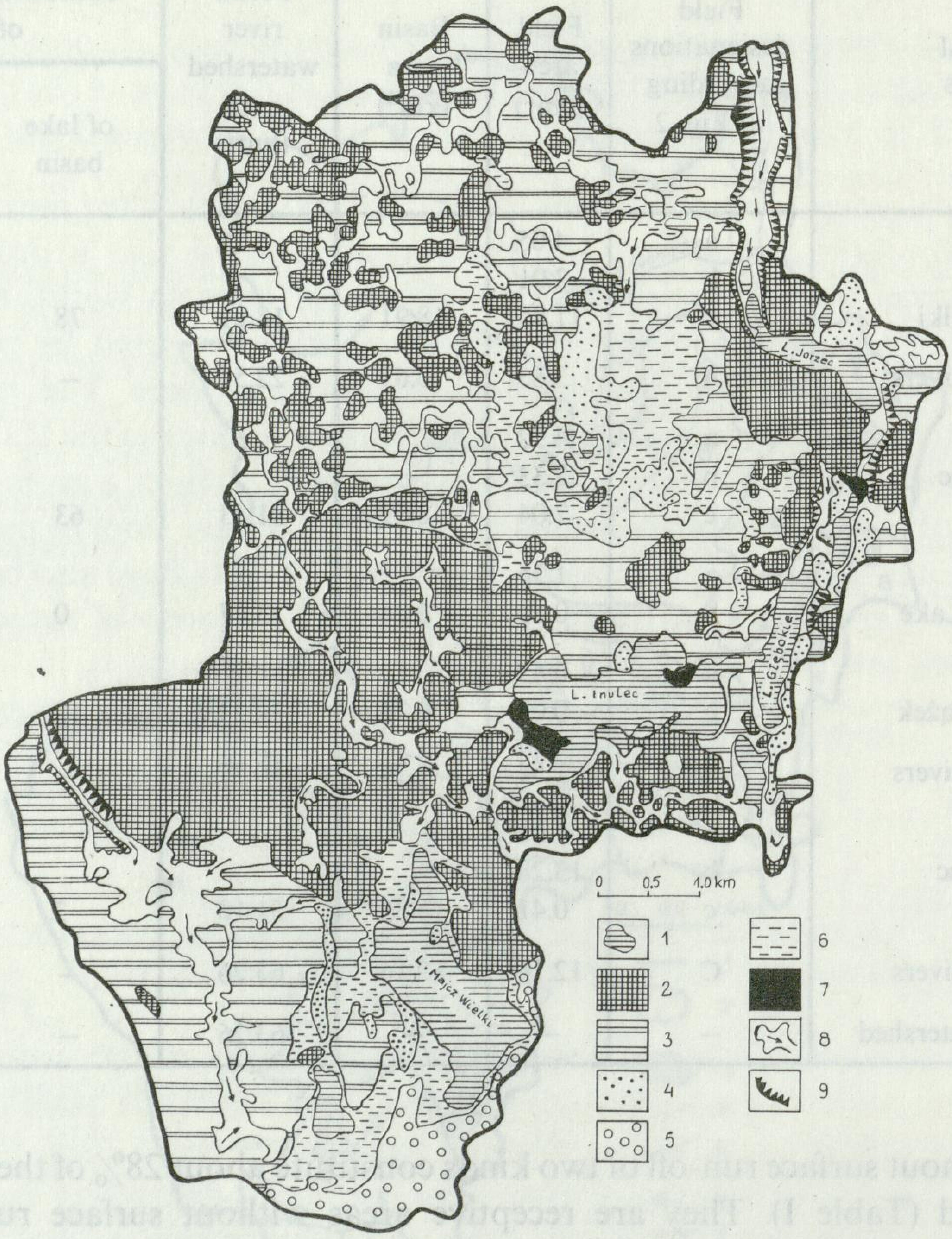

Fig. 3. A map of the river Jorka watershed relief
1 – lakes, 2 – ridges, hills and terminal and dead-ice moraine mounds, 3 – ground and ablation moraine plains, 4 – esker ridges, hills, ridges, kame mounds and kame terraces, 5 – sandy outwash plains, 6 – kettles, 7 – clear lake terraces made up of lacustrine clays and calcareous gyttjor, 8 – meltwater streamway valleys, 9 – channel slopes

The relief of the basin is reflected in the slope of the terrain. Terminal moraine hills, kames and eskers attain considerable absolute heights (from 160 to 206 m a.s.l.) and a gradient of 5 to 20°. Smaller gradient values (up to 5°) are found for ablation moraine plains, ground moraine plains, as well as for Holocene accumulation plains found in depressions. The greatest hypsometrical diversity occurs in the south-western part of the watershed (L. Majcz Wielki basin) and the south-eastern part (south of L. Inulec).

Of decisive importance to the physical geographic conditions, therein also hydrogeological conditions of the area under study are Quaternary (Pleistocene and Holocene) deposits. They determine the conditions for the water cycle in the basin, i.e., the magnitude of infiltration, surface and underground retention, and, indirectly, the surface run-off potential. Positively dominant among the surface deposits of the watershed considered is very-fine sandy loam and sandy loam with boulders, occupying 34% of the area, sandy soil with all sand fractions – 21% of the area, and peats – 10% of the watershed area. As the surface rocks, even of the same kind, differ in permeability, they have been divided into permeability classes according to Pazdro's (1977) classification, and each of the classes has been assigned a

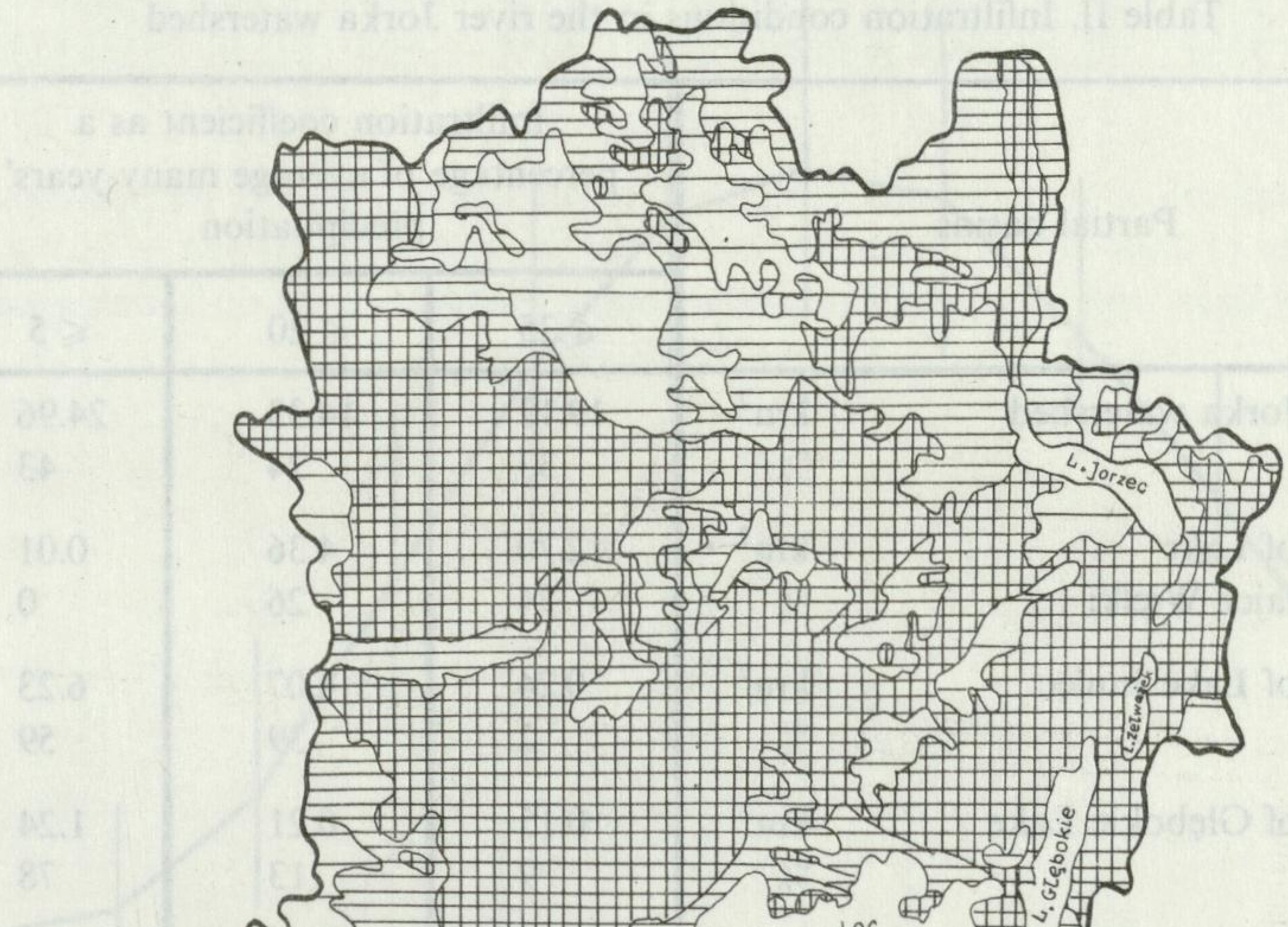

Fig. 4. A permeability map of surface deposits
1 – good permeability – up to 25% of precipitation infiltrates, 2 – intermediate permeability – up to 20% of precipitation infiltrates, 3 – poor permeability – up to 5% of precipitation infiltrates

coefficient of effective infiltration (Fig. 4). In about 43% of the watershed area poor infiltration conditions are found (up to 5% of precipitation sinks), in 33% of the area permeability is good (up to 25% of precipitation infiltrates), whereas in the remainder of the watershed, i.e., 24% of the area an intermediate permeability is found (up to 20% of precipitation infiltrates). The best conditions for percolation (Table II) exist in the southern part of the watershed, that is, in the basin of L. Majcz Wielki (in 74% of the basin area good conditions for infiltration prevail), the worst conditions are found in the basin of L. Zełwążek (94% of the basin has bad infiltration conditions). According to an approximate estimation, the average value of infiltration for the whole area of the river Jorka watershed amounts to 88 mm water a year. This corresponds to 242 $m^3 \cdot 24\ hours^{-1} \cdot km^{-2}$ of the watershed, but for the watershed area with the best infiltration conditions (L. Majcz Wielki basin) the respective values are 138 mm water a year, that is to say, 376 $m^3 \cdot 24\ hours^{-1} \cdot km^{-2}$ of watershed area.

Table II. Infiltration conditions in the river Jorka watershed

Partial basins		Infiltration coefficient as a percentage of average many-years' precipitation		
		⩽ 25	⩽ 20	⩽ 5
River Jorka watershed	km^2	19.17	14.33	24.96
	%	33	24	43
Basin of Lake Majcz Wielki	km^2	12.70	4.36	0.01
	%	74	26	0
Basin of Lake Inulec	km^2	0.24	4.07	6.23
	%	2	39	59
Basin of Głębokie Lake	km^2	0.15	0.21	1.24
	%	9	13	78
Basin of Lake Zełwążek	km^2	–	0.04	0.60
	%	–	6	94
Basin of Lake Jorzec	km^2	0.19	6.00	8.72
	%	1	40	59
Basin of Baranowska Struga river	km^2	0.19	5.15	7.94
	%	1	39	60
Basin of Struga Cudnochy river	km^2	–	**4.71**	6.17
	%	–	**43**	57

3.3. CLIMATIC CONDITIONS

The Jorka watershed, like the Great Masurian Lakes Region, to which it belongs climatically (K o n d r a c k i 1978), is characterized by a generally relatively cold (the number of frosty days comes up to about 50, days with ground-frost above 130, with snow cover up to 90), windy and wet (annual precipitation 525 – 600 mm, summer precipitation predominating) climate.

On the basis of weather data (average for the period 1951 – 1975) from the weather station of the Institute of Meteorology and Water Economy located on the Mikołajskie Lake about 10 km south-east of the opening of the Jorka river into L. Tałty, representative of the climatic conditions of the region, the following description can be given for the area under study:

(1) Mean annual air temperature +6.8°C (mean minimum +3.3°C, mean maximum +10.7°C, mean circadian amplitude 7.4°C), January temperature −4.4°C, July temperature +17.5°C. The widest circadian air temperature amplitudes (9 – 10°C) are recorded in the summer months (Fig. 5). Relative humidity, with a slight seasonal variation, ranges (on the average 81%) from 75 to 88%.

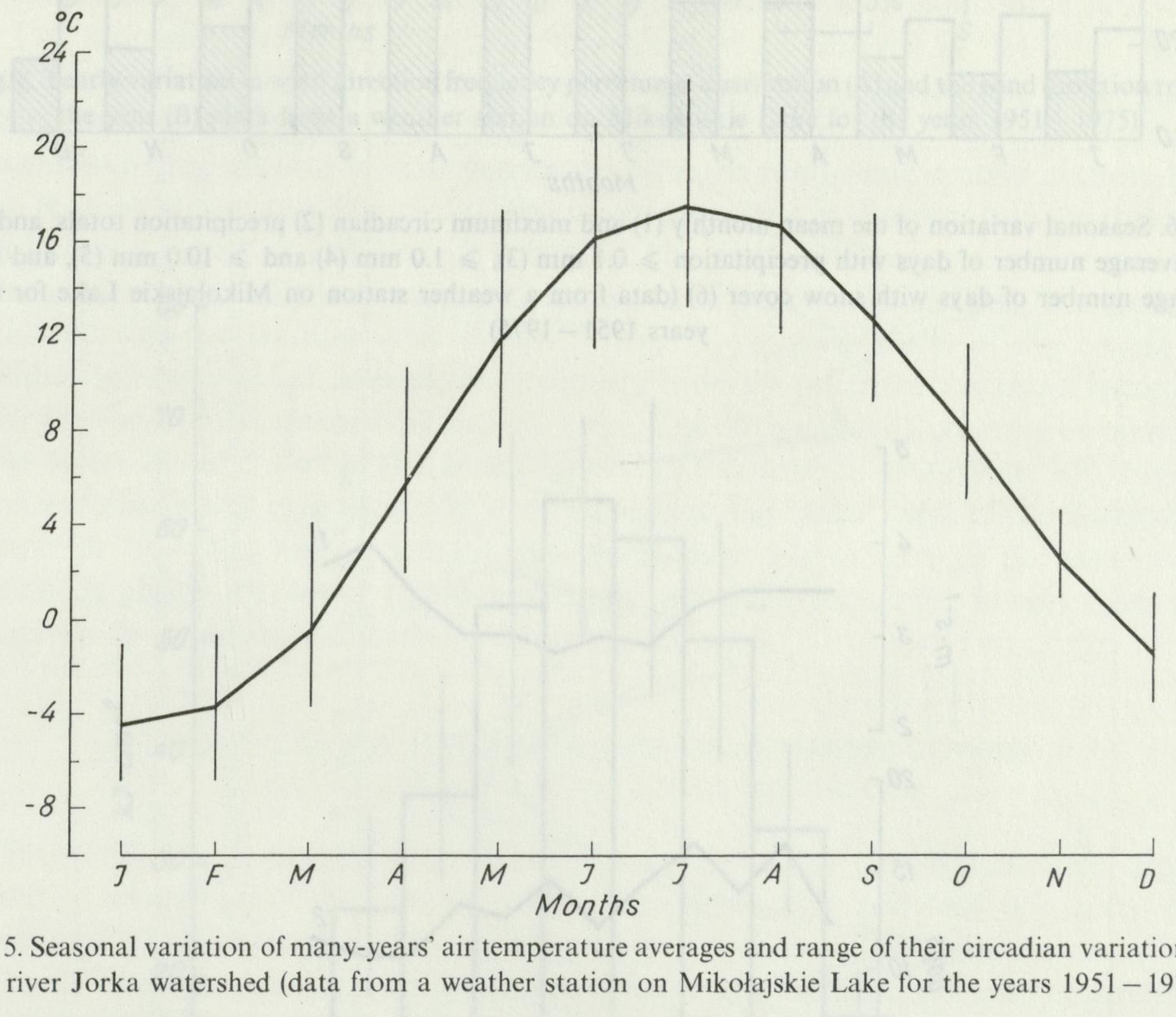

Fig. 5. Seasonal variation of many-years' air temperature averages and range of their circadian variation in the river Jorka watershed (data from a weather station on Mikołajskie Lake for the years 1951 – 1975)

(2) The growing season lasts 206 days (when the mean circadian air temperature is above 5.0°C), from April 10 to November 1.

(3) Mean annual precipitation total comes up to 580 mm, with the maximum monthly total (on the average 81 mm) occurring in June and the maximum circadian total in August (78.4 mm). There are 162 days with precipitation ⩾ 0.1 mm, therein 106 days with precipitation ⩾ 1.0 mm. The heaviest rains (above 10.0 mm) occur mainly in the months June-August (Fig. 6).

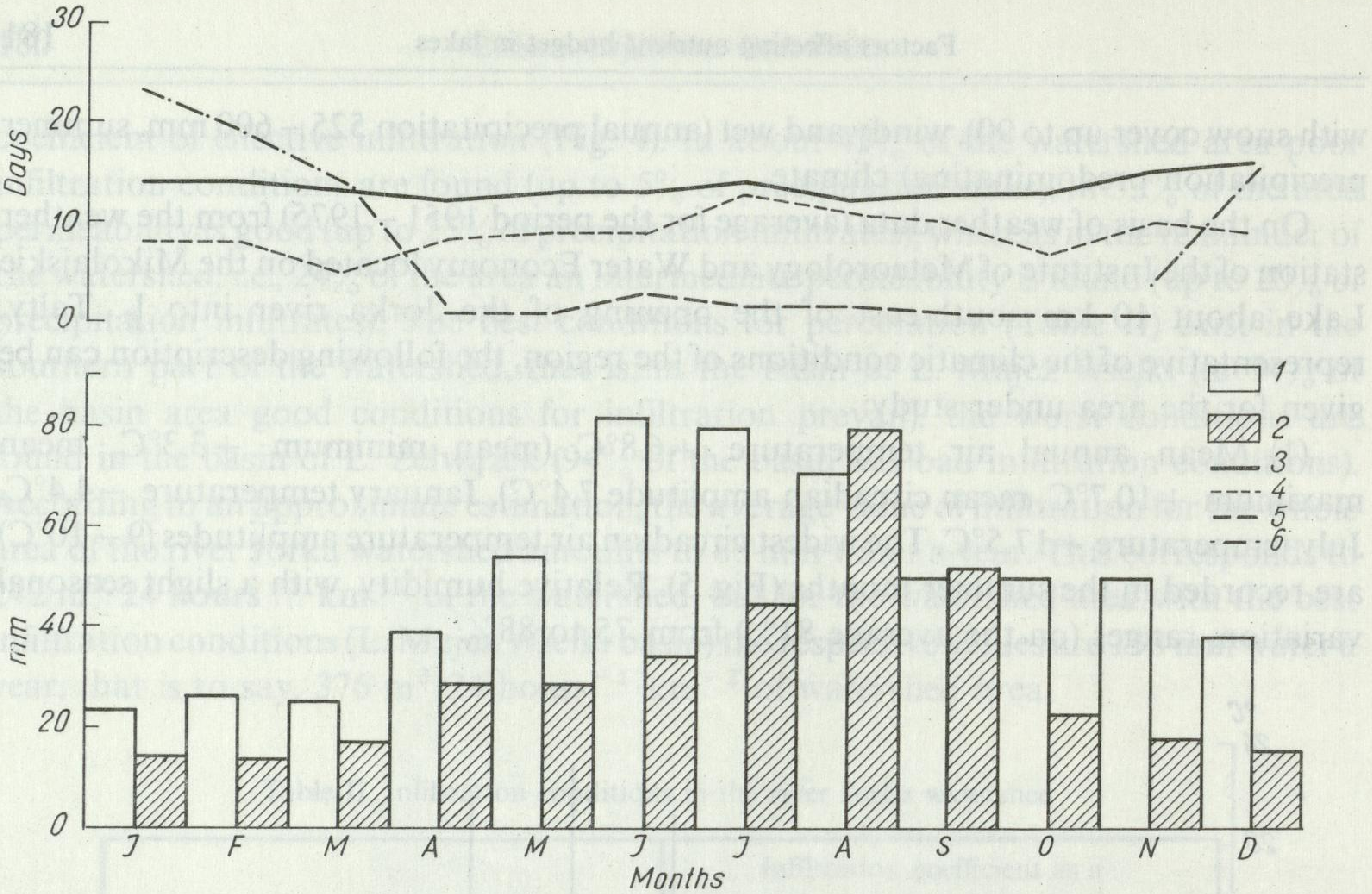

Fig. 6. Seasonal variation of the mean monthly (1) and maximum circadian (2) precipitation totals, and of the average number of days with precipitation ⩾ 0.1 mm (3), ⩾ 1.0 mm (4) and ⩾ 10.0 mm (5), and the average number of days with snow cover (6) (data from a weather station on Mikołajskie Lake for the years 1951 – 1975)

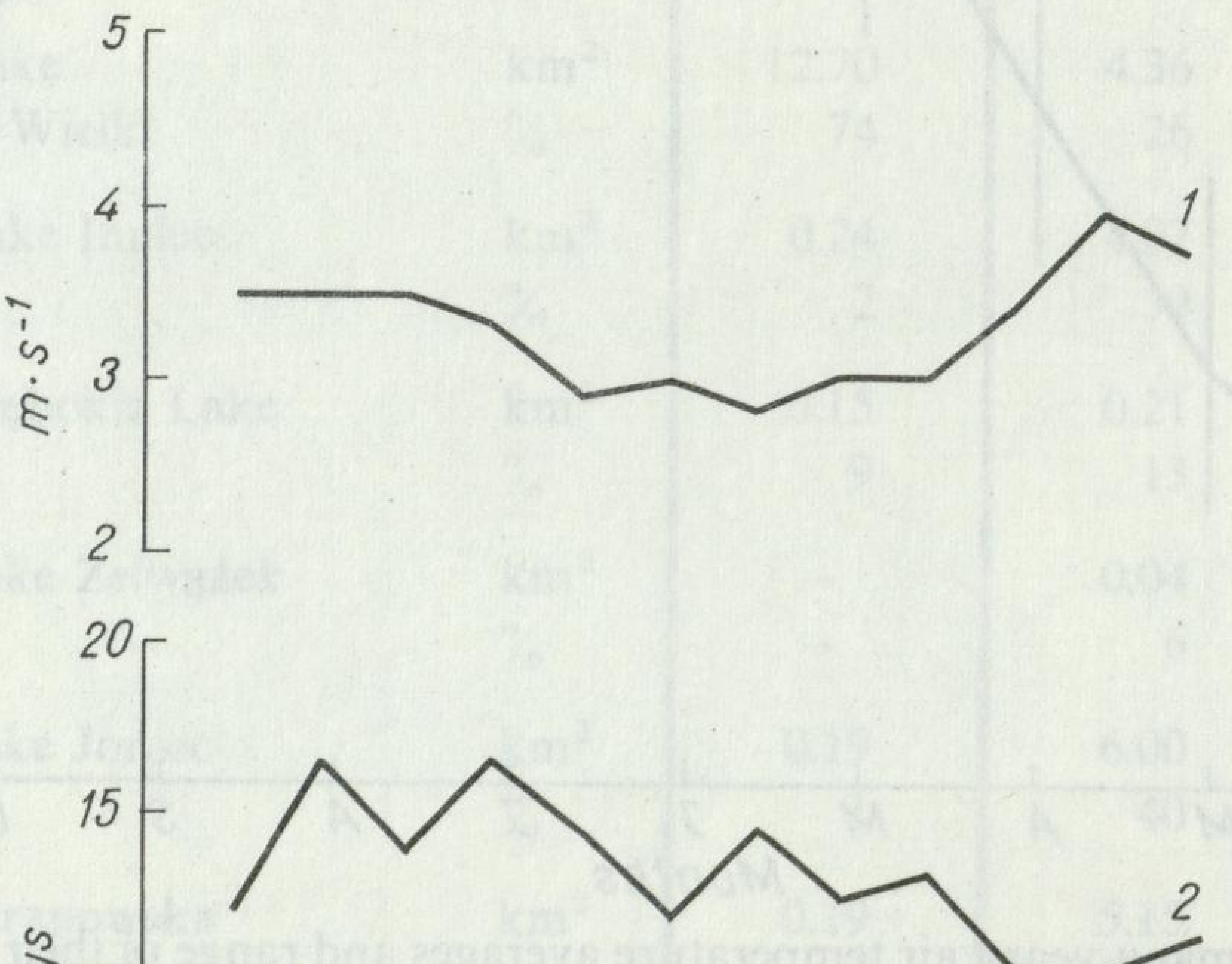

Fig. 7. Seasonal variation of mean circadian wind velocity (1) and of the number of stills (2) and the number of days with strong winds (⩾ 10 $m \cdot s^{-1}$) (3) (data from a weather station on Mikołajskie Lake for the years 1951 – 1975)

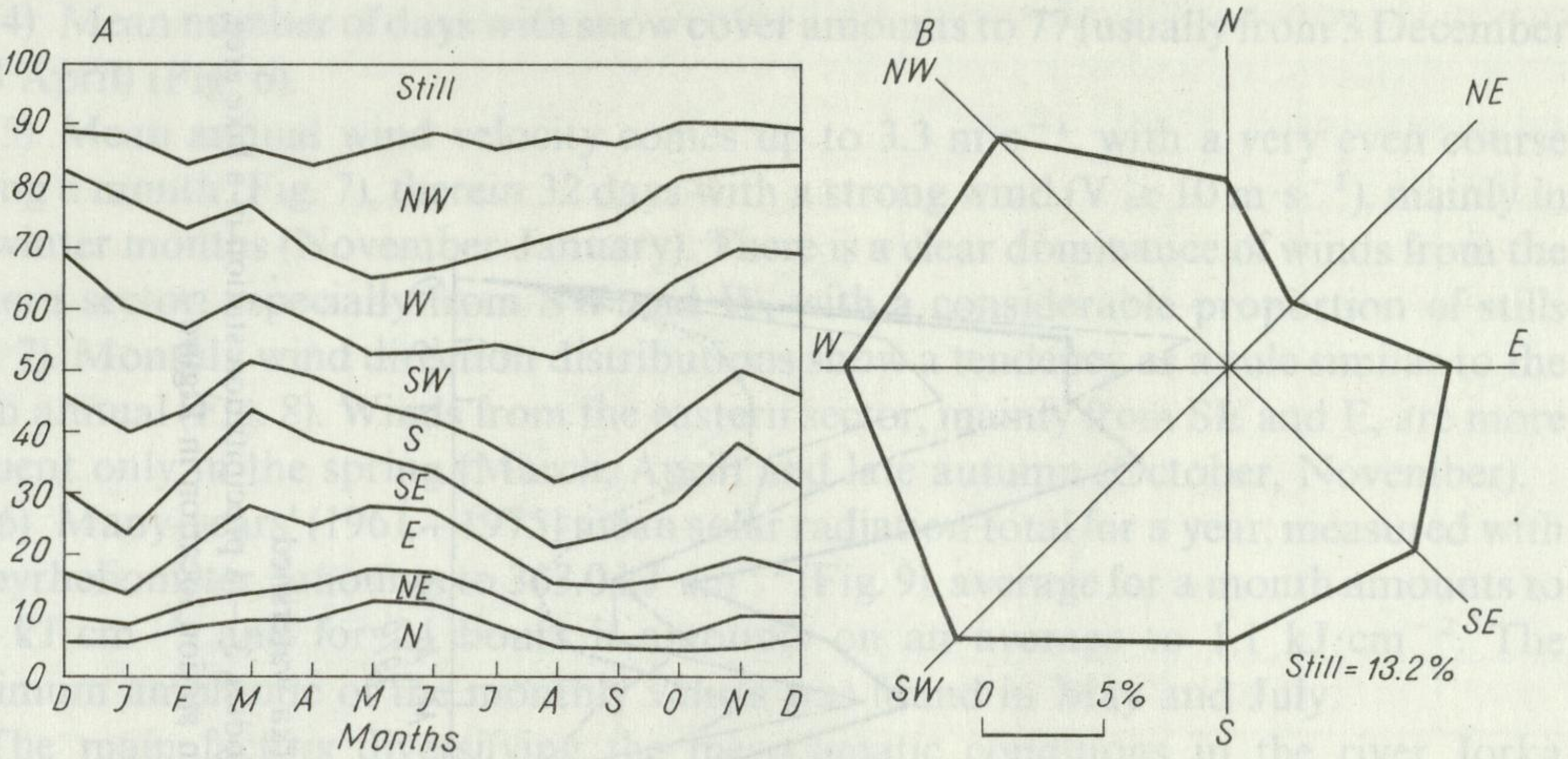

Fig. 8. Yearly variation in wind direction frequency percentage distribution (A) and the wind direction rose of the year (B) (data from a weather station on Mikołajskie Lake for the years 1951 – 1975)

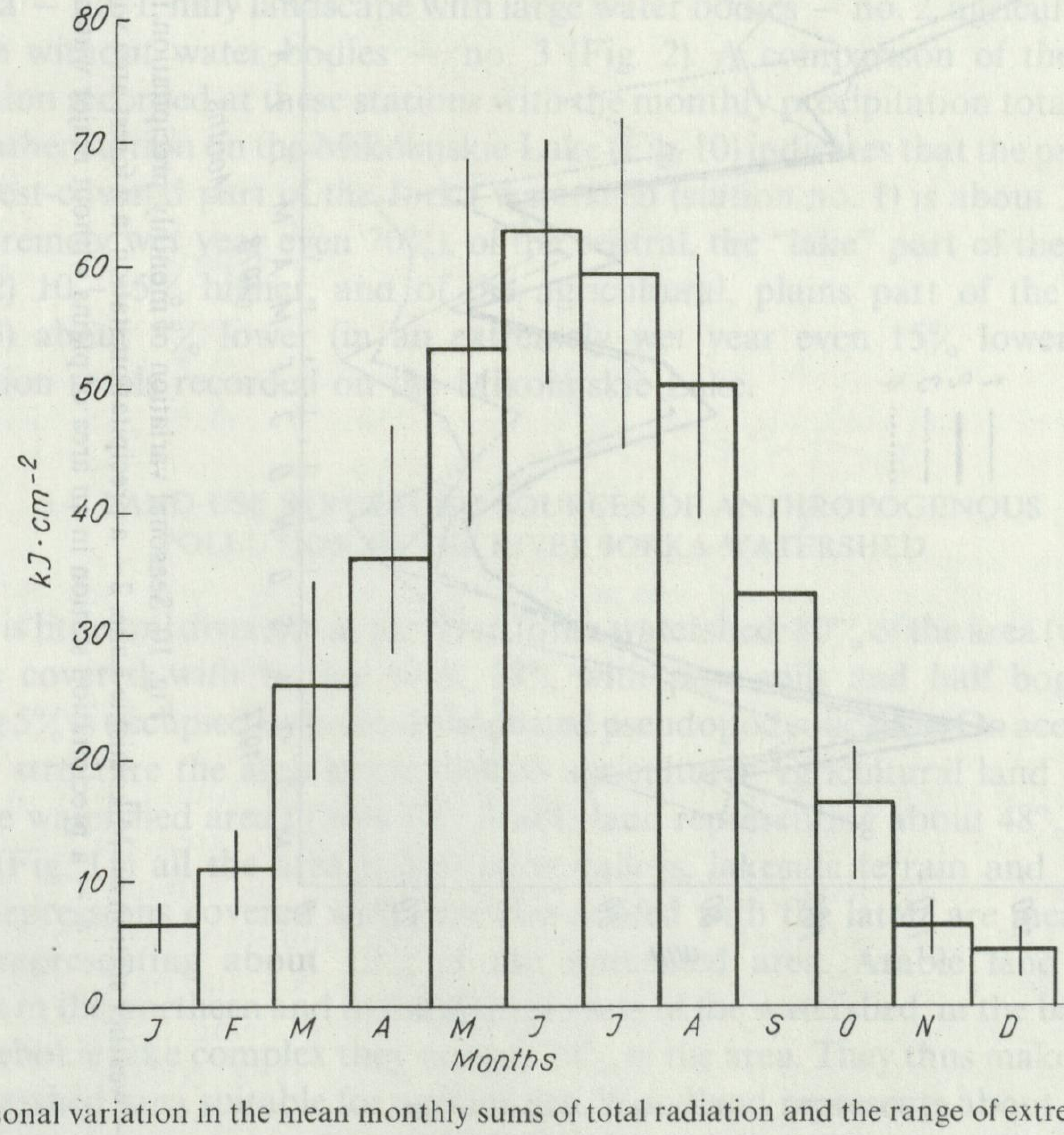

Fig. 9. Seasonal variation in the mean monthly sums of total radiation and the range of extreme changes in $kJ \cdot cm^{-2}$ (data from a weather station on Mikołajskie Lake for the years 1961 – 1975)

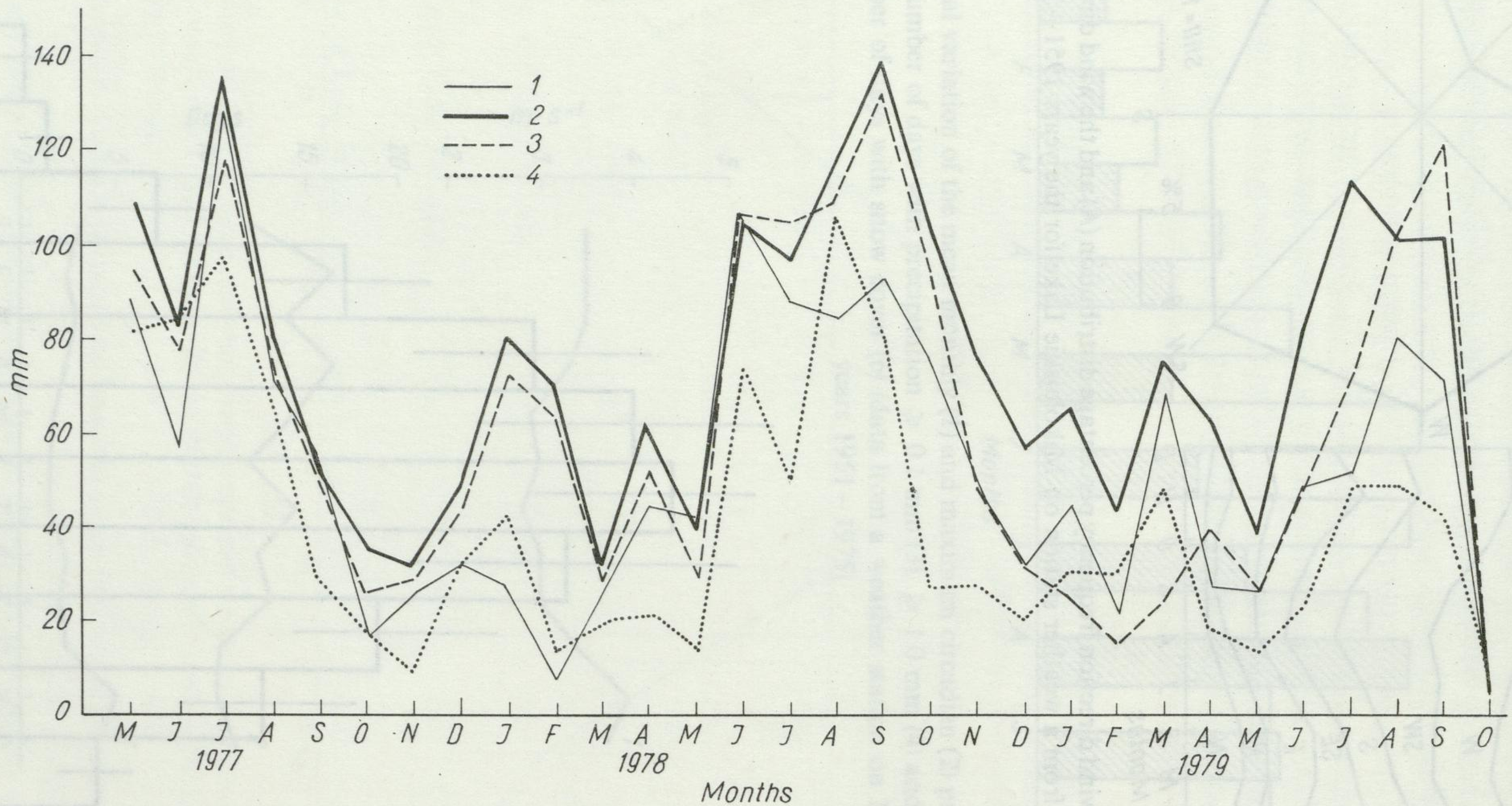

Fig. 10. Seasonal variation of monthly precipitation totals in the river Jorka watershed
1 – weather station on Mikołajskie Lake, 2 – a precipitation station in a forest area without major water bodies, 3 – a precipitation station in a lake area, 4 – a precipitation station in an area of plains without major water bodies; precipitation station location in Figure 2

(4) Mean number of days with snow cover amounts to 77 (usually from 3 December to 3 April) (Fig. 6).

(5) Mean annual wind velocity comes up to 3.3 $m \cdot s^{-1}$, with a very even course during a month (Fig. 7), therein 32 days with a strong wind ($V \geqslant 10\ m \cdot s^{-1}$), mainly in the winter months (November-January). There is a clear dominance of winds from the western sector, especially from SW and W, with a considerable proportion of stills (Fig. 7). Monthly wind direction distributions show a tendency as a rule similar to the mean annual (Fig. 8). Winds from the eastern sector, mainly from SE and E, are more frequent only in the spring (March, April) and late autumn (October, November).

(6) Many-years' (1961 – 1975) mean solar radiation total for a year, measured with the pyrheliometer, amounts to 363.0 $kJ \cdot cm^{-2}$ (Fig. 9), average for a month amounts to 30.3 $kJ \cdot cm^{-2}$, and for 24 hours it amounts on an average to 1.1 $kJ \cdot cm^{-2}$. The maximum amplitude of the monthly values was found in May and July.

The main factors diversifying the mesoclimatic conditions in the river Jorka watershed are the cover of the terrain (closed-canopy forest complexes, larger water bodies, marsh plains) and the nature of the relief (landscape of hills, landscape of plains). The climatic element that is most dependent on these conditions is precipitation. For these reasons, three pluviometric stations have been set up in the river Jorka watershed (Bajkiewicz-Grabowska 1985). The stations represent: closed-canopy forest area – no. 1, hilly landscape with large water bodies – no. 2, agricultural plains landscape without water bodies – no. 3 (Fig. 2). A comparison of the course of precipitation recorded at these stations with the monthly precipitation totals recorded at the weather station on the Mikołajskie Lake (Fig. 10) indicates that the precipitation of the forest-covered part of the Jorka watershed (station no. 1) is about 20% higher (in an extremely wet year even 70%), of the central, the "lake" part of the watershed (station 2) 10 – 15% higher, and of the agricultural, plains part of the watershed (station 3) about 5% lower (in an extremely wet year even 15% lower) than the precipitation totals recorded on the Mikołajskie Lake.

3.4. LAND-USE STRUCTURE; SOURCES OF ANTHROPOGENOUS POLLUTION IN THE RIVER JORKA WATERSHED

There is little soil diversity in the river Jorka watershed: 80% of the area (without the forests) is covered with brown soils, 15% with peat soils and half bog soils, the remaining 5% is occupied by podzolic soils and pseudopodzolic soils. On account of the soil cover structure the area lends itself to agriculture. Agricultural land constitutes 58% of the watershed area (Table III), arable land representing about 48% thereof. It occupies (Fig. 11) all the area except river valleys, lakeside terrain and larger flat-floored depressions covered with peat. Associated with the latter are meadows and pastures representing about 12% of the watershed area. Arable land positively dominates in the northern and in the central parts of the watershed: in the basins of the Inulec-Głębokie lake complex they occupy 74% of the area. They thus make about 2/3 of the watershed area suitable for agriculture. Woodland represents about 30% of the area, and forms, in essence, only one closed complex in the south-western and southern parts of the area considered, mainly in the basin of L. Majcz Wielki (68% of the area). In the northern, agricultural part of the watershed there are only small wood islands and woody scrub around lakes.

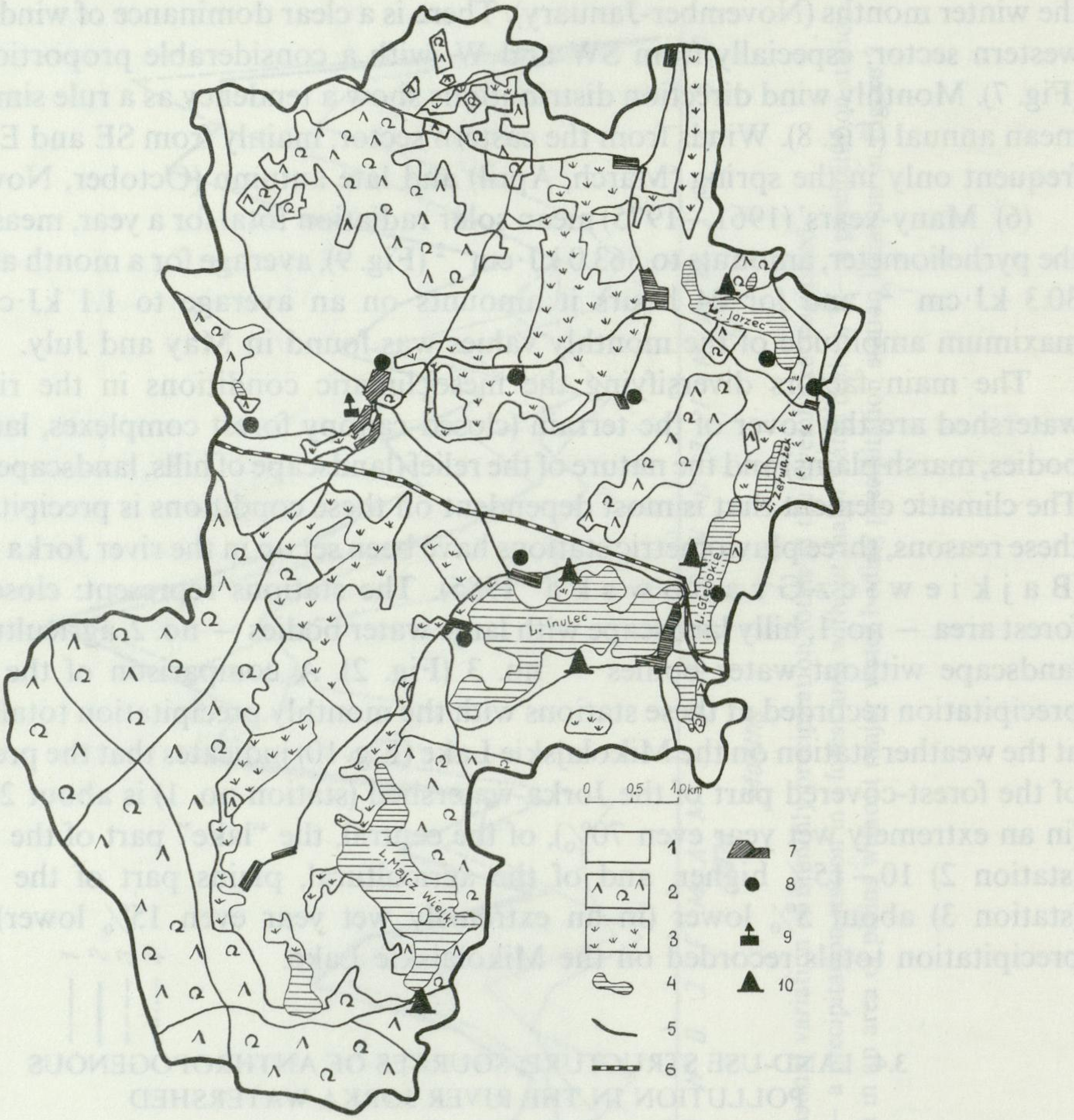

Fig. 11. Land use structure and main pollution sources in the river Jorka watershed
1 — arable land, 2 — forests, 3 — meadows and pastures, 4 — lakes, 5 — roads, 6 — railway, 7 — compact building, 8 — animal-raising farms, 9 — distillery, 10 — bivouac sites

In the forest complex there mainly coniferous trees are found, with a positive predominance of the pine (about 85% of the woodland area), a considerable contribution of the spruce (about 5%), birch (about 6%), oak (about 2%) and alder (about 2%). The dominant forest habitat type is the medium-moist pine forest (about 59% of the forest area of the watershed), where the main tree stand bulk consists of the pine, spruce and oak, the hornbeam, birch and linden being admixture species. Another, also frequent habitat type is the mixed forest type, covering 30% of the woodland in the watershed, with the pine, spruce and oak as the main species, and an

Table III. Land use in the river Jorka watershed and in selected lake basins

Land used as	River Jorka watershed		Basin of Lake Majcz Wielki		Basin of lakes Inulec-Głębokie		Basin of Lake Jorzec		Basin of Baranowska Struga river	
	km²	%	km²	%	km²	%	km²	%	km²	%
Forests	19.10	30.2	12.92	68.3	1.26	8.6	0.19	9.3	1.31	9.9
Arable land	28.85	45.6	2.91	15.4	9.00	61.7	1.38	67.3	7.96	60.0
Grassland	7.28	11.5	1.17	6.2	1.75	12.0	0.05	2.4	3.72	28.0
Surface waters	4.80	7.6	1.84	9.7	2.42	16.6	0.41	20.0	0.01	0.1
Others (buildings, roads)	3.23	5.1	0.07	0.4	0.16	1.1	0.02	1.0	0.28	2.0
Total	63.26	100	18.91	100	14.59	100	2.05	100	13.28	100

admixture of the hornbeam and birch. There also occur a moist mixed forest (4% of the area) and medium-moist woodland (3% of the forest area of the watershed).

Surface waters, primarily lakes, occupy 8% of the watershed area, whereas the remaining 5% includes built-up areas and roads (Table III).

There is a clear diversity of arable land structure, crop type and nature of agriculture in the watershed. In the northern part of the watershed (north of L. Głębokie), in about 2/3 of the agricultural land, multi-hectare fields predominate, with an average fertilizing rate of about 300 kg of NPK per 1 ha and 5 tons of Ca per 1 ha. In the southern part of the watershed (near L. Inulec and L. Majcz Wielki) about 1/3 of the agricultural land is in the hands of individual holders of farms of several hectares each, applying about 100 – 150 kg of NPK per 1 ha, and about 2 – 3 tons of Ca per 1 ha.

Grains, mainly wheat (about 18%) and barley (about 16%) occupy 60% of the arable land, oats and corn playing a secondary role. Root crops, including potatoes and beets, occupy about 20% of the arable land; industrial plants, primarily rape, about 15%, the remaining 5% being used for growing fodder crops, such as alfalfa, corn and vetch.

Apart from animal husbandry by individual land holders, in the river Jorka watershed there are farms (Fig. 11) rearing cattle, pigs, sheep, coypus and foxes. In Głębokie L. rainbow trouts are reared in cage cultures (P e n c z a k et al. 1985). In the years 1977 – 1979, the total number of animals (apart from fish) reared in the area under study was as follows: cows and fat cattle 1750 heads, 1400 pigs, 5300 sheep, 120 horses, coypus and foxes 500 heads, 4200 hens, 1600 ducks, 1100 geese. A large proportion (about 70 – 90%) of the stock of cows, cattle, pigs and sheep is concentrated at several points (Fig. 11), on animal husbandry farms, several hundred on each. Liquid manure is used to fertilize fields near the farm buildings.

In the river Jorka watershed there are a number of villages and several score isolated farms where a total number of 1200 resident inhabitants live, which gives a population density of 18 inhabitants per 1 km² of the watershed area, therein about 10 persons per 1 km² in the basin of L. Majcz Wielki, and twice as many – about 22 persons per 1 km² in the remaining area. There are several permanent bivouac sites

Table IV. Approximate assessment of nutrient load to the river Jorka watershed according to the main sources of pollution*

Source of pollution	Numbers present in the watershed	Adopted quantity expressions per capita**	Assessment	
			in kg·year^{-1}· entire watershed^{-1}	in kg·year^{-1}· 1 ha watershed^{-1}
1. Resident population	1200 persons·year^{-1}	N – 12 g·person^{-1}·24 hrs^{-1}	N – 5256	N – 0.831
		P – 3 g·person^{-1}·24 hrs^{-1}	P – 1314	P – 0.208
2. Tourists	20 persons·90 days = = 1800 person-days		N – 21.6	N – 0.003
			P – 5.40	P – 0.001
3. Animals:				
sheep	5300 heads·year^{-1}	N – 8.93 kg·year^{-1}	N – 47329	N – 7.48
		P – 1.50 kg·year^{-1}	P – 7950	P – 1.26
cattle	1750 heads·year^{-1}	N – 70.2 kg·year^{-1}	N – 122850	N – 19.4
		P – 1.50 kg·year^{-1}	P – 13387.5	P – 2.12
pigs	1400 heads·year^{-1}	N – 18.93 kg·year^{-1}	N – 26502	N – 4.19
		P – 5.63 kg·year^{-1}	P – 7882	P – 1.26
horses	120 heads·year^{-1}	N – 76.8 kg·year^{-1}	N – 9216	N – 1.46
		P – 11.4 kg·year^{-1}	P – 1368	P – 0.216
poultry	7900 heads·year^{-1}	N – 0.55 kg·year^{-1}	N – 4345	N – 0.69
		P – 0.20 kg·year^{-1}	P – 1580	P – 0.25
4. Fertilizing:				
state-owned farms	ab. 2400 ha	N – 106 kg·year^{-1}·ha^{-1}	N – 254400***	N – 40.2
		P – 78 kg·year^{-1} ha^{-1}	P – 187200***	P – 29.6
individual holdings	ab. 1200 ha	N – 56 kg·year^{-1}·ha^{-1}	N – 67200***	N – 10.6
		P – 38 kg·year^{-1}·ha^{-1}	P – 45600	P – 7.2

*Without fish-farming. **For people acc. to Liebmans, for animals acc. to Vollenweider (after K a j a k 1979). ***In kg·year^{-1} per arable land area.

on the lake-sides there (Fig. 11) which about 20 person a day visit during the three summer months every year. The villages and individual farms have no sewer system.

The map of points of a heavy pollution in the watershed, that is, larger concentrations of people, bivouac sites and animal husbandry farms, includes a distillery which has a mechanical treatment plant discharging its effluents via the Baranowska Struga river into L. Jorzec (Fig. 11).

By using Liebmans's per capita rates for human beings (after F l o r c z y k, G o ł o w i n and S o l s k i 1975), and Vollenweider's per capita (after K a j a k 1979) for animals (except fish culture and coypu farms) the total loading of the basin with N and P per ha has been estimated approximately as the total (in kg) of the two nutrients polluting the waters and derived from fertilization, settlement, animal rearing and tourism (Table IV). This quantity comes up to about 84 kg N and 43 kg P per 1 ha of the watershed, except the lake area, per year.

3.5. CHARACTERISTICS OF THE HYDROGRAPHIC ENTITIES

Lakes are the dominant hydrographic entities in the river Jorka watershed. They play the basic role in the determination of the water relations in the basin: they are the source of potential evaporation, natural storage reservoirs exerting a draining effect on the underground waters of the watershed, and they control the magnitude of the outflow. Their joint area comes up to 4.8 km^2, constituting 8% of the watershed area. These lakes differ from one another in the parameters describing their shape, depth, basin relief (Table V, Figs. 12–16), and in the impact of the watershed on them (Table VI).

The largest of the lakes ($A > 150$ ha) are L. Majcz Wielki and L. Inulec (Table V), the deepest ($z_{max} \geqslant 30$ m) Głębokie L. (Fig. 14), the shallowest ($z_{max} \geqslant 7$ m) and at the same time the smallest ($A > 20$ ha) are: L. Majcz Mały and L. Zełwążek (Fig. 15) and L. Płociczno.

The highest value of the shoreline complication index ($z:z_{max} > 2$) is found for L. Inulec and L. Jorzec (Table V). Głębokie L. (Fig. 14), L. Płociczno, L. Zełwążek (Fig. 15) and L. Jorzec (Fig. 16) are of the type of sub-glacial channels, whereas the remaining three, i.e., L. Majcz Mały, L. Majcz Wielki (Fig. 12) and L. Inulec (Fig. 13) are kettle-hole lakes. Five of the seven lakes described in Table V have been studied thoroughly (L. Majcz Wielki, L. Inulec, Głębokie L., L. Zełwążek and L. Jorzec), so they will be discussed in more detail in a further part of this.

The potential impact of the watershed on the particular lakes and their role in the water cycle in the basin has been described on the basis of several indices (Table VI). O h l e's i n d e x, known in hydrology as the lake ratio (P a s ł a w s k i 1975), is the quotient of the total lake basin area divided by the lake area. S c h i n d l e r's i n d e x is the quotient of the total lake basin area divided by the capacity of the lake hollow. This index describes the ratio of the total area "catching" the matter supplying a lake to the "diluting" factor, the bulk of water (the greater the index, the stronger the dependence of the lake on the basin). T h e l a k e a r e a i n d e x (B o g o s l o v s k i j 1960) is the quotient of the lake area divided by the area of its

Table V. Morphometric parameters of river Jorka watershed lakes (according to data of The Inland Fisheries Institute)

Lake	Lake area (including) an island) A (km^2)	Maximum length L max (km)	Maximum breadth B max (km)	Elongation $\frac{L\ max}{B\ max}$	Maximum depth z_{max} (m)	Average depth $\bar{z}$ (m)	Depth index $\frac{\bar{z}}{z_{max}}$	Shoreline complication $\frac{L}{2\sqrt{\pi A}}$	Shoreline complication $\frac{L}{A}$ ($m \cdot ha^{-1}$)
Majcz Mały	0.2	0.75	0.35	2.1	3.3	1.8	0.54	1.3	100
Majcz Wielki	1.74	2.70	1.20	2.2	16.4	6.0	0.36	1.8	50
Inulec	1.61	2.40	0.90	2.6	10.1	4.6	0.46	2.4	61
Głębokie	0.46	1.80	0.41	4.4	34.3	11.8	0.34	1.6	93
Płociczno	0.17	0.87	0.33	2.6	4.7	2.3	0.49	1.5	128
Zelwążek	0.12	0.80	0.20	4.0	7.4	3.7	0.50	1.5	157
Jorzec	0.41	1.84	0.30	6.1	11.6	5.5	0.47	2.1	101

Table VI. Indices of lake dependence on the basin

Lake	Lake area A(km^2)	Area of the lake's immediate basin Az (km^2)	Area of river Jorka basin up to the outflow from the lake Ac (km^2)	Lake volume V (10^6 m^3)	Ohle's index $Ac \cdot A^{-1}$	Schindler's index $Ac \cdot V^{-1}$	Weighed lake rate $\frac{A_1Az_1 + ... + A_nAz_n}{Ac^2}$
Majcz Wielki	1.74	18.91	18.91	10.5	10.8	1.96	0.9
Inulec	1.61	12.32	31.23	7.61	19.4	4.1	1.4
Głębokie	0.46	2.24	33.47	5.31	72.8	6.3	1.4
Zelwążek	0.12	0.76	34.23	0.42	285	8.2	1.5
Jorzec	0.41	15.33	51.30	2.20	125	23.3	1.6

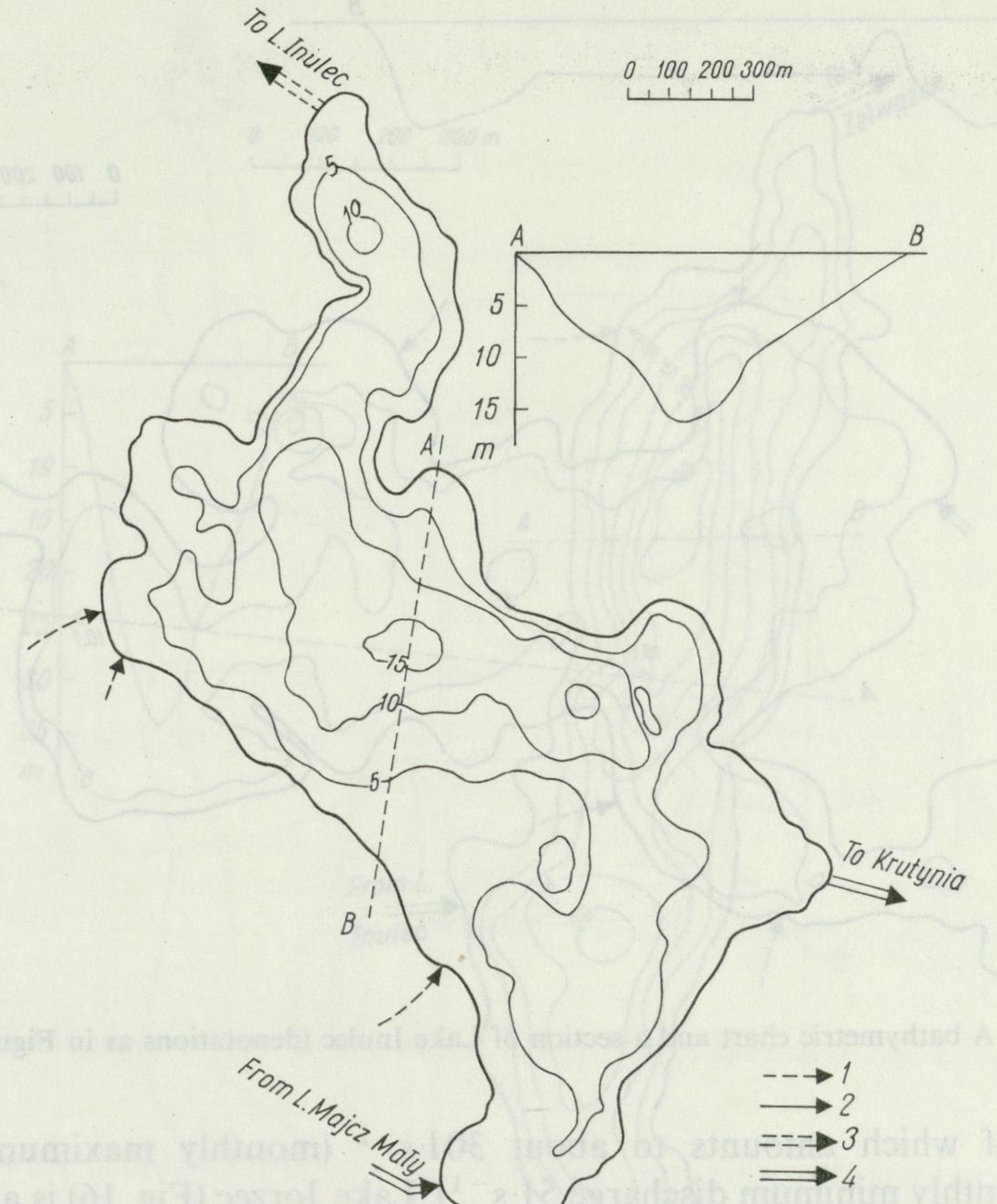

Fig. 12. A bathymetric chart and a section of Lake Majcz Wielki
1 – seasonal streams, 2 – permanent streams (in addition to the Jorka river), main inflow and outflow (river Jorka) functioning seasonally (3) and permanently (4)

basin. It may be indicative of the role of a lake in the water cycle in its basin. The weighted lake ratio is the quotient of the sum in succession of the products of the lake surface area and its surface basin divided by the square of the total basin area. The value of this index depends on the position of a lake in the basin – it attains the largest value for a lake located on the course of the main river in the lower part of the basin, whereas for lakes situated closer to the divide zone its value is lower.

The highest values of Ohle's, Schindler's indices and of the weighted lake ratio are recorded for lakes situated along the lower course of the Jorka river, i.e., L. Zełwążek and L. Jorzec (Table VI). They are, therefore, lakes showing the highest relative dependence on the basin. The effect of the basin on the remaining lakes is relatively lower – the lowest for Głębokie L. (Table VI).

A measure of the potential impact of the basin on a lake may also be the number of watercourses entering it (Table VII, Figs. 12–16). Lake Inulec is supplied by two permanent watercourses, therein by the river Jorka (Fig. 13), the annual average

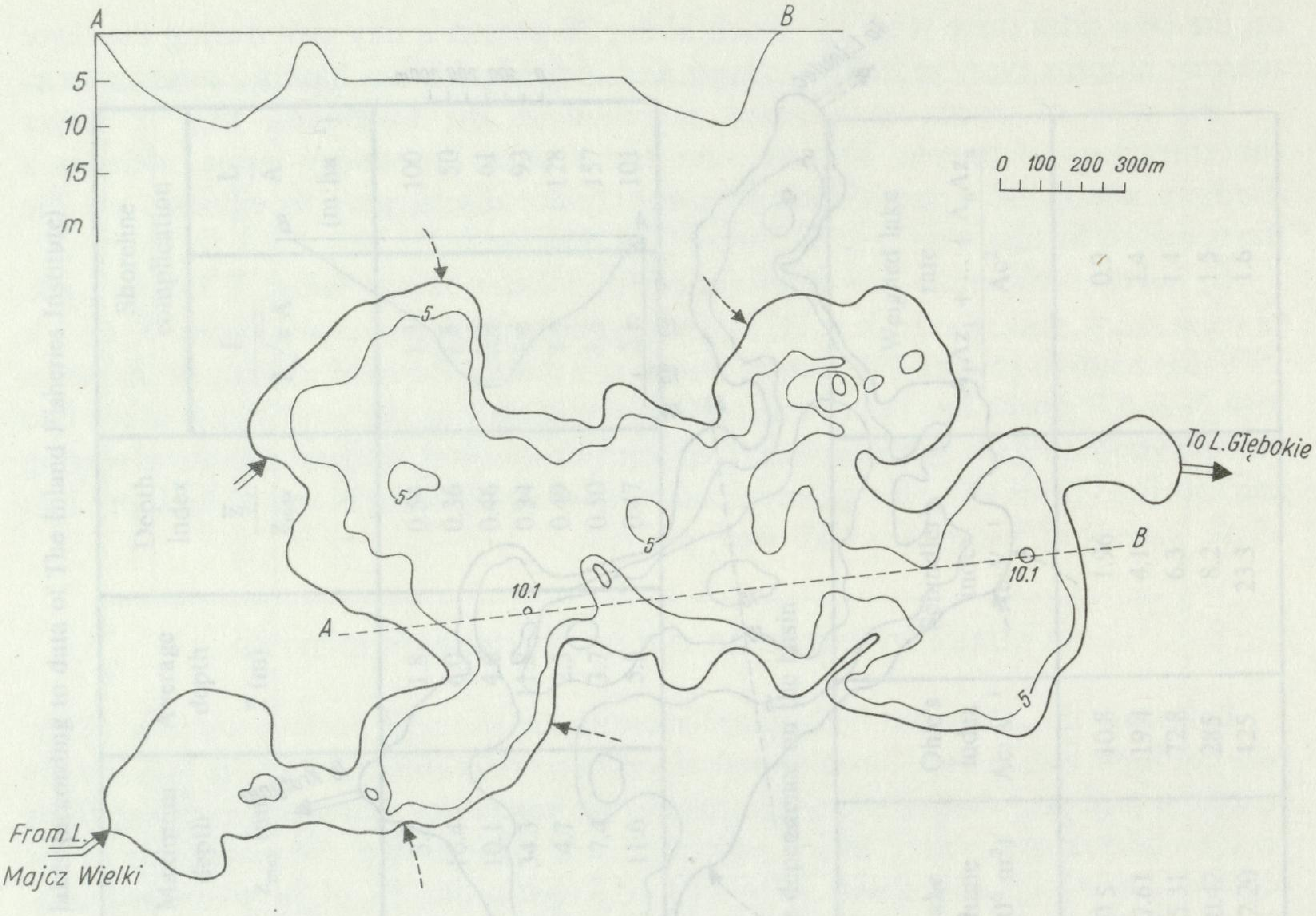

Fig. 13. A bathymetric chart and a section of Lake Inulec (denotations as in Figure 12)

discharge[2] of which amounts to about 30 l·s^{-1} (monthly maximum discharge 175 l·s^{-1}, monthly minimum discharge 5 l·s^{-1}). Lake Jorzec (Fig. 16) is also supplied by two permanent watercourses: the Jorka river (with an annual average discharge of 114 l·s^{-1}, monthly maximum discharge 1400 l·s^{-1}, monthly minimum discharge 9 l·s^{-1}) and the Baranowska Struga river (annual average discharge 80 l·s^{-1}, monthly maximum discharge 350 l·s^{-1}, monthly minimum discharge 16 l·s^{-1}). Głębokie L. (Fig. 14) is fed by three watercourses, including two permanent ones, one of which is the Jorka river (annual average discharge 110 l·s^{-1}, monthly maximum discharge 750 l·s^{-1}, monthly minimum discharge 19 l·s^{-1}), and the other is the inflow from L. Płociczno (annual average discharge of the order of 31 l·s^{-1}). L. Zełwążek (Fig. 15) is only fed by the Jorka river. In dry periods (the autumn of 1976) the river may dry up completely. In 1978, 1979, when hydrometric checking was carried out, the annual average discharge of the Jorka river above L. Zełwążek was 120 l·s^{-1}. Lake Majcz Wielki (Fig. 12) is supplied only by seasonal watercourses.

The heaviest "load" per lake surface area by watercourses functioning throughout the year is found for L. Jorzec (207 m·ha^{-1}) and Głębokie L. (96 m·ha^{-1}), and the highest load by seasonal watercourses for L. Zełwążek (570 m·ha^{-1}) (Table VII). At a low water state the lakes of the river Jorka watershed become seasonally through-flow

[2] Average values for 1978, 1979 (acc. to Bajkiewicz-Grabowska 1985).

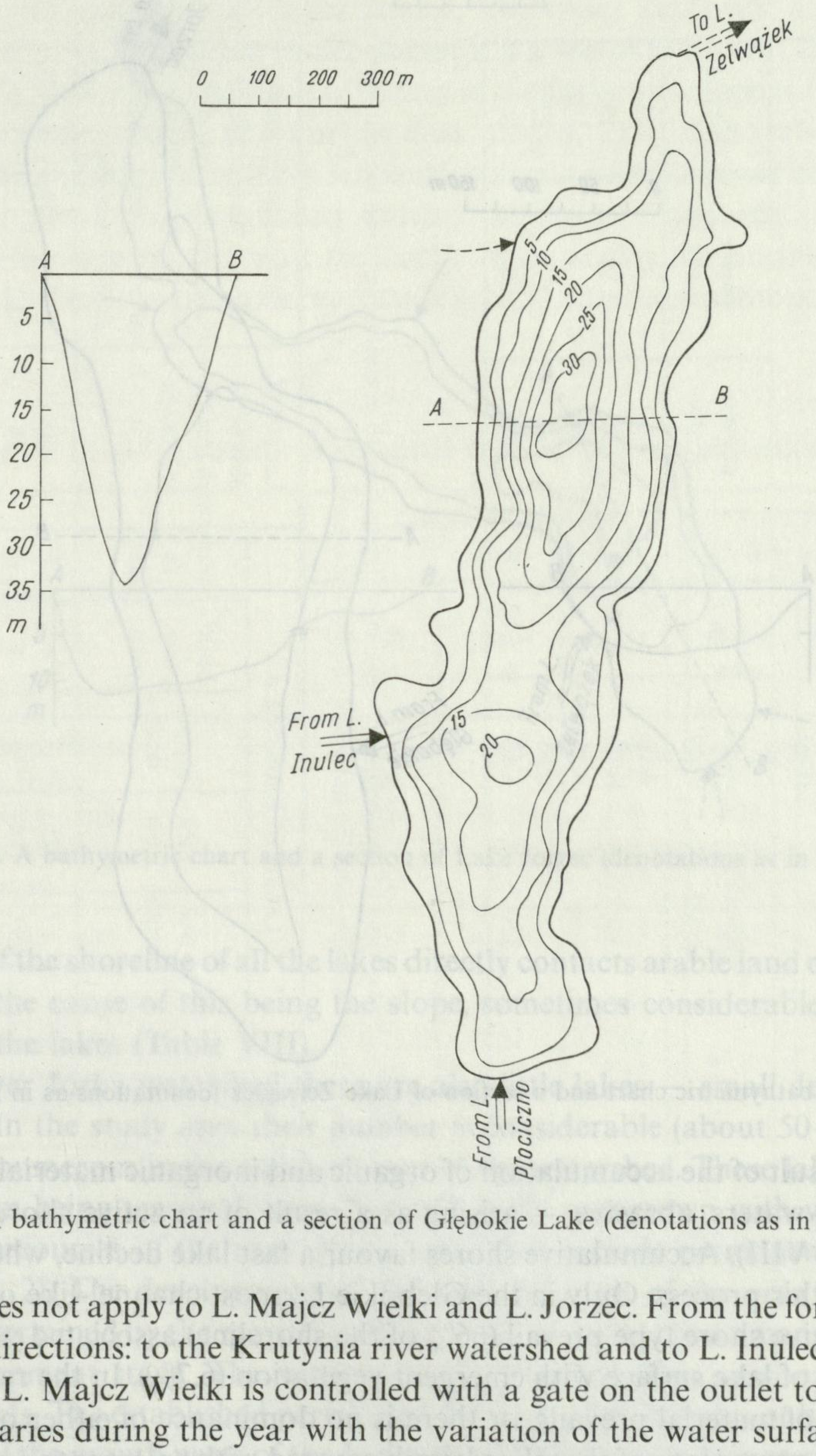

Fig. 14. A bathymetric chart and a section of Głębokie Lake (denotations as in Figure 12)

lakes. This does not apply to L. Majcz Wielki and L. Jorzec. From the former the water flows in two directions: to the Krutynia river watershed and to L. Inulec (Fig. 12). The outflow from L. Majcz Wielki is controlled with a gate on the outlet to the Krutynia river, and it varies during the year with the variation of the water surface level in the lake. As a rule more water flows towards the Krutynia river (2/3 of the total outflow). Lake Jorzec is an outflow water body, and it is from it that the permenent course of the Jorka river begins. Connections between the remaining lakes function seasonally, depending on the hydrometeorological situation, due to which the potential effect of the basin located at a higher level on these lakes is seasonally limited.

The lakes of the river Jorka differ from one another in the conditions prevailing in the shore- and littoral zones. According to Drwal and Gołębiowski (1968), three geomorphological types of shore can be distinguished: accumulative –

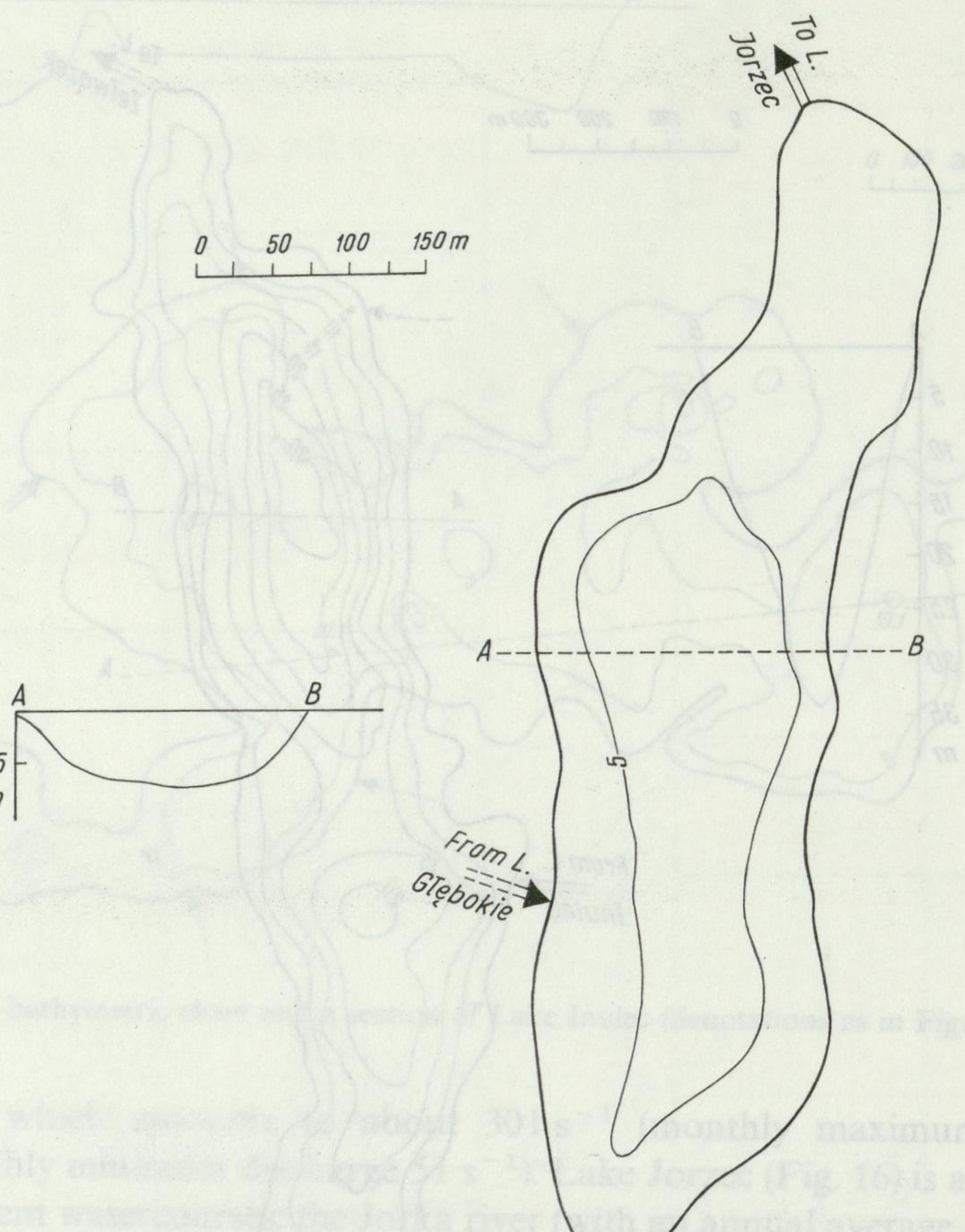

Fig. 15. A bathymetric chart and a section of Lake Zełwążek (denotations as in Figure 12)

formed as a result of the accumulation of organic and inorganic material brought with river and lake waters, abrasive – arising as a result of an active shore erosion, and neutral (Table VIII). Accumulative shores favour a fast lake decline, whereas abrasive shores retard this process. Only in the Głębokie L., most channel-like of all the lakes, does the abrasive shore type prevail (66% of the shoreline) associated with the lowest per cent cover of lake surface with emergent vegetation (6.7%). In the remaining lakes accumulation of material prevails, or there is no dominance of either of the opposite processes. The percentage of shoreline length covered with emergent vegetation is very high (85–94%) everywhere, and the cover of the lake surface by this vegetation comes up to 12–23%. The highest index values are found for the pond-type. L. Zełwążek (Table VIII). A considerable proportion (up to 68%) of the shoreline of the lakes considered is in contact with tree or bush scrub (the dominant species being alder, birch, rowan, raspberry bush), and it is only L. Majcz Wielki that borders on larger forest complexes (up to 52% of its shoreline) (Table VIII). A considerable proportion of the shoreline of L. Inulec (34%) borders on pastures and meadows, and only a small

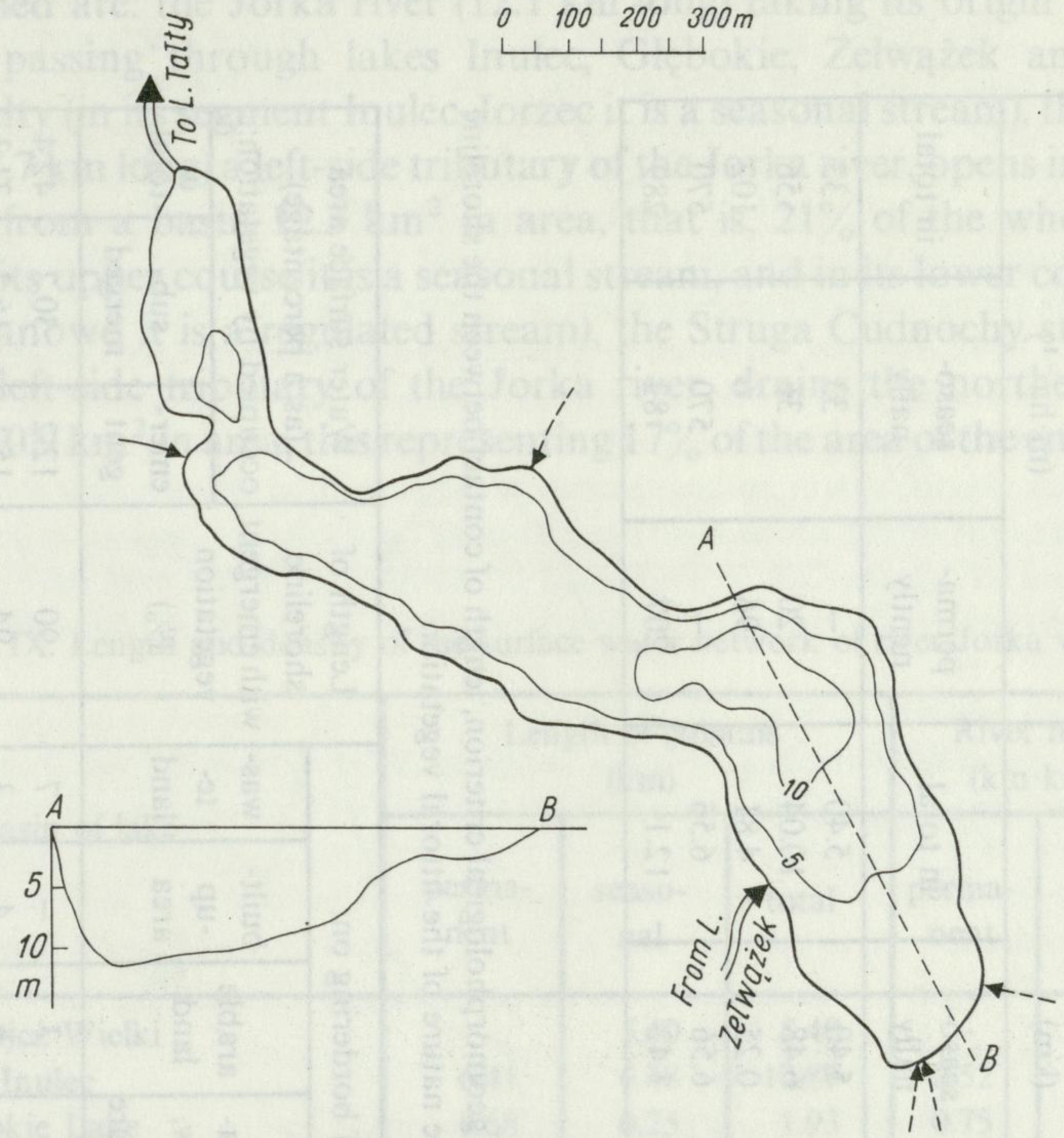

Fig. 16. A bathymetric chart and a section of Lake Jorzec (denotations as in Figure 12)

percentage of the shoreline of all the lakes directly contacts arable land or built up areas (up to 8%), the cause of this being the slope, sometimes considerable, of the terrain adjacent to the lakes (Table VIII).

In the river Jorka watershed there are also little lakes – small depressions filled with water. In the study area their number is considerable (about 50 – 70). They are particularly numerous in the northern part of the watershed. These lakes vary in size, many of them being seasonal water bodies heavily overgrown with vegetation.

The watercourses of the river Jorka watershed include permanent and seasonal streams (Fig. 2). The development of the river network of the area under study is primarily determined by the morphogenesis of the area and shows many features of the initial development stage. The watercourses are short, often seasonal, with poorly developed beds. The established permanent river network includes only a lake channel and valleys of the mouth parts of the Jorka river, Baranowska Struga river and Struga Cudnochy river. The terminal moraine hills area is connected to the river Jorka system via a reclamation drainage system, and seasonal and short-lived streams that function during spring floods or long-lasting summer or autumn rains. In many cases the river network is only supplied by the topmost horizon of underground waters, hence the considerable proportion of seasonal streams in the overall river network length (Table IX). The total density of the river network amounts to 0.76 $km \cdot km^{-2}$ of the basin, therein the density of the permanent network 0.39 $km \cdot km^{-2}$. The main streams

Table VII. Stream load to river Jorka watershed lakes

Lake	Number of streams discharging into the lake:			Length of the streams discharging into the lake: (km)			Length of the streams discharging into the lake per lake area unit: ($m \cdot ha^{-1}$)		
	permanently	seasonally	in total	permanently	seasonally	in total	permanently	seasonally	in total
Majcz Wielki	–	4	4	–	5.40	5.40	–	33	33
Inulec	2	4	6	3.56	6.48	10.04	20	36	56
Głębokie	2	1	3	4.56	0.25	4.81	96	6	102
Zełwążek	–	1	1	–	6.56	6.56	–	570	570
Jorzec	2	4	6	8.67	3.42	12.1	207	82	289

Table VIII. Lake shore types (in percentages of shoreline) according to: the geomorphological criterion, length of contact between the shoreline and the particular land use type, and the nature of the littoral vegetation

Lake	Shoreline length (km)	Geomorphological shore type:				Length of bordering on:						Length of shoreline with emergent vegetation (%)	Water surface area (as a percentage) occupied by vegetation:		
		accumulative:		abrasive	neutral	closed-canopy wood	tree scrub	meadow, pasture	arable land	built-up area	wasteland		emergent	submerged	total
		organic	inorganic												
Majcz Wielki	8.2	8	59	23	10	52	12	26	3	–	7	90	12.2	30.2	42.4
Inulec	11.0	25	28	20	27	–	53	34	6	4	3	94	15.1	16.2	31.3
Głębokie	4.41	15	19	66	–	14	68	10	8	–	–	77	6.7	16.2	22.9
Zełwążek	1.81	30	16	40	14	–	56	42	2	–	–	93	22.6	35.6	58.2
Jorzec	4.26	23	17	43	17	28	43	24	5	–	–	85	14.5	7.8	22.3

of the watershed are: the Jorka river (12.1 km long) taking its origin from L. Majcz Wielki, then passing through lakes Inulec, Głębokie, Zełwążek and Jorzec, and entering L. Tałty (in its segment Inulec-Jorzec it is a seasonal stream), the Baranowska Struga river (7.7 km long) a left-side tributary of the Jorka river, opens into L. Jorzec; it carries water from a basin 12.3 km^2 in area, that is, 21% of the whole river Jorka watershed (in its upper course it is a seasonal stream, and in its lower course below the village of Baranowo it is a regulated stream), the Struga Cudnochy stream (4.12 km long), also a left-side tributary of the Jorka river, drains the northern part of the watershed of 10.9 km^2 in area, this representing 17% of the area of the entire river Jorka watershed.

Table IX. Length and density of the surface water network of river Jorka watershed

Basin of lake	Length of streams (km)			River network density ($km \cdot km^{-2}$ of basin)		
	permanent	seasonal	total	permanent	seasonal	total
Basin of L. Majcz Wielki	–	5.40	5.40	–	0.28	0.28
Basin of Lake Inulec	6.41	6.48	12.89	0.52	0.52	1.05
Basin of Głębokie Lake	1.68	0.25	1.93	0.75	0.11	0.86
Basin of L. Zełwążek	0.78	0.20	0.90	0.96	0.26	1.18
Basin of L. Jorzec	8.52	3.2	11.94	0.56	0.22	0.78
River Jorka watershed	24.36	23.87	48.23	0.39	0.37	0.76
Including:						
river Jorka	11.96	0.20	12.16	–	–	–
river Baranowska Struga	6.12	1.62	7.74	–	–	–
river Struga Cudnochy	1.80	2.32	4.12	–	–	–

As a result of the complex geomorphological and geological relations of the study area there is a considerable diversity of ground-water occurrence in Quaternary deposits. The field study covered the exploited water-bearing horizon which has a hydraulic contact with river and lake waters. The following three types of ground waters were found:

(1) Subsurface waters on clay, associated with drainage-less areas occupied by marshes, or little lakes permanently or seasonally drained by the river network.

(2) Clay waters drained mainly by the lakes.

(3) Waters beneath clay which may only be in a hydraulic contact with the deepest lakes.

As indicated by the curve of variation of the water table in the water-bearing horizons distinguished (Fig. 17), waters beneath clay vary insignificantly (annual amplitude about 20 cm), waters on clay vary considerably (annual amplitude 80 cm), whereas clay waters show a very wide variation (annual amplitude up to 200 cm).

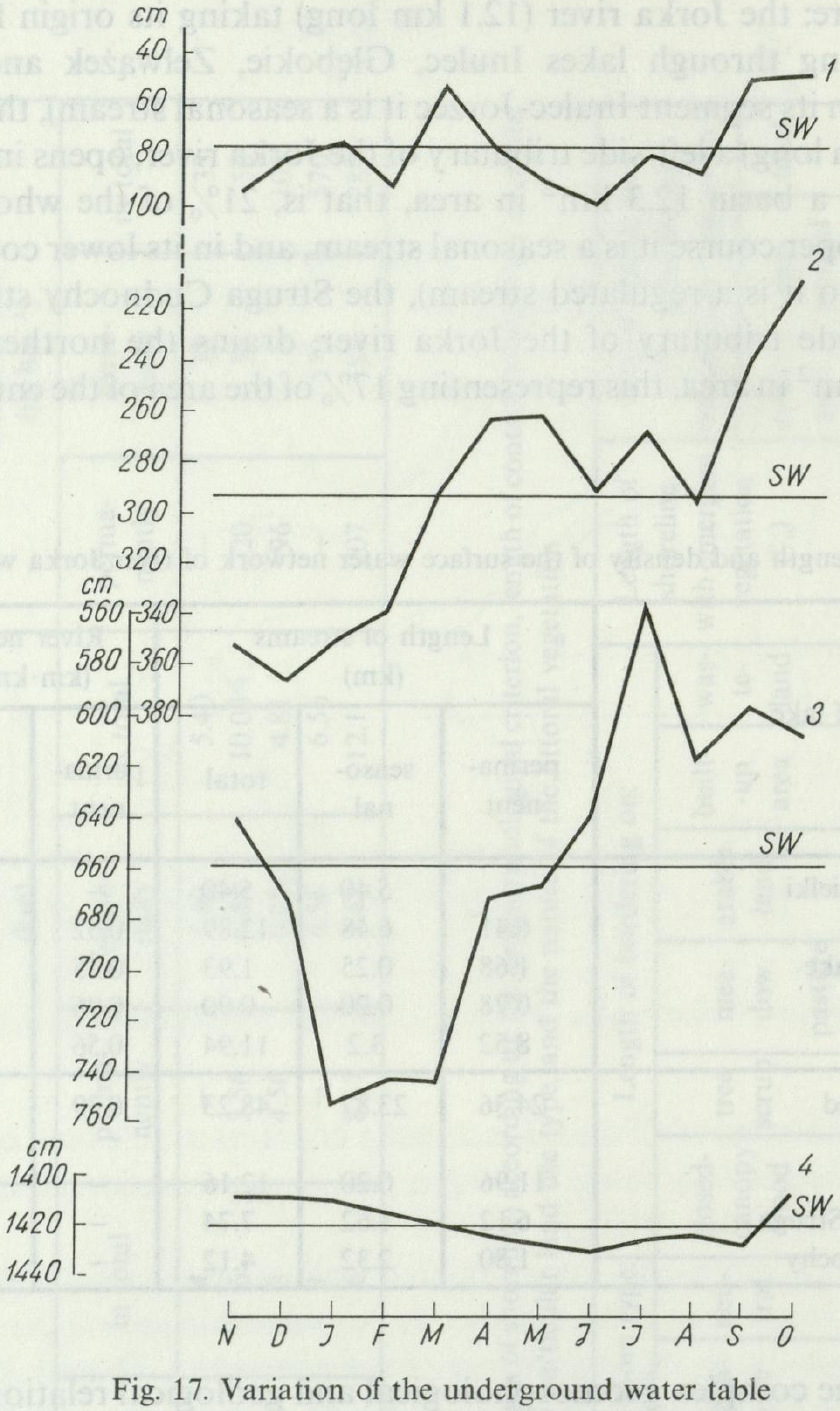

Fig. 17. Variation of the underground water table
1 – waters on clay, 2, 3 – clay waters, 4 – waters beneath clay, SW – average yearly groundwater state

4. SUMMARY

The area under study is typically a lakeland watershed (Fig. 1) and can be considered representative of the Masurian Lakeland. This is indicated by both climatological data (Figs. 5 – 10), morphometric parameters of the watershed, such as: surface area of the watershed (up to 100 km^2), its form (0.43) and elongation (1.62), slope (11‰), and physical-geographic parameters, and thus a considerable proportion of areas without surface outflow (28%) (Table I), a high lake ratio (8%), a considerable percentage of woodland (30%) (Table III) or the seasonal nature of the river network (only half of the watercourses function permanently) (Tables VII, IX). Characteristically, in the watershed under study, as in the basins of lakeland rivers, there are several lakes along the main watercourse (Fig. 2).

Typical of the river Jorka watershed are two kinds of youthful-glacial landscape connected with the range of the Masurian lobe of the Baltic glaciation: the lakeland hills landscape and the lakeland outwash plains landscape (Fig. 3). Due to the predominance of the former landscape in the river Jorka watershed, the area shows considerable slopes and bad conditions for infiltration (Fig. 4, Table II).

The chief element in the hydrographic network of the river Jorka watershed is lakes (Fig. 2). They differ in their origin and in the values of the basic morphometric parameters (Table V, Figs. 12 – 16) and impact of the basin (Table VI). The hydrographic network of the watershed is supplemented with permanent and seasonal watercourses (Table IX). The basic river network includes: the Jorka river (12.1 km long) and its left-side tributaries, the Baranowska Struga river (7.7 km long) and the Struga Cudnochy river (4.12 km long) (Fig. 2). Three types of ground waters: ground waters on clay, clay waters and waters beneath clay play a considerable role in the underground feeding of the rivers and lakes (Fig. 17).

On account of the considerable slopes and bad conditions for percolation, it must be expected that there is a considerable surface run-off to the streams and lakes in the river Jorka watershed. On the other hand, the presence of a considerable number of areas without surface outflow, a considerable number of seasonal watercourses, as well as the land-use structure (Table III), and the lack of a direct contact between lakes and arable land (Table VIII) have a limiting effect on the magnitude of this run-off. The seasonal nature of a stream connecting lakes also reduces the possibility of a continuous impact of the watershed on the different water bodies.

The sources of pollution found in the river Jorka watershed are small, but concentrated. Because of the limited surface run-off, the inflow from fields, meadows and forests seems to be small. More dangerous, however, is inflow from point sources. This mainly are various sewage discharges and outlets of tile drains (Fig. 11). Estimated approximately, the total loading of the watershed in kg per ha with N and P, as the total of the two nutrients derived from fertilizers, settlements, animal husbandry and tourism, and causing water pollution, comes up to about 84 kg of N and 43 kg of P a year per 1 ha of the watershed without the lake surface area (Table IV).

5. POLISH SUMMARY

Badany obszar jest typową zlewnią pojezierną (rys. 1) i może stanowić zlewnię reprezentatywną dla Pojezierza Mazurskiego. Świadczą o tym zarówno dane klimatologiczne (rys. 5 – 10), parametry morfometryczne dorzecza, takie jak: powierzchnia dorzecza (do 100 km^2), jego kształt (0,43) i wydłużenie (1,62), stoczystość (11‰), jak również parametry fizyczno-geograficzne, a więc duży udział obszarów powierzchniowo bezodpływowych (28%) (tab. I), wysoka jeziorność (8%), znaczne zalesienie (30%) (tab. III), czy okresowość sieci rzecznej (jedynie połowa cieków funkcjonuje stale) (tab. VII, IX). Cechą charakterystyczną omawianego dorzecza i zarazem typową w zlewniach rzek pojeziernych jest usytuowanie kilku jezior na trasie głównego cieku (rys. 2).

Dla dorzecza rzeki Jorki są typowe 2 gatunki krajobrazu młodoglacjalnego związanego z zasięgiem lobu mazurskiego zlodowacenia bałtyckiego. Są to krajobraz pagórkowaty pojezierny i krajobraz sandrowy pojezierny (rys. 3). Przewaga na obszarze dorzecza rzeki Jorki krajobrazu pagórkowatego pojeziernego sprawia, że obszar ten charakteryzują znaczne spadki terenu i złe warunki infiltracji (rys. 4, tab. II).

Głównym elementem sieci hydrograficznej dorzecza rzeki Jorki są jeziora (rys. 2). Różnią się one między sobą genezą, a także wielkością podstawowych parametrów morfometrycznych (tab. V, rys. 12 – 16) i stopniem oddziaływania zlewni (tab. VI). Sieć hydrograficzną dorzecza uzupełniają cieki stałe i okresowe (tab. IX). Podstawową sieć rzeczną stanowią: rzeka Jorka (długość 12,1 km) i jej lewe dopływy rzeka Baranowska Struga (długość 7,7 km) i rzeka Struga Cudnochy (długość 4,12 km) (rys. 2). W zasilaniu podziemnym rzek i jezior znaczną rolę odgrywają 3 typy wód podziemnych: wody gruntowe naglinowe, wody glinowe i wody podglinowe (rys. 17).

Znaczne spadki terenu i złe warunki infiltracji podłoża sugerują, iż należy się w dorzeczu rzeki Jorki liczyć ze znacznym spływem powierzchniowym do cieków i jezior. Z drugiej zaś strony znaczna liczba obszarów powierzchniowo bezodpływowych, znaczna liczba cieków okresowych, czy sposób użytkowania terenu (tab. III), a także brak bezpośredniego kontaktu jezior z gruntami ornymi (tab. VIII) wpływają ograniczająco na wielkość tego spływu. Okresowy charakter cieku łączącego jeziora również ogranicza możliwość ciągłego oddziaływania zlewni na poszczególne zbiorniki wodne.

Źródła zanieczyszczeń w zlewni rzeki Jorki są niewielkie, ale występują w formie skoncentrowanej. Dopływy obszarowe z pól, łąk i lasów ze względu na ograniczenia spływu powierzchniowego wydają się niewielkie, większe zagrożenie stanowią natomiast dopływy punktowe. Są to głównie różnego rodzaju zrzuty ścieków, jak również ujścia sączków drenarskich (rys. 11). Szacunkowa ocena całkowitego obciążenia zlewni w kg N i P na ha, jako suma tych 2 pierwiastków decydujących o zanieczyszczeniu wód, a pochodząca z nawożenia, osadnictwa, hodowli i turystyki, daje wielkość ok. 84 kg N i 43 kg P na rok na 1 ha dorzecza bez powierzchni jezior (tab. IV).

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