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TYPES OF BASINS WITHOUT DRAINAGE AND FACTORS AFFECTING THE WATER CYCLE IN THEM IN THE PRESENT-DAY LANDSCAPE OF THE MASURIAN LAKELAND *

ABSTRACT: Several hydrological types of basins without drainage have been identified. An important relationship has been found between the magnitude of seasonal fall of the water level in a mire situated in a basin without runoff and the proportion of the mire surface area in the total area of the basin. In a hummocky lakeland landscape there are basins with mires in them, as well as whole areas without surface drainage where seasonal retention of water and its long-term storage are favoured to a variable extent.

KEY WORDS: Basin without drainage (runoff), mire, minerotrophic fens, ombrotrophic bogs, ground-water table, water retention.

1. INTRODUCTION

The presence of basins without drainage brings about the functioning of a specific hydrographic system in areas with a varied young-glacial relief. The unique nature of their hydrology results from the fact that in the floors of some of the basins there are flood areas and waterlogged areas, most of them being peat-lands.

The aim of the present study is to find the principal agents determining the nature of the water cycle in various types of basins without surface drainage under the climatic conditions of north-eastern Poland. This will be done by tracing their spatial distribution and analysing water-table variation in the basins and its causes.

In this paper a basin without surface drainage is considered identical with an elemental catchment area without runoff (Drwal 1982), that is to say, the smallest

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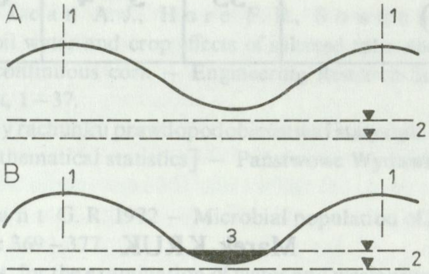

Fig. 1. A diagram to show a drainageless basin in cross-section
A – mireless, B – with a mire, 1 – runoffless basin boundaries (watersheds of a catchment area without surface drainage), 2 – range of water-table variation, 3 – mire

separable (on a 1 : 5000 contour-line map) catchment area bounded by a continuous watershed. It may be a basin with or without a mire in its floor (Fig. 1).

The term "mire" will be used for land tracts with water permanently or temporarily present on their surface, and with ground waters making the substrate permanently damp. A mire may at the same time be a peat-land if it contains peat deposits.

It must be noted that in basins without surface drainage there is underground flow-off, or ground-water runoff. We are dealing on the one hand with units that are totally permeable to water, and on the other with a state close to a complete lack of runoff (surface and subsurface flow). These features imply a highly diversified, spatially, pattern of the cycle of matter in a hummocky lakeland landscape currently dominated by agriculture.

2. STUDY AREA

Lack of surface drainage was studied in an area of 3147 ha located in north-eastern Poland, west of the town of Mikołajki (Fig. 2). According to Kondracki's (1978) physical-geographic division of Poland, the area belongs to the Masurian Lakeland macroregion and the mesoregions: Mrągowo Lake Region and District of Great Masurian Lakes. The boundaries of the study area are the watershed of Lake Jorzec catchment area (exclusive of the catchment area of Lake Majcz Wielki and that of Struga Baranowska), Lake Krujanka catchment area, and of the water-parting area without drainage between lakes Jorzec, Zelwążek, Głębokie and Płociczno on one side, and Lake Tałty on the other (Fig. 2).

The general geomorphological system of the study area is characterized by the presence of a meridionally situated glacial trough, i.e., the trough of lakes Głębokie and Jorzec, a large dead ice depression of Lake Inulec and fragments of morainic plateaux. Elevated areas have an irregular knob-and-kettle topography, where knobs and ridges (up to 30 m in relative height) are accompanied by kettles and flat peat-lands. Genetically, there can be distinguished glacial forms of accumulation origin such as end

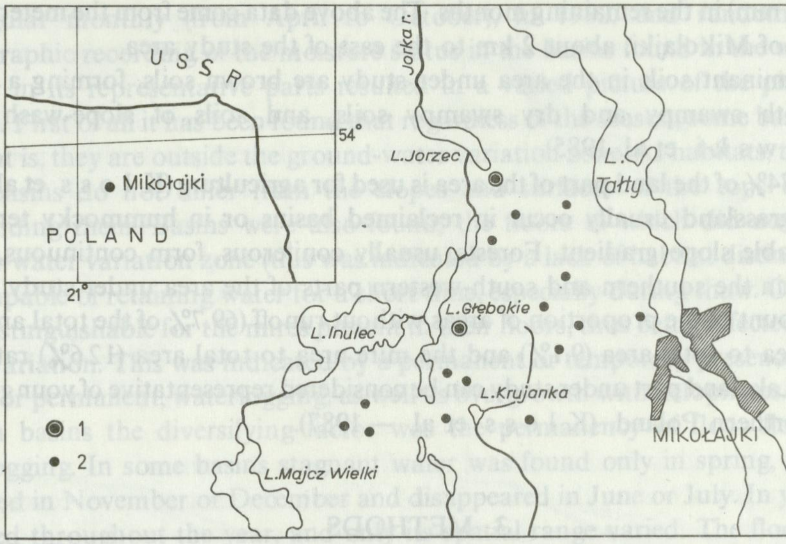

Fig. 2. Location of the study area and study stations
1 – 2-year observations, 2 – seasonal observations

moraines of marginal zones III and IV of the Pomeranian stage of the Baltic (Würm) glaciation, the undulate surface of a ground moraine and features that resulted from glacier thawing such as kames, an esker and dead ice depressions at present occupied by lakes and peat-lands.

The above-presented relief system determines the spatial distribution of runoff network: the only permanent watercourse – the Jorka river that flows through lakes Inulec, Głębokie, Zełwążek and Jorzec, directly drains only those depressions in which the above-enumerated lakes are situated, and the morainic plateau slopes. For the morainic plateau areas do not possess a developed runoff network (except the catchment areas of temporary watercourses in drain ditches), and a considerable part of them are areas without surface drainage. There is only underground flow-off there. The climatic conditions of the neighbourhood of Mikołajki are determined by the influence of the continental and Sub-Boreal climates. The most characteristic features of the climate are temperatures below the average temperatures for Poland, a shorter growing season, winters with snow and higher amounts of precipitation (the effect of the Baltic and lakes) up to an average of 525–600 mm a year (Bajkiewicz-Grabowska 1985). In the first study year: April 1982 – March 1983 precipitation amounted to 561.3 mm, with the highest amount in August and May and the lowest in October and September. In the second study year precipitation amounted to 439.9 mm – April was the wettest month and February the poorest in precipitation. In the period April 1982 – October 1982 when the seasonal water-table fall was measured the level of precipitation was 332.6 mm. The highest precipitation (about 75 mm) was recorded in May, June and August, medium precipitation (45.8 mm) in July and low

(10.9 – 28.3 mm) in the remaining months. The above data come from the meteorological station of Mikołajki, about 2 km to the east of the study area.

The dominant soils in the area under study are brown soils, forming a mosaic pattern with swampy and dry swampy soils, and soils of slope-wash origin (Rytelewski et al. 1985).

About 74% of the land part of the area is used for agriculture (Kloss et al. 1987). Tracts of grassland usually occur in reclaimed basins or in hummocky terrain of a considerable slope gradient. Forests, usually coniferous, form continuous, closed complexes in the southern and south-western parts of the area under study.

On account of the proportion of areas without runoff (69.7% of the total area) and the lake area to total area (9.1%) and the mire area to total area (12.6%) ratios the Masurian Lakeland part under study can be considered representative of young-glacial areas of northern Poland (Kloss et al. – 1987).

3. METHODS

To recognize the water relations prevailing in areas without surface drainage, surface waters and wet areas were recorded in the spring of 1982. By precisely determining the water level in mires and by observation-well measurement the level has been established of the near-surface water table of ground waters. Data were marked on a 1 : 5000 work-chart. To reveal seasonal variation in water relations in areas without surface drainage, the registration of water entities was repeated in different seasons of the years 1982 – 1984.

Every month the level of surface waters and the water table of ground waters were measured: in 19 mires located in basins without runoff (Fig. 2) in the period April 1982 – October 1982, and in two mires of the same location for two years April 1982 – March 1984.

Data on the lithology of the surface deposits were taken from maps (Mapy glebowo-rolnicze... 1969), descriptions of soil outcrops contained in them and from the author's own borings. For sounding the thickness of peat deposits a chambered borer was used.

For finding boundaries of hydrographic entities in agreement with the reality, a stereoscopic analysis of aerial photographs on the 1 : 10000 scale was carried out.

4. RESULTS

4.1. IDENTIFICATION OF TYPES OF BASIN WITHOUT SURFACE DRAINAGE

The object of field observation, aimed at identifying basins without surface drainage, was temporal variation in the occurrence of surface waters and ground moisture in basins.

Regular monthly (from April to October), in 1982, and random, in 1983, hydrographic recording of the moisture status in the basins found in the whole study area or in its representative parts resulted in a varied picture of the phenomenon studied. First of all it has been found that regardless of the season, some basins remain dry, that is, they are outside the ground-water variation zone. As habitats, the floors of these basins do not differ from the slopes and surfaces of the tops of the hills surrounding them. Basins were also found, the floors of which did not reach the ground-water variation zone (this was indicated by a lack of habitat distinctness), but were capable of retaining water for a short time, especially during thaw. Other basins were distinguishable for the mires present in their floors, thus being affected by water-table variation. This was indicated by a permanent or temporary presence of surface waters or permanent, waterlogging, as well as overgrowth with helophytes. In the case of such basins the diversifying factor was the permanency of floor flooding and waterlogging. In some basins stagnant water was found only in spring, in others it appeared in November or December and disappeared in June or July. In yet others it persisted throughout the year, and only its spatial range varied. The floors of these basins were grown up with various swamp plants characteristic of fens: reed fen, sedge fen, willow scrub and alder swamp. Water bodies were also found with floating water plants. A separate group included basins with a very wet mire surface, but without flooding during the whole year. They were basins with bogs covered with sphagnum and pine swamps. In a number of close basins grasslands were found, the water relations of which were regulated by drainage ditches and drain lines.

Adopting the following as distinctive features: relationship to the water table and the permanency of flooding and floor waterlogging, basins without surface drainage can be classified into three principal groups and a number of types (Fig. 3).

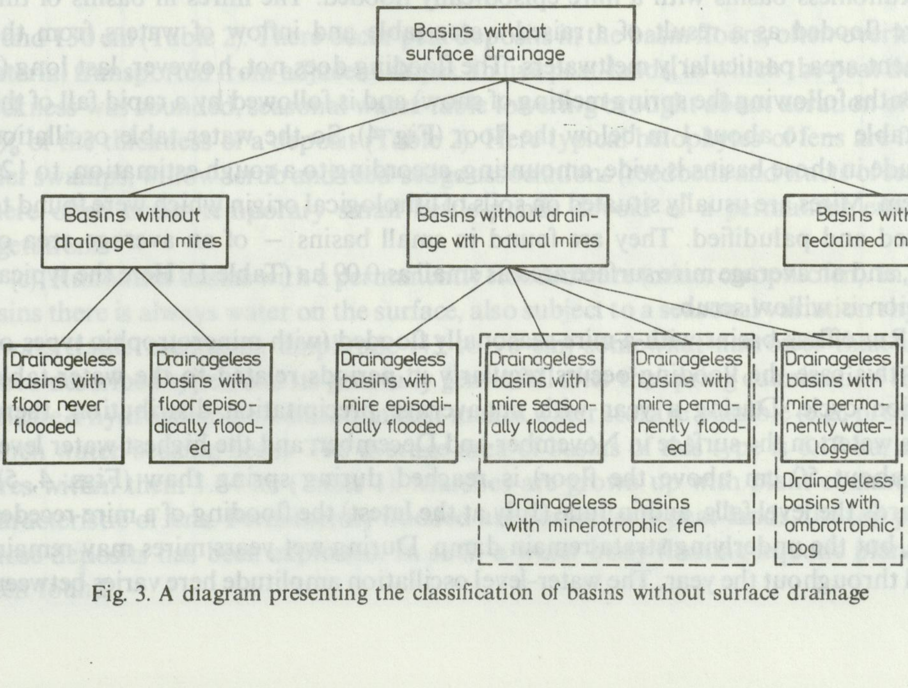

Fig. 3. A diagram presenting the classification of basins without surface drainage

(1) A group of basins without runoff and mires, including those closed surface catchment areas which are not connected with water-table oscillations (with the water table at a depth of at least 1.5 m).

(2) An opposite group consists of basins without runoff in which natural mires are found. They include all elemental, closed surface catchment areas with a permanent relationship to ground waters. The level of these waters does not usually drop more than 1.5 m below a basin's floor, and in most cases it permanently or seasonally floods the surface. Another distinctive feature is the permanent presence here of swamp vegetation. This group includes basins with fens (minerotrophic type) and bogs (ombrotrophic type).

(3) A separate group is represented by basins without surface outlet with reclaimed mires. Drainage ditches and drain lines, if they function correctly, prevent water from covering a mire's surface which is used as grassland.

A group of mireless basins without runoff includes 2 types:

(a) Drainageless basins, the floor of which is never flooded. It is not covered with water during even a flood period. No difference can be seen between the vegetation on the floor and that on the slopes of the basins.

(b) Runoffless basins with their floor episodically flooded. In basins of this type flood appears during thaw or heavy precipitation. The water does not remain there longer than 2–3 weeks. The cause of this short retention is a low permeability of the substrate – loams and strongly loamy sands. Since meltwaters do not always recede from these basins before the beginning of farming work in spring, their floors are often left as grasslands or unutilized grass communities (about 20 ha, that is, 1% of the cultivated land area in the terrain under study).

A group of drainageless basins with natural mires comprises 4 types:

(a)Runoffless basins with a mire episodically flooded. The mires in basins of this type are flooded as a result of a raised water table and inflow of waters from the catchment area, particularly meltwaters. The flooding does not, however, last long (1 – 2 months following the spring melting of snow) and is followed by a rapid fall of the water table – to about 1 m below the floor (Fig. 4). So the water table oscillation amplitude in those basins is wide, amounting, according to a rough estimation, to 120 – 150 cm. Mires are usually situated on soils of lithological origin which were found to be gleyed and paludified. They are found in small basins – of an average area of 1.32 ha, and an average mire surface area as small as 0.09 ha (Table 1). Here the typical vegetation is willow scrub.

(b) Runoffless basins with a mire seasonally flooded (with minerotrophic types of fen). In this case the flooding occurs regularly in periods related to the water-table oscillation cycle. During a year with an average precipitation distribution, there appears water on the surface in November and December, and the highest water level (up to about 50 cm above the floor) is reached during spring thaw (Figs. 4, 5). Afterwards the level falls, and in June (July at the latest) the flooding of a mire recedes (Fig. 5), but the underlying strata remain damp. During wet years mires may remain flooded throughout the year. The water-level oscillation amplitude here varies between

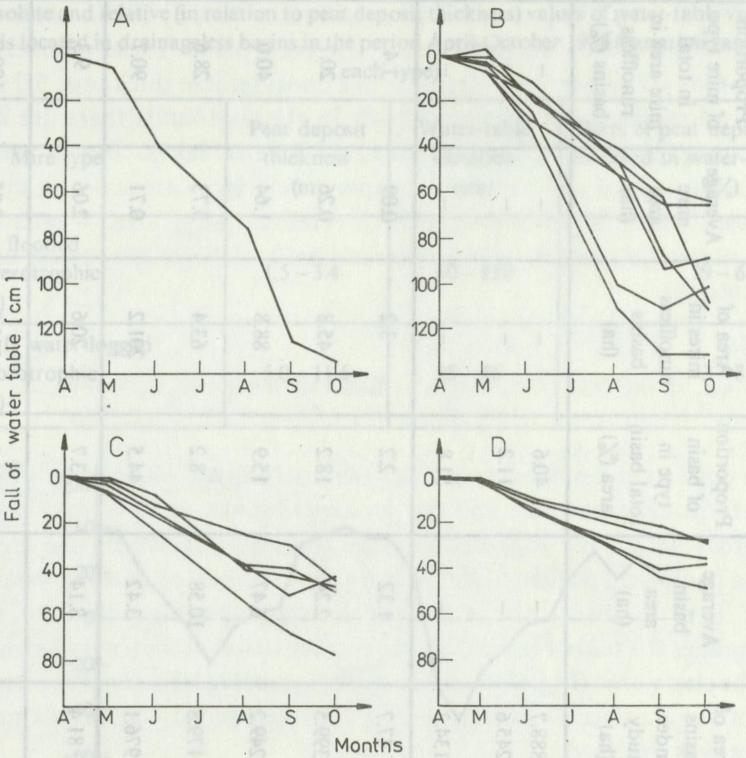

Fig. 4. Course of seasonal water-level lowering in mires situated in runoffless basins
A – in mires episodically flooded, B – in mires seasonally flooded, C – in mires permanently flooded, D – in permanently waterlogged mires

60 and 130 cm (Table 2). There occur peat deposits in the basin floors, often overlain by material transported from adjacent slopes. In five peat-lands, in which the peat deposit thickness was sounded, seasonal water-table lowering brought about aeration of 29 to 61% of the thickness of a deposit (Table 2). Here typical helophytes of fens are found: alder swamps, willow scrub and reed-sedge associations (reedbeds and tracts of sedges). There often occur temporary small kettle-ponds devoid of a permanent emergent vegetation.

(c) Runoffless basins with a permanently flooded mire (minerotrophic fen). In those basins there is always water on the surface, also subject to a seasonal variation rhythm. A water-table oscillation amplitude (43 to 90 cm) somewhat narrower than in the above-described types, and its generally gentle fall after the spring culmination (Fig. 4) indicate a hydrogeological situation that makes water storage possible (e.g., proximity of rich water-bearing beds). The average area of basins of this type is 6.17 ha, and of mires within them 1.64 ha (Table 1). Marshes are grown up with plant communities characteristic of fens. Permanently flooded are particularly peat-lands, the top part of whose deposits has been exploited. In such a water body floating aquatic plants are often found.

Table 1. Area ratios between runoffless basins and mires in the neighbourhood of Mikołajki (area under study = 3147 ha)

Runoffless basins		Number of basins with mires in study area	Area of basins under study (ha)	Average basin area (ha)	Proportion of basin type in total basin area (%)	Area of mires in runoffless basins (ha)	Average mire area (ha)	Proportion of mire type in total mire area in runoffless basins (%)
Mireless	with floor never flooded	–	888.7	–	40.6	–	–	–
	with episodically flooded floor	–	245.6	–	11.2	–	–	–
	total	–	1134.3	–	51.8	–	–	–
With natural mires	with an episodically flooded mire	36	47.7	1.32	2.2	3.2	0.09	1.4
	with a seasonally flooded mire	178	399.5	2.24	18.2	45.8	0.26	20.7
	with a permanently flooded mire	54	249.2	6.47	15.9	88.8	1.64	40.0
	with a permanently waterlogged mire	17	179.8	10.58	8.2	63.4	3.73	28.6
	total	285	976.1	3.42	44.5	201.2	0.71	90.7
With a reclaimed mire		10	81.4	8.14	3.7	20.6	2.06	9.3
Total		295	2191.8	–	100.0	221.8	0.75	100.0

Table 2. Absolute and relative (in relation to peat deposit thickness) values of water-table variation in mires – peat-lands located in drainageless basins in the period April-October 1982 (variation ranges in 5 mires of each type)

Mire type	Peat deposit thickness (m)	Water-table variation (cm)	Parts of peat deposit thickness involved in water-table changes (%)
Seasonally flooded mires (minerotrophic peat-lands)	1.5 – 3.4	60 – 130	29 – 61
Permanently water-logged mires (ombrotrophic peat-lands)	5.0 – 11.6	25 – 46	3 – 8

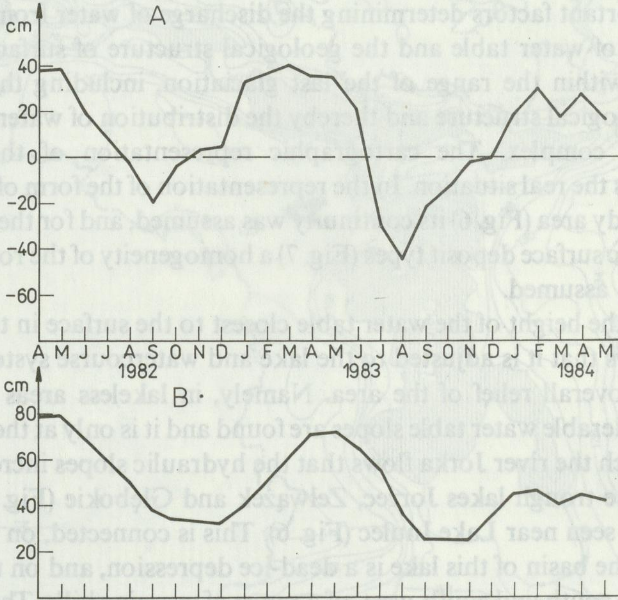

Fig. 5. Course of water-table variation in mires situated in runoffless basins
A – in a seasonally flooded mire (minerotrophic peat-land), B – in a permanently waterlogged mire (ombrotrophic peat-land), 1 – mire surface

(d) Runoffless basins with a permanently waterlogged mire (ombrotrophic bog). The surface of bogs remains highly moist throughout the year as a result of narrow variations in bog water level during a year. These oscillations range from 25 to 46 cm, i.e., as little as 3 – 8% of the thickness of the peat deposits (Table 2). Another feature of bogs at earlier stages of development is the pulsation of floating mats connected with water level variation. Only in peat-lands which are pine swamps is the water level slightly below the surface. In the bog type considered the water level variation during a year is gentle (Figs. 4. 5). The peat-lands discussed often occupy basins of former lakes where sedimentation of clay particles and gyttja took place. These sediments are at present isolated by sphagnum peat deposits of a considerable thickness, 5.0 to 11.6 m (Table 2) and a low degree of decomposition. In the peat-lands there are bodies of surface and underground waters – relicts of former lakes. Basins with mires permanently waterlogged are basins of comparatively large areas – on an average 10.58 ha (Table 1). Peat-lands also represent a relatively large area – on an average 3.73 ha. The vegetation found there is characteristic of bogs: sphagnum cover and spruce pine swamps.

4.2. SELECTED CONDITIONS DETERMINING THE RUNOFF IN THE STUDY AREA

The more important factors determining the discharge of water from a catchment area are: the form of water table and the geological structure of surface deposits.

In hilly areas within the range of the last glaciation, including the environs of Mikołajki, the geological structure and thereby the distribution of water-bearing beds are irregular and complex. The cartographic representation of these elements, therefore, simplifies the real situation. In the representation of the form of groundwater horizon I in the study area (Fig. 6) its continuity was assumed, and for the picture of the distribution of basic surface deposit types (Fig. 7) a homogeneity of the rock material to several metres was assumed.

An analysis of the height of the water table closest to the surface in the area under study (Fig. 6) shows that it is adjusted to the lake and watercourse system, and at the same time to the overall relief of the area. Namely, in lakeless areas (on morainic plateaux) no considerable water table slopes are found and it is only at the border of the basin through which the river Jorka flows that the hydraulic slopes increase, reaching about 10% near the trough lakes Jorzec, Zełwążek and Głębokie (Fig. 6). Relatively uniform slopes are seen near Lake Inulec (Fig. 6). This is connected, on the one hand, with the fact that the basin of this lake is a dead-ice depression, and on the other with the presence, to the south and south-west, of a range of moraine hills. The result of this topography is a "cascading" position of most of the mires in the area.

A study of the ground water contours made it also possible to establish the boundaries of: Lake Jorzec catchment area and a small catchment area of Łake Krujanka – area A, and a drainageless catchment area in a part of a morainic plateau between troughs – area B (Fig. 6). In area A the water table shows a clear slope towards the Jorka river and other watercourses draining this area. There are no major, directed hydraulic gradients in water-parting area B, a considerable part of it is encompassed by ground water contours 126 and 128 m asl (Fig. 6). Here subsurface flow-off can only occur through deeper aquifers.

Spatial distribution of precipitation is also affected by the composition of surface deposits. In the area under study sandy and clayey deposits occur in combinations that vary considerably (Fig. 7) due to a varied degree of glacial sediment transformation.

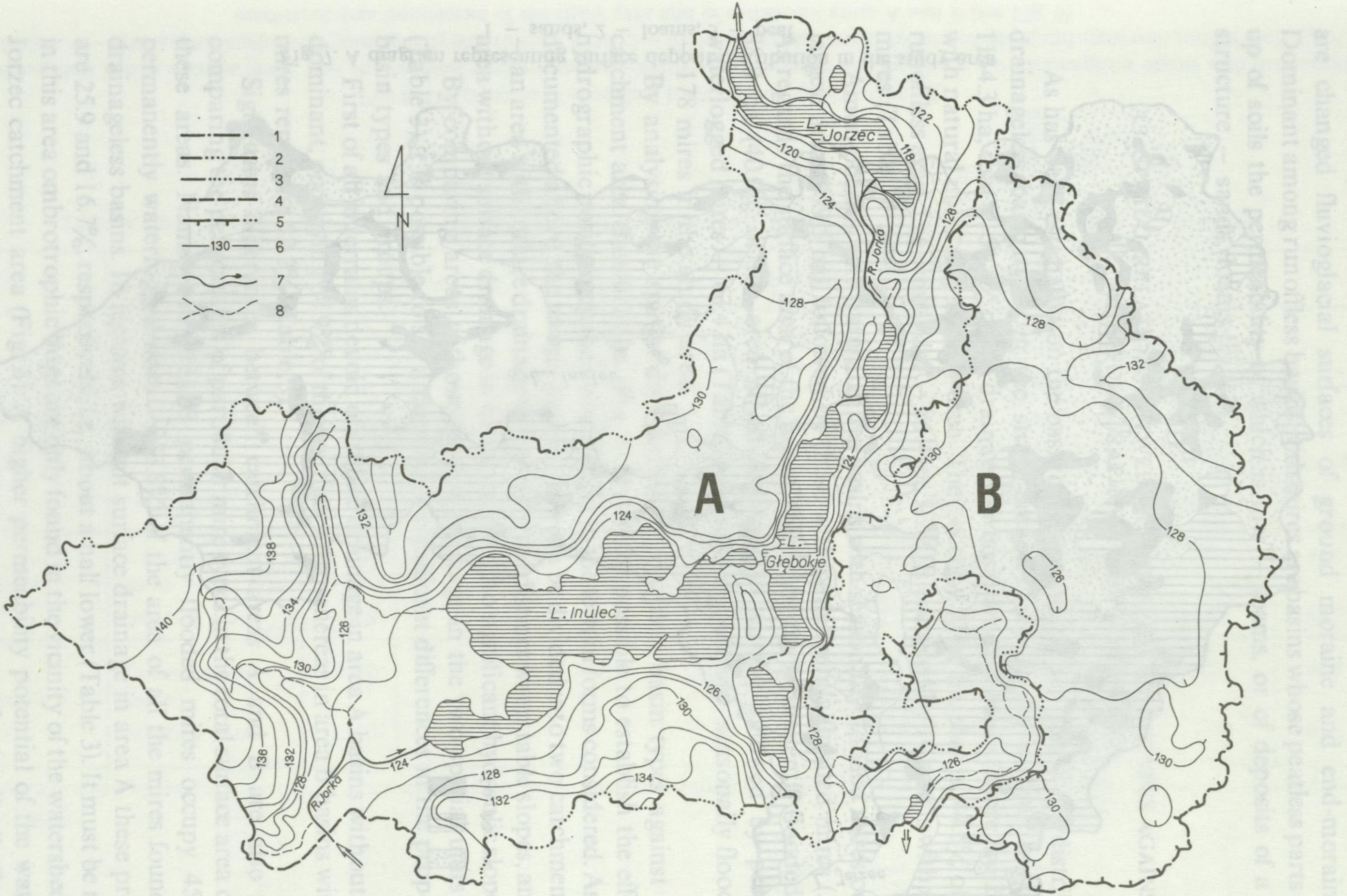

Fig. 6. Hydrographical division of the study area according to the height of occurrence of the water table closest to the surface
A — catchment area drained by the Jorka river and other watercourses, B — catchment area without surface drainage, 1 — first-order watershed, 2 — fourth-order watershed, 3 — fifth-order watershed, 4 — other watersheds, 5 — boundary of catchment area B, 6 — groundwater contours, 7 — permanent watercourses, 8 — seasonal watercourses

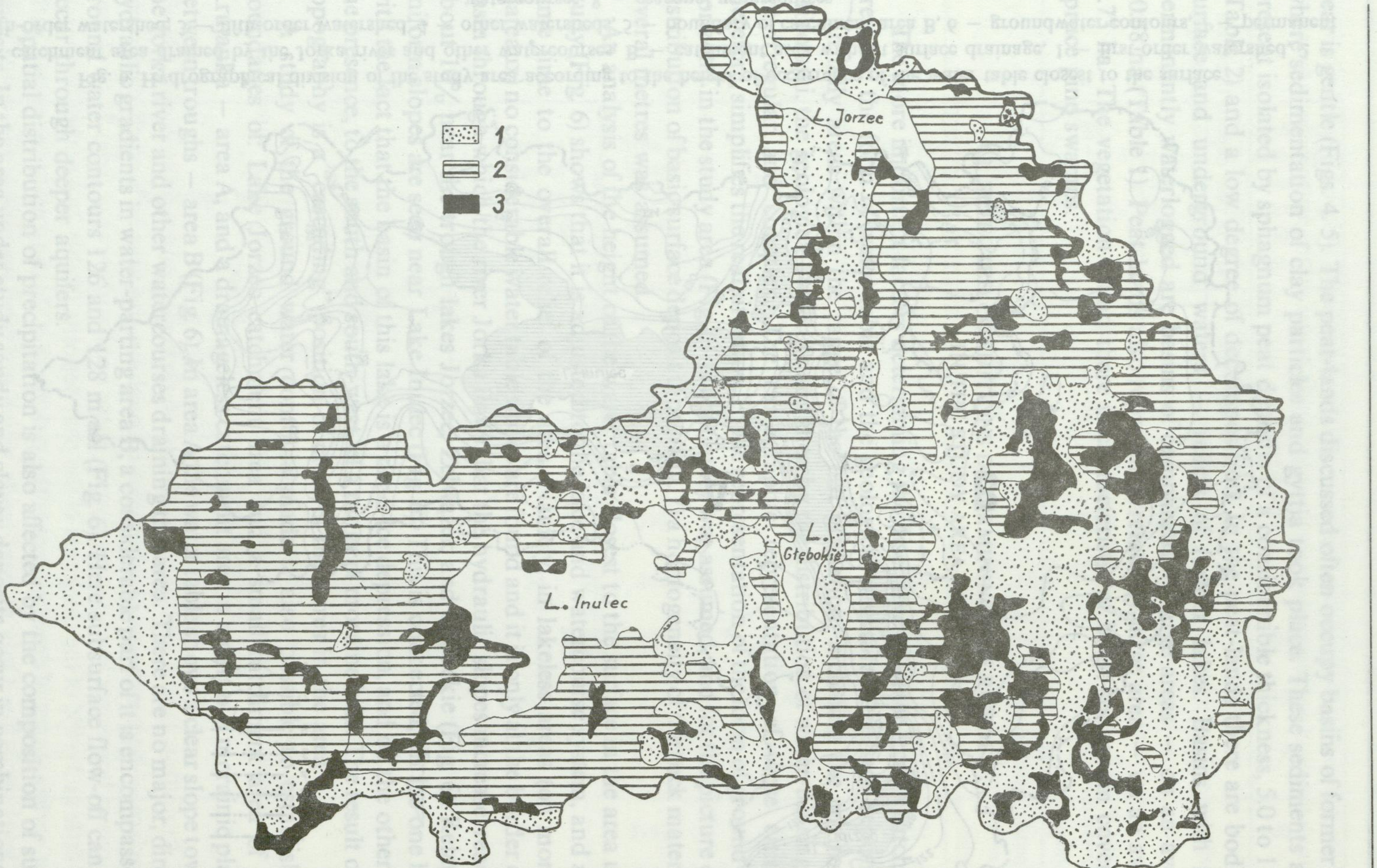

Fig. 7. A diagram representing surface deposit distribution in the study area
1 – sands, 2 – loams, 3 – peat

Mireless areas without surface drainage occupy mainly (about 70%) sandy areas. They are changed fluvioglacial surfaces of ground moraine and end-moraine zones. Dominant among runoffless basins with mires are basins whose peatless parts are made up of soils the permeability of which is low – loams, or of deposits of a complex structure – sands, loams (Fig. 7).

4.3. SPATIAL RELATIONS BETWEEN RUNOFFLESS BASIN TYPES AGAINST THE HYDROGRAPHY OF THE STUDY AREA

As has been estimated on the basis of a cartometric analysis of the distribution of drainageless basin types in the study area (Fig. 8), basins without mires occupy 1134.3 ha, that is, 51.8% of the drainageless basin area (Table 1). There are 285 basins with natural mires in the study area. They occupy 976.1 ha, that is, 44.5% of the total runoffless area. The remainder – 81.4 ha, 3.7%, is occupied by 10 basins with reclaimed mires (Table 1).

Among basins with natural mires basins with seasonally flooded mires occupy the largest area (399.5 ha), followed by those with permanently flooded mires (349.2 ha). As regards the surface area of the mires, dominant are permanently flooded mires – 88.8 ha (40.0% of the area of all drainageless mires), followed by permanently waterlogged mires – 63.4 ha (Table 1). Most numerous are seasonally flooded mires – 178 mires in the study area.

By analysing the spatial distribution of runoffless basin types against a general catchment area classification (Fig. 8) it may be possible to establish the effect of the hydrographic position on the water budget in the terrain forms considered. As has been documented above, the terrain under study can be divided into two catchment areas: A – an area with surface drainage where there are distinct water table slopes, and B – an area without surface drainage in which there are no significant hydraulic slopes (Fig. 6).

By comparing areas without surface drainage in the two spatial units A and B (Table 3) it is possible to see a number of significant differences in the proportions of basin types and groups.

First of all in terrains devoid of surface drainage in area A basins without mires are dominant, occupying 64.9% of their surface area, whereas in area B basins with natural mires represent 62.2% (Table 3).

Significant differences between catchment areas A and B are also found by comparing the percentages of particular mire types in the total surface area of mires in these areas. Namely, in area B permanently flooded mires occupy 45.3%, and permanently waterlogged ones – 33.8% of the area of all the mires found there in drainageless basins. In terrains without surface drainage in area A these proportions are 25.9 and 16.7%, respectively, i.e., about a half lower (Table 3). It must be noted that in this area ombrotrophic bogs are only found in the vicinity of the watersheds of Lake Jorzec catchment area (Fig. 8). A higher permeability potential of the watercourse-drained area (A) is further indicated by the proportions of episodically flooded and seasonally flooded mires – 4.2 and 45.8% of the total area of runoffless mires in this

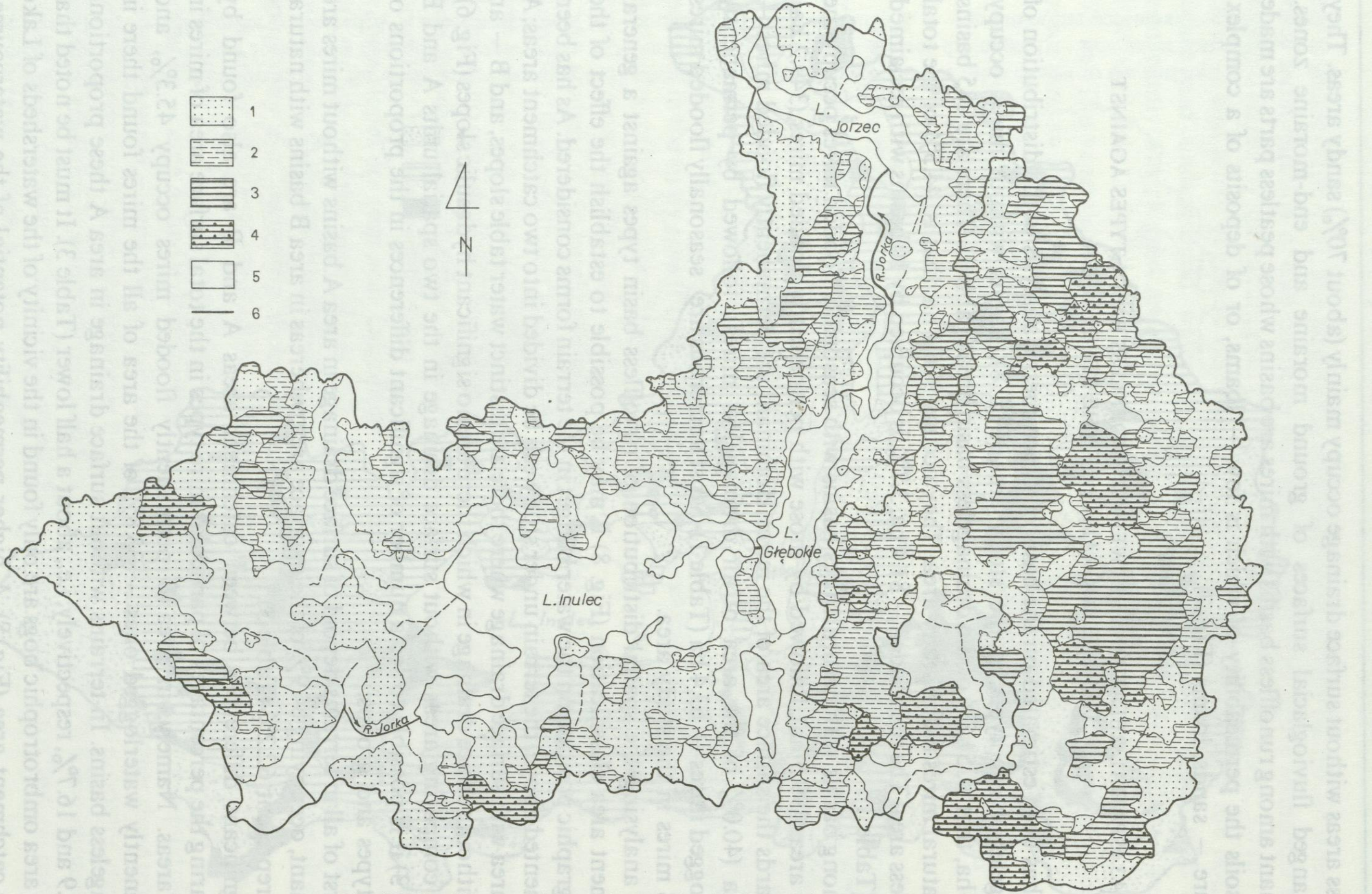

Fig. 8. Distribution of runoffless basins in the area under study

1 – drainageless basins without mires, 2 – drainageless basins with episodically and seasonally flooded mires, 3 – drainageless basins with permanently flooded mires, 4 – drainageless basins with permanently waterlogged mires, 5 – drainageless basins with reclaimed mires, and areas with surface drainage, 6 – catchment area boundaries of the study area and of catchment areas A and B (see Fig. 6)

Table 3. Effect of hydrographic position on the area ratios between drainageless basins and mires in the environs of Mikołajki

Areas without surface drainage		Total area (ha)	Proportion in total area (%)							
			drainageless basins without mires			drainageless basins with natural mires				
			with floor never flooded	with episodically flooded floor	total	with an episodically flooded mire	with a seasonally flooded mire	with a permanently flooded mire	with a permanently waterlogged mire	total
Of area A *	of drainageless basins	1184.8	47.4	17.5	64.9	3.3	18.7	8.0	2.6	32.6
	including mires	67.6	–	–	–	4.2	45.3	25.9	16.7	92.2
Of area B **	of drainageless basins	1007.0	28.7	3.8	32.5	0.9	21.5	25.3	14.8	62.5
	including mires	154.1	–	–	–	0.2	9.8	46.3	33.8	90.1

* Area drained by the Jorka river and other watercourses, with clear water-table clopes (Fig. 5). ** Water-parting drainageless area, with levelled water tables (Fig. 5).

area. In spatial unit B this percentage is as low as 0.2 and 9.8%, respectively (Table 3). The lower water relation stability in area A is also manifested by a considerable percentage of basins without mires, but with episodically flooded floor – 17.5% of the surface area of all the runoffless basins, while in area B this proportion is as small as 3.8% (Table 3).

The above comparisons lead to the conclusion that areas without surface drainage located within the boundaries of underground catchment areas of watercourses (area A) possess a clearly lower proportion of mires – permanent water bodies, and thereby a lower water relation stability than water-parting areas without surface drainage and with a significantly more difficult underground flow-off (area B).

By comparing the distribution of the types of runoffless basins with mires (Fig. 8) with the surface deposit chart of the study area (Fig. 7) it is possible to establish that with an increasing water relation stability in a mire the proportion decreases of basins situated on low-permeability soils – loams and clays. As many as 76% of episodically flooded, 49% of seasonally flooded, 44% of permanently flooded, and only 24% of permanently waterlogged mires have clayey surface catchment areas.

4.4. REGULARITIES GOVERNING WATER LEVEL VARIATION IN MIRES LOCATED IN BASINS WITHOUT SURFACE DRAINAGE

The field observation of water level changes in mires located in basins without surface drainage was also aimed at finding the causes of existing differences in this water budget element between the basins under study.

The water level in mires without surface drainage was found to be at its highest during thaw and immediately thereafter (Fig. 5). This suggests the conclusion that significant for the feeding of water to mires may be waters retained in the snow cover in mire catchment areas, particularly in the immediate surface catchment area, that is, in the mineral not swampy part of a drainageless basin. In larger surface catchment areas one might expect a bigger inflow and a more significant mire water level rise than in smaller catchment areas.

Meltwater supply in a mire in successive spring and summer months is lost by evapotranspiration from the vegetation that covers the mire surface, and by subsurface flow-off (Figs. 4, 5). It seems that the mechanism responsible for the subsurface flow-off of the spring culmination waters from mires located in basins is as described below.

The filling of a mire with water derived mainly from the remaining part of a basin during thaw and immediately after it results after some time, in the appearance of or increase in local hydraulic gradients between the level of the water retained in a mire and the level of gravitational underground waters in neighbouring mineral areas (drained by watercourses or water bodies at lower levels). It should be expected that the magnitude of subsurface flow-off from mires depends mainly on the local water level slopes that arise in this way. The highest gradients must in turn arise in the neighbourhood of mires in which the water level rose most (due to meltwater inflow from the catchment area). This, therefore, applies to mires with the largest, relatively, surface catchment areas, that is, they cover a small part of their basins without surface drainage. Contrariwise, comparatively small surface catchment areas of a mire would imply the occurrence of small water level slopes in the neighbourhood of the mire, and a low-magnitude subsurface flow-off from it.

To sum up, the statement may be put forward that in basins without surface drainage the ratio between the mire surface area and the total basin area (mire and its surface catchment area) has an influence on the magnitude of both the inflow of meltwater to a mire and groundwater flow-off from it. This ratio can be expressed in terms of mire area percentage in the total surface area of a basin without surface drainage:

$$P_m = \frac{M}{B} \cdot 100\%$$

where: P_m — percentage of mire in its basin without surface drainage, M — mire surface area, B — surface area of drainageless basin and mire.

In connection with the above regularities one might expect that the magnitude of water level fall in a mire, from the early-spring culmination to the lowest summer-autumn level (y), is correlated with the mire area percentage in the basin area (x).

The distribution of the two variables enumerated above for a series of 19 measurements made in mires found in basins without surface drainage can be seen in Figure 9. Eight observations were carried out in mires seasonally covered with water,

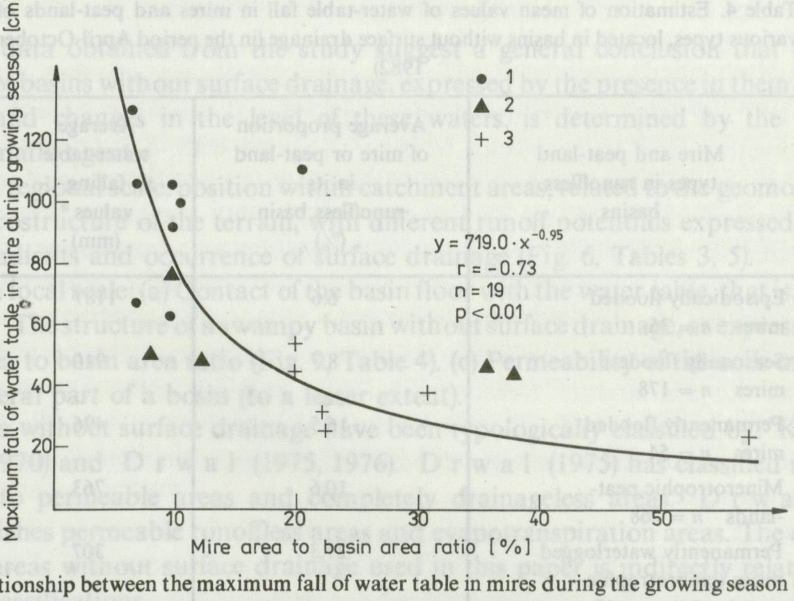

Fig. 9. Relationship between the maximum fall of water table in mires during the growing season (x) and the mire area to basin area ratio (y)

1 — seasonally flooded mires (minerotrophic peat-lands), 2 — permanently flooded mires (minerotrophic peat-lands), 3 — permanently waterlogged mires (ombrotrophic peat-lands)

five in permanently flooded mires (that is 13 in minerotrophic fens) and six in permanently waterlogged (ombrotrophic bogs). Between the variables analysed a negative correlation was found — $r = -0.73$ (Fig. 9), which indicates a clear relationship between the water movement in a mire in a drainageless basin and the area ratio between the mire and basin. It follows that other factors which could cause changes in mire water level, such as evapotranspiration or swamp soil permeability play an insignificant role in the diversification of the phenomenon considered. This has indirectly proved the thesis of the dependence of the size of inflow to and groundwater flow-off from a mire on the ratio between the area of a mire and the area of its basin without surface drainage.

By using the relationship found (Fig. 9) it is possible to estimate and predict the average value of a seasonal water level drop in a whole series of different mire types and peat-lands located in runoffless basins in the study area (Table 4). The results suggest clear differences between particular types. For example, during the growing season in episodically flooded mires an average fall by 1187 mm may be found, in mires that are at the same time minerotrophic fens 763 mm, and in mires-ombrotrophic bogs by as little as 307 mm (Table 4).

If the real proportion of mire area in swampy runoffless basins is known, it is possible to estimate and predict (by using the equation presented in Fig. 9) the value of the overall water level lowering in the mires found in these areas. Namely, in mires situated in terrains without surface drainage in the whole area under study the water level may drop on an average by 417 mm (Table 5), but in areas without surface

Table 4. Estimation of mean values of water-table fall in mires and peat-lands of various types, located in basins without surface drainage (in the period April-October 1982)

Mire and peat-land types in runoffless basins	Average proportion of mire or peat-land in its runoffless basin (%)	Average water-table falling values* (mm)
Episodically flooded mires $n = 36$	6.6	1187
Seasonally floodes mires $n = 178$	8.7	910
Permanently flooded mires $n = 54$	16.5	496
Minerotrophic peat--lands $n = 268$	10.6	763
Permanently waterlogged mires (ombrotrophic peat-lands) $n = 17$	27.3	307

* Values calculated on the basis of statistical relationships (Fig. 9).

Table 5. Estimation of average values of water-table fall in mires found in drainageless basins in areas A and B in the terrain under study (in the period April-October 1982) A – area drained by watercourses with clear water-table slopes (Fig. 6), B – water-parting area without surface drainage with levelled water tables (Fig. 6)

Hydrographic position of mires in drainageless basins	Mire area proportion in the area of runoffless basins with mires (%)	Average value of water-table fall in mires * (mm)
Mires in drainageless basins in area A	16.2	504
Mires in drainageless basins in area B	22.1	375
Mires in drainageless basins of the study area	19.8	417

* Values calculated on the basis of statistical relationships (Fig. 9).

drainage situated within watercourse catchment area boundaries (area A in Fig. 6) – by 504 mm, and in drainageless water-parting area B (in Fig. 6) – by 375 mm (Table 5). Thus, the difference in average values of mire water level lowering between these two areas distinguished may amount to 129 mm.

5. DISCUSSION AND CONCLUSIONS

The data obtained from the study suggest a general conclusion that the water budget of basins without surface drainage, expressed by the presence in them of surface waters and changes in the level of these waters, is determined by the following extraclimatic agents:

On a regional scale: position within catchment areas, related to the geomorphological macrostructure of the terrain, with different runoff potentials expressed by water table gradients and occurrence of surface drainage (Fig. 6, Tables 3, 5).

On a local scale: (a) Contact of the basin floor with the water table, that is, there is a mire. (b) The structure of a swampy basin without surface drainage, as expressed by the mire area to basin area ratio (Fig. 9, Table 4). (c) Permeability of the soils making up the mineral part of a bosin (to a lesser extent).

Areas without surface drainage have been typologically classified by: Kowalska (1970) and Drwal (1975, 1976). Drwal (1975) has classified runoffless areas into permeable areas and completely drainageless areas. Drwal (1982) distinguishes permeable runoffless areas and evapotranspiration areas. The classification of areas without surface drainage used in this paper is indirectly related to the above classifications.

A range of values of water table oscillations, similar to those presented in Table 2, in basins without surface drainage (0.35 – 1.0 m) have been obtained by Drwal et al.

(1977) for the Cassubian Lakeland. Though the highest water levels were recorded there in January and February and not in March and April, water table falling stopped in spring months.

The proportion of a mire in its basin without surface drainage, that is, in its local drainage system, points to the dominant way of its feeding, and it affects the size of groundwater runoff. Namely, if a considerable part of a basin area is occupied by a mire, as in the case of basins with permanently waterlogged mires (ombrotrophic bogs), it is an indication that precipitation is predominant in the feeding and at the same time the groundwater flow-off is small. A low mire area proportion in a basin area indicates that the mire is predominantly fed by groundwater (from the remainder of its basin), which at the same time implies a considerable underground drainage. This system of surface relations is seen in most basins with seasonally and permanently flooded mires, that is, with minerotrophic fens.

In view of the above it may be concluded that low values of water level fall in permanently waterlogged mires, that is, in raised bogs – on an average 307 mm (Table 4) – are primarily the resultant of differences between precipitation and evaporation from mire surface. For the values of swamp water level fall in ombrotrophic bogs in the spring-summer period – 25–54 cm (Table 2) are values which could approximately be (taking peat porosity into account) values of the predominance of evaporation from the surface of these bogs over precipitation on them during the study season. Whereas a large-scale water level drop in mires permanently and seasonally covered with water, in most cases occupying fens – on an average by 763 mm (Table 4), would be related to differences between the input of water from the catchment area of a mire and the groundwater flow-off from it, this flow-off being dependent on the amount of water retained in the mire in spring.

The relationship between the water budget of mires (peat-lands) without surface drainage and the local and regional geomorphological situation is evident. This statement, with regard to peat-lands in general, agrees with Ingram's (1983) summarizing conclusions. In his analysis of the effect of a catchment area and water level oscillations in fens Kulczyński (1939/1940) emphasizes the effect of ground water retention which lessens these oscillations in large catchment areas. This phenomenon has not, however, any great significance in the area under the present study, where there are only small (the area of the largest of them is 45 ha, and of an average on 2.7 ha) fen catchment areas. Ivanov (1957) concludes that the amount of water fed into peat-lands in "forest zones" in the USSR during the growing season is determined by the amount of meltwaters in their catchment areas. As indicated by the findings of the present study, the conclusion is also true under the climatic conditions of the Masurian Lakeland.

The results obtained from this study support Eggelsmann's (1971) thesis assuming a low short-term (on seasonal scale) water-retaining capacity of ombrotrophic peat-bogs. The values of water level rise in a peat-bog (permanently waterlogged mires) – 40 and 22 cm in successive years (Fig. 5) were clearly lower than the corresponding quantities in a fen (a seasonally flooded mire) – 60 and 76 cm (Fig. 5).

They are at the same time quantities similar to the range of water level fall during the growing season in both types of peat-land – mire (Figs. 4, 5).

If, however, the capacity is taken into account of peat deposits to store water quantities that do not take part in the yearly hydrological cycle, an opposite situation is seen. For in mires permanently waterlogged (ombrotrophic peat-bogs) water level oscillations involved only 3–8% of the deposit thickness (Table 2), and in the raised bog studied by Eggelsmann (1971) – 3 to 10% of the water volume in the deposit. On the other hand, in seasonally flooded mires (minerotrophic bogs) water oscillations involved 29–61% of the thickness of peat deposits (Table 2).

From the above relationship it may be concluded that ombrotrophic bogs have a lower seasonal water-retaining capacity than minerotrophic fens, particularly those that are seasonally covered with water. Raised bogs at the same time lose far less water over the yearly cycle than do more fertile marshes – fens. On account of their being considerably richer in water not affected by seasonal oscillations, ombrotrophic bogs may play a significant role in long-term water storage (on a time scale measured in terms of climatic changes). Minerotrophic fens, in basins without surface drainage, particularly those seasonally covered by water are highly capable of both a seasonal water retention and its quick riddance by underground flow-off, which makes their hydrological nature similar to that of areas of lithological origin.

In young-glacial areas there may be terrains with particularly favourable conditions, as regards a long-term water storage in drainageless mires. An example of such terrains is inter-trough morainic plateaux with numerous dead-ice depressions. The condition here also is a lack of reclamation. The difference of 129 mm in water level lowering, after the spring culmination, between mires in such a terrain and those in a surface drainage area (Table 5) indicates that the role of runoffless areas with mires in the water cycle in a landscape may vary. The regulation of this cycle by surface retention (Drwal 1982) in marshy runoffless areas varies significantly.

As indicated by the results (Fig. 9, Tables 3–5), spatial diversity of a landscape (Figs. 6–8) has some important hydrological implications concerning the quantity of subsurface flow-off from individual basins without surface drainage, or whole areas. The differences found are significant ecologically, for they form a complex pattern of ecosystems, often with contrasting differences in the quantities retained in and output from the ecosystems of nutrients transported hydrologically. At the same time (this should be stressed) in a present-day landscape, dominated by intensive farming, natural ecosystems occupying mid-field mires are supplied with considerable amounts of nutrients (from inorganic fertilizers). There emerges an interesting problem of the response of these hydrologically diverse ecological systems to the ever-increasing pressure of agriculture.

6. SUMMARY

The aim of this study was to analyse the principal extraclimatic factors determining the nature of water cycle in basins without surface drainage in some of which there are mires (most of which are peat-lands). The study was carried out in the neighbourhood of Mikołajki in the Masurian Lakeland, under conditions typical of a young-glacial landscape at present dominated by agriculture.

The following groups and types of basins without surface drainage have been identified (Fig. 3):

A group of drainageless basins, without mires, including basins with a never-flooded floor and ones with a floor episodically covered with water.

A group of drainageless basins with natural mires including: drainageless basins with episodically flooded mires, with seasonally flooded mires, with permanently flooded mires and with permanently waterlogged mires. Seasonally flooded and permanently flooded mires are minerotrophic fens, whereas permanently waterlogged mires are ombrotrophic bogs.

A separate group includes runoffless basins with reclaimed mires.

Figures 4 and 5, and Table 2 represent water-level variation in different types of basins with natural mires. A characteristic feature is the decreasing water-level lowering in the successive basin types (Fig. 4).

An analysis of the height of occurrence of the water table closest to the surface has made it possible to distinguish two areas differing in the nature of their water cycle: area A with a clear water table gradient, drained by the Jorka river and other watercourses, and area B – without a surface drainage and with a levelled water table (Fig. 6).

The occurrence of runoffless basins was compared with the spatial distribution of surface deposits (Fig. 7). The comparison shows that the underlying beds of about 70% of the drainageless areas without swamps are highly permeable – sands.

Table 1 presents the percentages of the particular basin groups and types in the total area of drainageless tracts in the terrain under study, whereas their distribution in it is presented in Figure 8. It appears that those drainageless basins which are also mireless basins, and whose floor is never flooded, occupy the largest area, and among basins with mires – those with seasonally flooded and permanently flooded mires, that is, minerotrophic fens. As regards the surface area of mires in drainageless basins, the dominant types are permanently flooded and permanently waterlogged mires.

A comparison has also been made of the spatial distribution of basin types in areas A and B (Table 3). In water-parting drainageless area B basins with permanently flooded mires are dominant, and among mires – those permanently flooded and permanently waterlogged. In terrains without surface drainage of catchment area A, drained by watercourses, basins without mires represent the highest percentage, whereas dominant among basins with mires are those with seasonally flooded mires.

A statistical analysis revealed a clear inverse correlation (correlation coefficient $r = -0.73$) between the value of water level lowering in a mire located in a basin (y) and the proportion of the area of a mire in the area of its basin (x) (Fig. 9). The distribution of the above-mentioned factors is of a contrasting nature in the case of drainageless areas with mires episodically and seasonally flooded, and basins with permanently waterlogged mires (Fig. 9, Table 4).

During the growing season considerable differences in water level lowering are seen between minerotrophic fens (on an average 763 mm) and ombrotrophic bogs (on an average 307 mm) (Table 4). It appears that the average value of water-level drop during the spring-summer period in mires situated in the area under consideration in basins without surface drainage is 417 mm (Table 5), in drainageless area B this quantity being 375 mm, that is, 129 mm lower than in drained area A (Table 5).

7. POLISH SUMMARY

Celem pracy było przeprowadzenie analizy głównych pozaklimatycznych czynników warunkujących charakter obiegu wody w zagłębieniach powierzchniowo bezodpływowych, z których część posiada w swoim obrębie mokradła (będące w większości torfowiskami). Badania przeprowadzono w okolicach Mikołajek na Pojezierzu Mazurskim, w warunkach typowych dla krajobrazu młodoglacjalnego, zdominowanego współcześnie przez gospodarkę rolną.

Wyodrębniono następujące grupy i typy zagłębień powierzchniowo bezodpływowych (rys. 3):

Grupę zagłębień bezodpływowych bez mokradeł obejmującą zagłębienia z dnem niezatapianym i zagłębienia z dnem epizodycznie zatapianym.

Grupę zagłębień bezodpływowych z mokradłami naturalnymi, w skład której wchodzą: zagłębienia bezodpływowe z mokradłami epizodycznie zatapianymi, z mokradłami okresowo zatapianymi, z mokradłami stale zatopionymi i z mokradłami stale podtopionymi. Mokradła okresowo zatapiane i stale zatopione tworzą torfowiska minerotroficzne (niskie), a mokradła stale podtopione torfowiska ombrotroficzne (wysokie).

Osobną grupę stanowią zagłębienia bezodpływowe z mokradłami zmeliorowanymi.

Rys. 4 i 5, a także tab. 2, przedstawiają zmiany zwierciadła wód w różnych typach zagłębień z mokradłami naturalnymi. Cechą charakterystyczną jest zmniejszanie się wielkości opadania poziomu wody w kolejnych typach zagłębień (rys. 4).

Analiza wysokości występowania najbliższego powierzchni zwierciadła wód podziemnych doprowadziła do wydzielenia dwóch obszarów o odmiennym charakterze obiegu wody: obszaru A o wyraźnych nachyleniach poziomu wód gruntowych odwadnianego przez rzekę Jorkę i inne cieki oraz obszaru B – bezodpływowego powierzchniowo z wyrównaną powierzchnią lustra wód gruntowych (rys. 6).

Porównano występowanie zagłębień bezodpływowych z przestrzennym układem utworów powierzchniowych (rys. 7). Z porównania wynika, że ok. 70% obszarów bezodpływowych pozbawionych zabagnień położonych jest na gruntach dobrze przepuszczalnych – piaskach.

Tab. 1. zawiera udział wydzielonych grup i typów zagłębień w ogólnej powierzchni obszarów bezodpływowych terenu badań, w którym ich rozmieszczenie przedstawia rys. 8. Okazuje się, że największą powierzchnię zajmują zagłębienia bezodpływowe bez mokradeł z dnem niezatapianym, a wśród zagłębień z mokradłami – zagłębienia z mokradłami okresowo zatapianymi i stale zatopionymi, czyli z torfowiskami minerotroficznymi. Natomiast, jeżeli chodzi o powierzchnię mokradeł w zagłębieniach bezodpływowych, to dominują mokradła stale zatopione i stale podtopione.

Dokonano również porównania rozkładu przestrzennego typów zagłębień na obszarach A i B (tab. 3). Na wododziałowym obszarze bezodpływowym B dominują zagłębienia z mokradłami stale zatopionymi, a wśród mokradeł, obiekty stale zatopione i stale podtopione. Z kolei, na terenach powierzchniowo bezodpływowych obszaru zlewniowego A drenowanego przez cieki, największy udział posiadają zagłębienia bez mokradeł, a wśród zagłębień z mokradłami przeważają te z mokradłami okresowo zatapianymi.

Posługując się analizą statystyczną, znaleziono wyraźną odwrotną zależność (współczynnik korelacji $r = -0{,}73$) pomiędzy wielkością opadania zwierciadła wód w mokradle położonym w zagłębieniu (y), a udziałem powierzchni mokradła w powierzchni swojego zagłębienia (x) (rys. 9). Rozkład dwóch wymienionych czynników ma charakter kontrastowy w przypadku zagłębień bezodpływowych z mokradłami epizodycznie i okresowo zatapianymi oraz zagłębień z mokradłami stale podtopionymi (rys. 9, tab. 4).

Znaczne różnice w wielkościach opadania poziomu wód w sezonie wegetacyjnym występują pomiędzy torfowiskami minerotroficznymi (średnio 763 mm), a torfowiskami ombrotroficznymi (średnio 307 mm) (tab. 4). Okazuje się, że przeciętna wielkość obniżenia się poziomu wody w okresie wiosenno-letnim w mokradłach położonych na terenie badań w zagłębieniach powierzchniowo bezodpływowych, wynosi 417 mm (tab. 5). Przy czym na obszarze bezodpływowym B wielkość ta wynosi 375 mm i jest o 129 mm niższa niż na obszarze drenowanym A (tab. 5).

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