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DIVERSIFICATION OF WATER RUNOFF IN POJEZIERZE ŁĘCZYŃSKO-WŁODAWSKIE

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Summary. Even though it seems otherwise, the area of Pojezierze Łęczyńsko-Włodawskie is a region of poor water resources. It results from the low amount of water fed from the atmosphere and the ground conditions for water circulation, mainly because of the impermeable layers occurring close to the surface. Due to the occurrence of periodic excess and deficiency of water, numerous attempts at regulating the water conditions on a local scale were made in areas characterised by a naturally slow water circulation. As a result, these actions diminished the water resources, accelerated the exchange of water, and modified the hydraulic relationships between the underground and surface water. The average specific runoff from the area of Pojezierze Łęczyńsko-Włodawskie is only 3.81 $dm^3 \cdot s^{-1} \cdot km^{-2}$ with a high fluctuation in its value. Last year, water resources were very poor and the flow of low water occurred at the end of spring and at the beginning of summer. The unusual hydrological conditions were documented by performing a control measurement twice of the discharge in all the rivers of Pojezierze Łęczyńsko-Włodawskie.

Key words: water runoff, discharge of low water, water resources, Pojezierze Łęczyńsko-Włodawskie

INTRODUCTION

Pojezierze Łęczyńsko-Włodawskie is a subregion of Polesie Lubelskie and it constitutes the western border of the Polesie region. It is situated in the area of the European Lowland in a region adjacent to the uplands area (Lublin Upland). The river Bug constitutes the border of the region to the east, Pagóry Chełmskie to the south, Garb Włodawski to the north, and the Tyśmienica valley to the west. The latitudinal extent within the described borders is approx. 55 km, the longitudinal extent is only 20 km, and the area is approx. 1160 km^2 (Fig. 1). It is an area of natural and landscape attributes that are unique throughout Europe and, at the same time, it is characterised by low resistance of the environment whose attractiveness and natural values are dependent on the water conditions.

What is interesting about this small region is the number of lakes of different genesis which are the only group in Poland located beyond the reach of the continental glacier of the last glaciation. The landscape is distinctly marked by groundwater occurring near the surface, large areas that are constantly or periodically waterlogged, and numerous lakes and divergent water reservoirs [Wilgat 1954]. The bed-rock consists of Quaternary formations with a maximum thickness of 80 m [Buraczyński 1983, Henkiel 1983] occurring on chalk and marls of the Upper Maastrichtian. The Upper Cretaceous carbonate rocks are surfacing locally, thus creating small hills up to 20 m high. In places where they have occurred near the surface, karst pits have appeared – in diverse shapes and sizes, periodically filled with water, thus highlighting the landscape character typical of Polesie.

From the hydrographical point of view, the area of Pojezierze Łęczyńsko--Włodawskie is located in the interfluve of the Wieprz and Bug rivers and a watershed of the second order runs through its middle (Fig. 1). The western part belonging to the Wieprz river basin is drained by the Tyśmienica river and its tributaries: the Piwonia, Ochoża, Bobrówka, Brzostówka, and Świnka. To the east, the Włodawka river and its tributaries, the Mietiułka, Tarasienka, and Krzemianka, transport their water into the Bug. The slight terrain inclination and small amounts of water drained do not encourage the creation of a natural and well-formed network of outflowing water, which has made the swamps and marshlands endure [Wilgat 1963, Borowiec 1990]. Their surface has decreased significantly in the past decades, especially in the meliorated areas [Wilgat *et al*. 1991, 1997]. At the same time, the river-beds of the rivers of Pojezierze Łęczyńsko-Włodawskie have been straightened and deepened many times. The courses of rivers close to the watershed, currently impossible to be distinguished from artificial ditches, do not possess well-formed valleys and are only characterised by a slight drop. The character of the fluvial network and the surface water density changed after the Wieprz-Krzna Canal was built, whose route runs through the region of Pojezierze Łęczyńsko-Włodawskie in the area of the watershed of the second order which constitutes the border between the river basins of Wieprz and Bug (Fig. 1). The canal is 140 m long and starts in the town of Borowica. It is supplied with water by the Wieprz at an average discharge of 3.0 $m^3 \cdot s^{-1}$ [Michalczyk 1997]. The water in the canal flows gravitationally and is distributed in the irrigated areas in the same manner. In the upper and middle courses of the canal, a part of the water from the canal bed infiltrates through its bottom and sides into the groundwater resources or reaches the surrounding ditches. It carries water of alkaline reaction which is rich in bicarbonates and significantly affects the decrease in the biodiversity of the Pojezierze Łęczyńsko-Włodawskie region.

MATERIAL AND RESEARCH METHODS

The hydrological features of the Pojezierze region are still scarce, mainly because of the small number of measuring points. Within the IMGW (Institute of Meteorology and Water Management) observation network, data from many years ago are available only for the water gauges that are closing the river basins in various physiographic regions: for the Włodawka in Okuninka, for the Świnka in Puchaczów, for the Piwonia in Parczew, and for the Tyśmienica in Siemień. As for the years between 1976 and 1990, measurement data for other lake district river basins are available: for the Tarasienka in Żłobek, for the Krzemianka in Luta, for the Włodawka in Suchawa, for the Piwonia in Sosnowica, and for the Tyśmienica in Ostrów. The volume of the underground and total runoff from particular river basins (Tab. 1), calculated mainly on the basis of the IMGW data, shows that the water resources in particular parts of Pojezierze are different [Michalczyk 1998].

Table 1. Average annual underground and total runoff between 1976 and 1990

River	Water gauge	Area of the river basin	Total runoff		Underground runoff		Runoff coefficient
			Q	q	Q	q	
		km^2	$m^3 \cdot s^{-1}$	$dm^3 \cdot s^{-1} \cdot km^{-2}$	$m^3 \cdot s^{-1}$	$dm^3 \cdot s^{-1} \cdot km^{-2}$	%
Świnka	Puchaczów	211	0.79	3.74	0.44	2.09	56
Piwonia	Sosnowica	115	0.521	4.53	0.292	2.54	56
Piwonia	Parczew	364	1.72	4.72	1.06	2.91	62
Tyśmienica	Ostrów	192	0.627	3.27	0.295	1.54	47
Tyśmienica	Siemień	1037	4.35	4.19	2.52	2.43	58
Krzemianka	Luta	88	0.355	4.03	0.178	2.02	50
Tarasienka	Żłobek Duży	110	0.424	3.85	0.178	1.62	42
Włodawka	Suchawa	434	1.64	3.78	0.938	2.16	57
Włodawka	Okuninka	576	2.32	4.03	1.32	2.29	57
Pojezierze Łęczyńsko-Włodawskie		1106	4.42	3.81	3.31	1.99	52

Q – przepływ, q – odpływ jednostkowy Q – discharge, q – specific runoff

The volume of the average runoff in many years' time was calculated on the basis of data from the 9 designated river basins and the materials from the IMGW (Tab. 1), encompassing in total a river basin area twice as large as Pojezierze Łęczyńsko-Włodawskie. The values presented do not contain data from all the typical river basins in this region. In order to evaluate the water resources and their diversification in the Pojezierze Łęczyńsko-Włodawskie region and to evaluate the quality of water in the rivers, a control measurement of the flow in 12 hydrometric sections of this region was performed. Data concerning the water resources for the 13 designated areas have been obtained, including the differential river basins. To evaluate the conditions shaping the quality of water, water

samples were taken for physical chemistry analyses during the measurement. Site surveys were planned in periods during which the shaping of the water resources in Polesie usually occurs. The first one was performed on 20th September, 2007, that is, after the period of the summer deficiency of water, and the second one on 23rd June, 2008, that is, in the first days of summer – in a period that is usually still abundant in water. The results of the measurement converted into the values of specific runoff from particular river basins are presented on the maps (Fig. 1, 2, 3).

VOLUME OF WATER RUNOFF

Average runoff

The landform features affect the rivers of Pojezierze Łęczyńsko-Włodawskie so that they are short, flow slowly, and gather water from small surfaces. The largest area is drained by the Włodawka – 726 km^2 (Fig. 1), whereas other upper rivers, the Piwonia, Tyśmienica, and Świnka drain water from the surface of several dozen to 300 km^2. Small feed areas and climatic conditions result in small amounts of water flowing in the river-beds. Furthermore, the slight terrain drop and small amounts of water prevented a natural outflow network from forming.

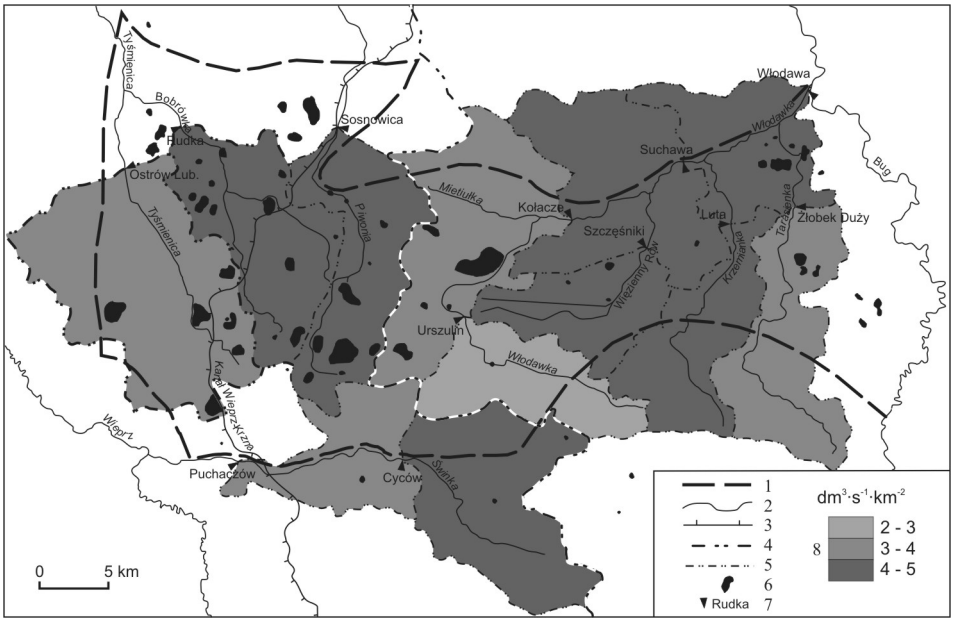

Fig. 1. Average specific runoff in the Pojezierze Łęczyńsko-Włodawskie river basins: 1 – region border, 2 – rivers, 3 – the Wieprz-Krzna Canal, 4 – watershed, 5 – country border, 6 – lakes, 7 – discharge measuring spots, 8 – specific runoff values

River runoff at the beginning of autumn 2007 and at the end of spring 2008

The average discharge of the largest rivers is between 1 to 3 $m^3 \cdot s^{-1}$ (Tab. 1). Besides the Bug and Wieprz rivers, the Włodawka has the highest discharge with an average of 2.7 $m^3 \cdot s^{-1}$ at the river mouth. The discharge of the other rivers of Pojezierze does not exceed 1 $m^3 \cdot s^{-1}$. From the seasonal and annual perspective, all the rivers of the examined area are characterised by a large discharge fluctuation. In the periods of low water, the specific runoff does not reach 1 $dm^3 \cdot s^{-1} \cdot km^{-2}$ and in the time of long-lasting droughts it falls even below 0.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$ [Michalczyk 1998]. The occurrence of rather deep low water is a result of low retention capabilities of the area that is rather firmly cut through by an artificial outflow network. In the part of the area situated on the river Bug and in the river basin of the upper Tyśmienica, the value of the average underground runoff depth is approx. 50 mm. In the area adjacent to the northern border of Wyżyna Lubelska, its value slightly exceeds 60 mm. The underground runoff depth from Pojezierze calculated for many years' time is 56 mm, which constitutes only 52% (Tab. 1) of the value of the total river runoff [Michalczyk 1998].

The water outflow showed little dynamism in natural conditions. Even in the period of the spring thaw and directly after heavy rains, the outflow through the river network was slow and time-consuming. An important factor regulating the river discharge was the fact that the groundwater occurred close to the surface and that there was a large number of terrain depressions where constantly or periodically waterlogged areas endured. Intensive work connected with land melioration in the 1960s and 1970s led to a change in the local base of drainage as well as accelerated the runoff and circulation of water in the river basins.

The small thickness of the unsaturated zone and the changes resulting from land melioration do not create good conditions for keeping the water within the river basin. In the central part of Pojezierze, the surface runoff actually exceeds the underwater feed slightly, which clearly shows that there are only faint possibilities for precipitation and meltwater retention in the thin unsaturated zone and in the areas cut through by irrigation ditches.

The average specific runoff from the Pojezierze Łęczyńsko-Włodawskie area is 3.81 $dm^3 \cdot s^{-1} \cdot km^{-2}$. It is a value that is definitely the lowest in the Lubelskie region and one of the lowest in Poland. The highest specific runoff was observed in the Bobrówka river basin – nearly 4.8 $dm^3 \cdot s^{-1} \cdot km^{-2}$ and the upper Piwonia – 4.53 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Slightly more than 4 $dm^3 \cdot s^{-1} \cdot km^{-2}$ flows out of the upper Świnka river basin, the Więzienny Rów, the Krzemianka, and from the lower Włodawka river basin to Okuninka. The smallest amount of water flows out of the Tyśmienica river basin to Ostrów, and out of the middle Świnka and the upper course of the Włodawka to the Kołacze profile – approx. 3.25 $dm^3 \cdot s^{-1} \cdot km^{-2}$ out of each. The specific runoff from the Tarasienka river basin to Żłobek and in the Bug river basin of Pojezierze is approx. 3.85 $dm^3 \cdot s^{-1} \cdot km^{-2}$.

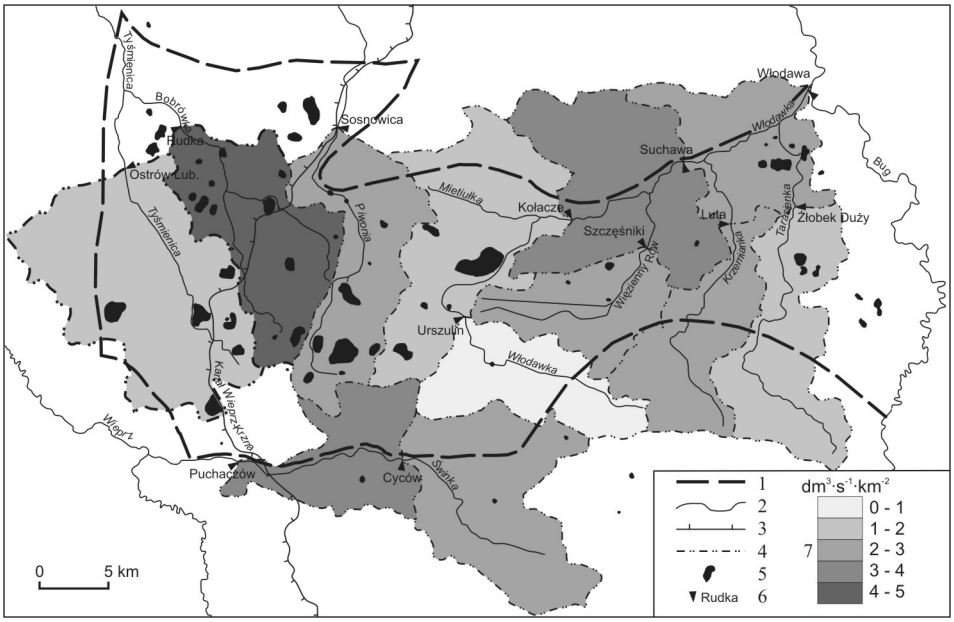

Fig. 2. Specific runoff from the river basin on 20th September, 2007: 1 – region border, 2 – rivers, 3 – the Wieprz-Krzna Canal, 4 – watershed, 5 – lakes, 6 – discharge measuring spots, 7 – specific runoff values

The measurement was performed on 20th September in the dry period when the water flowing in the rivers was coming from the underground feed alone. The resources of the region had been slightly replenished by the rainfall in the first ten days of September, when the total rainfall in Włodawa (between 4th and 11th September) was 55 mm. The rainfall in August was slightly lower than the average of many years' time (64 mm), and in July it was higher than normal (117 mm). The average specific runoff from Pojezierze at the beginning of autumn 2007 was 2.81 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Considering the season of the year, the water resources were rather rich and significantly diversified throughout Pojezierze. As for the volume of the water resources determined on the basis of the specific runoff, the Bobrówka river basin stands out – approx. 5 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Significantly less water flowed out of the middle Włodawka river basin, the upper Świnka (Fig. 2) and its middle course – with the water downthrow from the mine – between 3.0–3.3 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Approx. 2 $dm^3 \cdot s^{-1} \cdot km^{-2}$ flowed out of the Krzemianka, the Więzienny Rów, and the upper Piwonia river basins. 1.5–1.7 $dm^3 \cdot s^{-1} \cdot km^{-2}$ flowed out of the Tarasienka and upper Tyśmienica river basins. The highest part of the Włodawka was hydrologically inactive since there was no flow in the Urszulin water gauge and the specific runoff from the river basin to the Kołacze water gauge was only 1.1 $dm^3 \cdot s^{-1} \cdot km^{-2}$. These are flat areas where significantly drained peat surfaces play an important role in the retention. It is difficult to evaluate the discharge in the direct Bug river basin explicitly, since there are no water draining

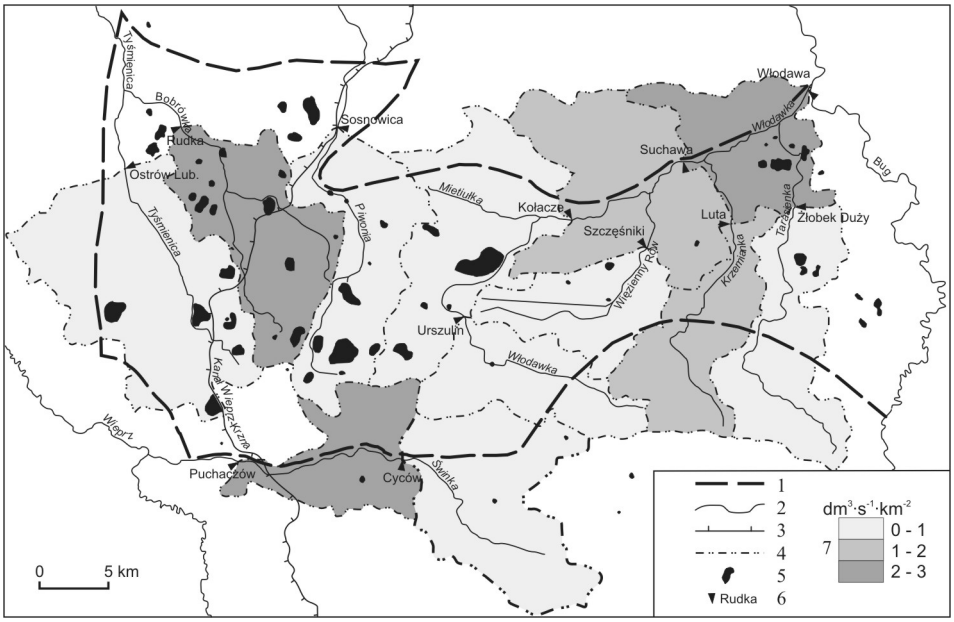

Fig. 3. Specific runoff from the river basin on 20th June, 2008: 1 – region border, 2 – rivers, 3 – the Wieprz-Krzna Canal, 4 – watershed, 5 – lakes, 6 – discharge measuring spots, 7 – specific runoff values

streams on the surface. It is an area of significant hypsometric differences where the groundwater in the Bug valley and the adjacent highlands is positioned in a specific drainage balance that is typical of border zones.

The spring of 2008 came rather early and the gravity feed was equal to the average of many years' time. The winter gravity feed, however, was not high and so the groundwater resources were not fully replenished. The measurement performed on 23rd June was done after a one-week dry period. On 14th June, the rainfall in Włodawa was 15 mm; it did not significantly increase the outflow which is proven by the low values of the specific runoff. These waters were submitted to retention in drained soil; the river feed was still scarce. The average specific runoff from Pojezierze Łęczyńsko-Włodawskie was only 0.91 $dm^3 \cdot s^{-1} \cdot km^{-2}$ at the beginning of summer 2008, that is, ¼ of the average value (Fig. 3). It is a very low value and does not reach half of the average value of the underground feed which is characteristic of the summer or early autumn deep low water.

On the day of the measurement and during other hydrological research, the Bobrówka river basin was the richest in water – 2.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$. A similar value was observed in the middle of the Świnka river basin (Fig. 3), caused by the water downthrow from the mine which supplied 1/3 of the flow in Puchaczów on the day of the measurement. The specific runoff in the remaining river basins was very small - between 0.63 $dm^3 \cdot s^{-1} \cdot km^{-2}$ in the upper Tyśmienica in Ostrów to 1.21 $dm^3 \cdot s^{-1} \cdot km^{-2}$ in the Krzemianka river basin. Only 0.1 $dm^3 \cdot s^{-1} \cdot km^{-2}$ flowed out

of the Tarasienka river basin and there was no outflow in the upper course of the Włodawka. The fact that the flow of the deep low water appeared so early will change the range of the hydrogenic areas of Pojezierze and it will accelerate the covering of lakes and marshes with plants which will be further advanced by higher eutrophication of water and high air temperature.

DISCUSSION

The presented values of the momentary specific runoff show that the water resources in the Pojezierze Łęczyńsko-Włodawskie region were very low in the last year. The time of their occurrence suggests deficiency of the gravity feed in winter and spring. Perhaps the unusual time for the occurrence of low water results from the periodicity of the hydrometeorological phenomena or climatic changes. It is also the effect of few possibilities of underground and surface water retention in Pojezierze Łęczyńsko-Włodawskie which is cut through by drainage ditches. In the last decades, the use of the groundwaters for the purpose of tourism and recreation has increased, which is proven by thousands of holiday cottages being built. In the south-western part of the area, the watershed has been relocated and, thus, the Piwonia river basin has been excluded from the Pojezierze area, which is a result of the environmental changes in the area caused by the hard coal mines. The total anthropogenic influence is highly conspicuous by the looks of the extreme water levels.

The observed values of the specific runoff show the retention possibilities of particular river basins of Pojezierze Łęczyńsko-Włodawskie which are currently inconsiderable. The natural water retention conditions have been transformed by the drainage and regulating treatments which have considerably accelerated the water circulation. The retention possibilities near the surface have been decreased and the river-beds have been straightened and deepened; they transport the rainfall and meltwater relatively fast. This is completely opposite to the features typical of the Polesie region where water was slowly flowing through a flat and boggy terrain.

Looking at the individual components of the water balance it is clear that in the summer term the water balance is negative and the excess of water is observable only in the cold period [Michalczyk 1998, Michalczyk *et al*. 2002]. The autumn rainfall replenishes the deficiency of water in the soil (unsaturated zone) which is usually high after the summer months. The balance deficiency of water in hydrogenic areas is replenished by the flow of the confined waters which ensures a stable water level on the waterlogged terrain even in periods of exceptionally low feed from the atmosphere. During the last decades, the conditions for the occurrence of the confined waters have also changed, both in the shallow and deep layers, which is a result of strong and multidirectional anthropopressure in Pojezierze Łęczyńsko-Włodawskie.

RESULTS

The area of Pojezierze Łęczyńsko-Włodawskie, even though seemingly abundant in water, is a region of poor water resources. It results from both the small atmospheric feed and the terrain conditions for the water circulation. The average specific runoff is only 3.81 $dm^3 \cdot s^{-1} \cdot km^{-2}$, with a high fluctuation in its value. Last year very poor water resources in the region and the flow of low water already appeared at the end of spring and at the beginning of summer. The unusual hydrological conditions were documented by performing control measurements of the discharge twice in all the rivers of Pojezierze Łęczyńsko-Włodawskie. Among the numerous river basins examined, the richest resources are in the Bobrówka river basin and the poorest are in the upper courses of the Tyśmienica and Włodawka river basins.

The changes in the water resources are connected to the meteorological conditions, especially with the seasonal and annual rainfall fluctuation; they are also a result of the growing anthropopressure. In the spring period, the water discharge is usually very significant, especially during precipitation and rising meltwater. In the long dry summer periods, the outflows from some river basins fall down even to 0.1 $dm^3 \cdot s^{-1} \cdot km^{-2}$ which clearly shows that groundwater resources are scarce. Such values of specific runoff appeared at the end of spring and at the beginning of summer 2008. At the same time, the water stages in lakes and reservoirs became lower and the waterlogged areas started drying.

It is the water conditions that give Pojezierze Łęczyńsko-Włodawskie features that are unique throughout Europe. In order to preserve them, it is necessary to take action aiming at slowing down the outflow and keeping the water within the river basins. Preserving the features of the environment requires drawing up and implementing a water abstraction and sewage disposal programme in the region, while taking into consideration the limitations of the exploitation of the groundwater from the deeper water-bearing horizon which determine the balanced water feed in the hydrogenic areas.

CONCLUSION

The already begun process of slow water resources degradation in the Pojezierze region cannot be allowed to continue. If the water stage falls even by 2 decimetres, the environment will be irreversibly transformed and, as a result, the hydrogenic areas will start to transform and disappear.

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ZRÓŻNICOWANIE ODPŁYWU WÓD NA POJEZIERZU ŁĘCZYŃSKO-WŁODAWSKIM

Streszczenie. Obszar Pojezierza Łęczyńsko-Włodawskiego, mimo pozorów obfitości wody, jest regionem o niskich jej zasobach. Wynika to zarówno z niskiego zasilania atmosferycznego, jak też z terenowych warunków obiegu wody. Średni odpływ jednostkowy wynosi tylko 3,81 $dm^3 \cdot s^{-1} \cdot km^{-2}$, przy dużym zróżnicowaniu jego wartości. W ostatnim roku zasoby wody regionu były bardzo małe, a przepływy niżówkowe pojawiły się już na przełomie wiosny i lata. Nietypowe warunki hydrologiczne udokumentowano poprzez dwukrotne patrolowe pomiary przepływu wykonane na wszystkich rzekach Pojezierza Łęczyńsko-Włodawskiego. Z wielu badanych zlewni najwyższe zasoby wykazuje dorzecze Bobrówki, a najniższe górne części zlewni Tyśmienicy i Włodawki. Zmiany zasobów wodnych nawiązują do warunków meteorologicznych, przede wszystkim do sezonowej i rocznej zmienności opadów, są też konsekwencją nasilającej się antropopresji. Zwykle w okresie wiosennym spływy wody są bardzo wysokie, szczególnie w czasie deszczowo--roztopowych wezbrań. W długich letnich okresach bezopadowych odpływy z niektórych zlewni obniżają się nawet do 0,1 $dm^3 \cdot s^{-1} \cdot km^{-2}$, co jednoznacznie wskazuje na małe zasoby wód podziemnych. Takie wielkości odpływu jednostkowego wystąpiły już na przełomie wiosny i lata 2008 r. Jednocześnie stwierdzono duże obniżenie się stanów wody w jeziorach i zbiornikach oraz wysychanie obszarów podmokłych.

Słowa kluczowe: odpływ wody, przepływ niżówkowy, zasoby wody, Pojezierze Łęczyńsko--Włodawskie