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HYDROLOGICAL CHARACTERISTICS OF THE KRĘŻNICZANKA RIVER

Zdzisław Michalczyk, Stanisław Chmiel, Sławomir Głowacki, Joanna Sposób, Beata Zielińska

Department of Hydrology, Faculty of Earth Sciences and Spatial Management, Maria Curie-Skłodowska University in Lublin, Kraśnicka Ave. 2d, 20-718 Lublin, Poland
e-mail: zdzislaw.michalczyk@umcs.lublin.pl, stanislaw.chmiel@poczta.umcs.lublin.pl, slawek.glowacki@poczta.umcs.lublin.pl, joanna.sposob@poczta.umcs.lublin.pl, beataz@poczta.umcs.lublin.pl

Abstract. The paper discusses the water resources of the Krężniczanka River catchment. The catchment with an area of 224.9 km^2 is located south-west of Lublin. The characteristics of the groundwaters and runoff were determined based on hydrological and hydrogeological materials of the Department of Hydrology of the Maria Curie-Skłodowska University (UMCS). Mean runoff in the period from 2010 to 2016 amounted to 125.7 mm, precipitation 629.4 mm, and evapotranspiration 503.7 mm. A strong relationship was determined between the rhythm of runoff and groundwater level fluctuations. The contribution of groundwater supply in total runoff equalled 81.5%.

Key words: groundwaters, runoff, water balance, the Krężniczanka River, Lublin Upland

LOCATION, STUDY AREA, STUDY OBJECTIVE

The Krężniczanka River catchment is located in the central part of the Lublin Upland. It occupies the area south-west of Lublin (Fig. 1). The Krężniczanka River is a left tributary of the Bystrzyca River. It flows into Bystrzyca in the southern part of the city, above the Zemborzycki Reservoir. The area of the catchment (224.9 km^2), similarly as the catchment of the Upper Bystrzyca River and its tributaries Czerniejówka and Czechówka, constitutes the direct area of development of water resources used for the needs of the agglomeration of Lublin with a population of 350,000. It is also a place of recreation of the city's residents.

The growing importance of the natural environment of suburban areas, and intensifying problems with covering needs for water resources in the city encouraged employees of the Department of Hydrology of UMCS to commence systematic observations as well as hydrometric and hydrochemical measurements of the Krężniczanka River. In the lower part of the catchment, for the

purposes of prospective water supply for Lublin, 24 wells of the "Strzeszkowice" water uptake were built. According to hydrological documentation, the efficiency of the uptake amounts to 2000 m^3 per hour. The objective of the paper is the evaluation of the conditions of occurrence of water resources, and particularly the discharge volume and variability in the Krężniczanka River.

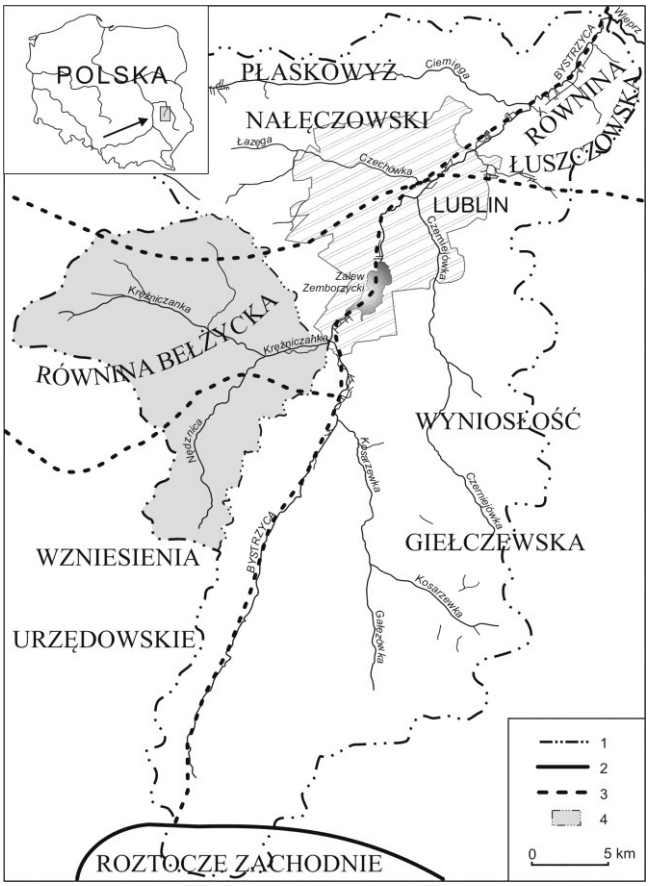

Fig. 1. Location of the Krężniczanka River catchment in the Bystrzyca River basin: 1 – watershed, 2–3 – physiographic regions [Chałubińska and Wilgat 1954], 2 – II order, 3 – III order, 4 – the Krężniczanka River catchment

The Krężniczanka River catchment occupies the central part of the Lublin Upland. The central part of the catchment is located in a subregion called the Bełżycka Plain (Fig. 1), with the lowest hypsometric variability. The southern part occupies the northern slope of the Urzędowskie Hills, and the northern part a small part of the Nałęczów Plateau [Chałubińska and Wilgat 1954]. The highest point of the catchment is located on the watershed in the southern part, and reaches

a height of 246.5 m a.s.l. The lowest point, at the mouth of Krężniczanka to Bystrzyca, has an altitude of 178.6 m a.s.l.

MATERIAL AND METHODS

After the establishment of the Department of Hydrography (currently Hydrology) of UMCS in 1956, research on the resources of the Bystrzyca River catchment involved preparing M.Sc. theses based on hydrographic mapping of the catchments of the Krężniczanka, Kosarzewka, Czerniejówka, and Upper Bystrzyca Rivers, concerning the resource area of Lublin. At the same time, measurements of springs and groundwater and surface water stages were undertaken. Results of the early field research provided the basis for the development of the concept of occurrence of groundwaters in the area of the Lublin Upland [Wilgat 1959, Szalkiewiczówna 1965]. In the following years, systematic measurements of springs were continued [Michalczyk and Rederowa 1992, Michalczyk 1993], and the analysis of the alimentation of rivers in the Bystrzyca catchment with groundwaters was commenced, including the development of a strategy of use of its resources [Michalczyk 1997]. From the beginning of the 1990's, field measurements have been performed on the rivers of the Lublin agglomeration with discharge decreasing within the depression cone [Michalczyk *et al*. 1983, Łoś and Michalczyk 1984].

For the purpose of determination of the volume and dynamics of water resources of the Krężniczanka River, an automatic water gauge was installed in Krężnica Jara on the lower course of the river in 2009 (Fig. 2). In the hydrometric profile, from 5 to 12 discharge measurements were performed annually, and water was sampled for analyses of its physical and chemical parameters. Based on the relationships between water stages and discharge, discharge rate curves were calculated, and then water stages were converted to hourly or daily discharges. A series of data on daily discharges in Krężniczanka was obtained for 2010–2016. It permitted the determination of monthly and annual characteristic values. Information on the dynamics of the water resources is supplemented by data concerning groundwater stages in the station in Babin (Fig. 2), recorded in the scope of the activity of the Polish Hydrogeological Survey of the Polish Geological Institute. Monthly precipitation totals were obtained for the station of IMGW in Radawiec, and the volume of evapotranspiration was calculated by the Konstantinow method based on data from the station on the Litewski Square in Lublin (Department of Meteorology and Climatology of UMCS) and from Radawiec (IMGW). The collected components of water circulation permitted the determination of the variability of water resources and retention in the catchment, and preparation of its water balance for the years 2010–2016. The characteristics of groundwaters together with groundwater table depth and con-

tour maps were particularly prepared based on materials of the Department of Hydrology of UMCS, covering results of hydrographic mapping of the Krężniczanka River catchment [Skrochocka 1987] and measurements of wells and water uptakes in 1995 [Michalczyk 1997]. Data included in hydrogeological and hydrographic maps were also used [Czerwińska-Tomczyk and Sadurski 1997, Pietruszka *et al*. 2002, Sposób 2006]. The surfaces of particular parts of the catchment and length of rivers was determined from the MPHP map [Map… 2010].

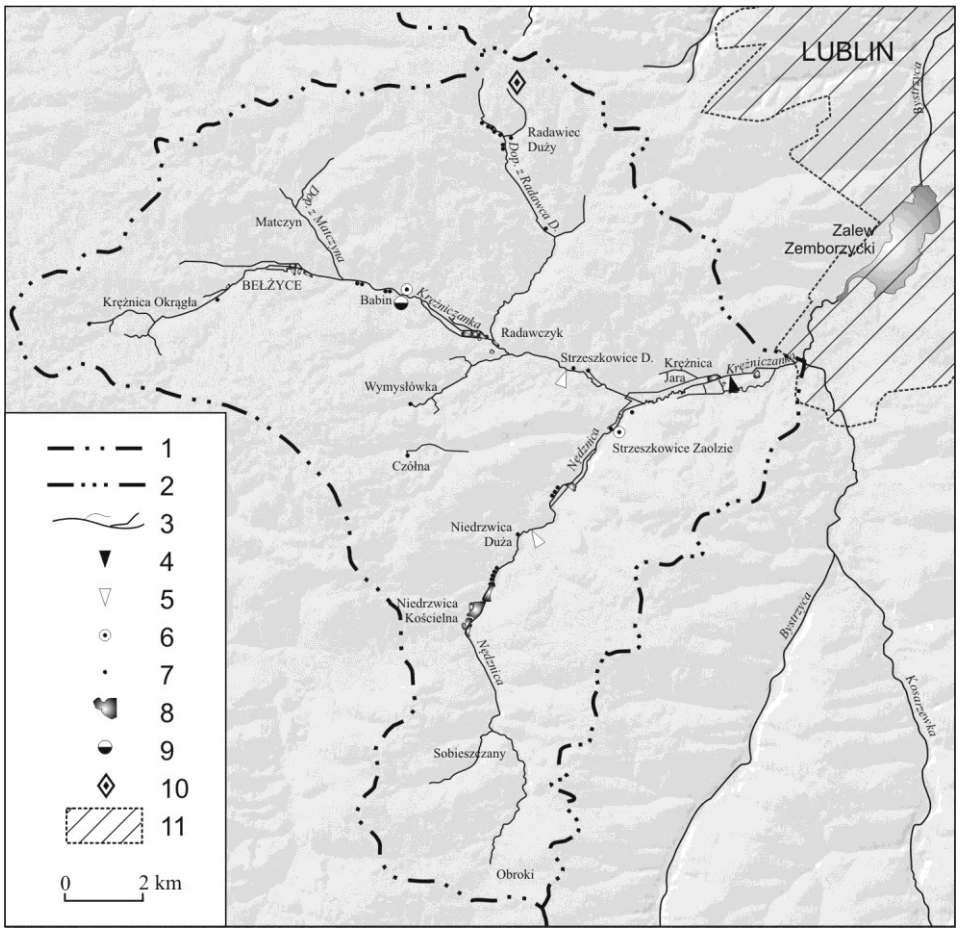

Fig. 2. River network and sites of hydrometric measurements in the Krężniczanka catchment: 1–2 – watersheds, 1 – II order, 2 – III order, 3 – rivers, 4 – water gauge, 5 – sites of periodical discharge measurements, 6 – springs with efficiency 10–30 $dm^3 \cdot s^{-1}$, 7 – springs below 10 $dm^3 \cdot s^{-1}$, 8 – ponds, 9 – groundwater monitoring station of the Polish Hydrogeological Survey, 10 – meteorological station of IMGW, 11 – territory of Lublin

HYDROGEOLOGICAL CHARACTERISTICS

The Upper Maastricht rocks play the primary role in water circulation and development of water resources. In the northern part of the catchment, they are covered by a several tens of meters thick series of Palaeocene rocks and a thin layer of Quaternary deposits. The series of Upper Cretaceous deposits begins with a layer of weathering loam with gaize fragments, deposited on limestones, marls, marly opokas, and gaizes. The thickness of particular lithological series varies from 0.1 to 2.3 m [Wyrwicka 1977]. In the central and southern part of the catchment, marls, opokas, and limestones of the Upper Maastricht locally crop out to the surface. In the northern part, they are covered by similarly lithologically developed Palaeocene marls and gaizes. The carbonate rocks are dissected by discontinuous faults the presence of which plays an important role in flow of groundwaters.

Upper Cretaceous and Palaeocene rocks are covered by a discontinuous layer of Quaternary deposits. Post-glacial boulder clays, gravels and sands, as well as loesses and loess-like formations associated with the end of the Vistulian Glaciation are deposited on Cretaceous or Palaeocene bedrock in the northern part of the catchment. In valleys and depressions, muds and sands are deposited, as well as Holocene alluvia of boulder clays and peats. In the remaining area, the layer of sandy-silty sediments is deposited on carbonate bedrock or on a series of washed out boulder clays. Locally, in the western part of the catchment, dune sands also occur on the surface.

Depending on the lithological composition of surface formations, the conditions of infiltration and filtration are varied. The content of silty or loamy fraction determines weaker permeability and high water capacity. In general, the permeability of surface formations in the Krężniczanka catchment is good, as confirmed by a high contribution of groundwater supply in total runoff. Overland flow lasts for a short time, and reaches relatively small volumes.

The primary useful aquifer in the Krężniczanka catchment is maintained in porous-fissure formations of the Cretaceous and Palaeocene. The aquifer horizon is composed of marls, opokas, and limestones of the Upper Maastricht, and marls, gaizes, and limestones of the Palaeocene. On plateaus on top of Cretaceous or Palaeocene weathered rock and on largely non-permeable layers of loams, suspended waters are retained [Skrochocka 1987, Michalczyk 1997]. River valleys are filled with medium- and highly permeable Quaternary deposits. Within them, the depth of occurrence of the useful aquifer is low (Fig. 3), and in the zone adjacent to river valleys the thickness of the aeration zone decreases even to several decimetres. Along with distance from valleys, the depth of occurrence of water increases to 20–30 m, and in the plateau areas of the south-eastern part of the catchment it exceeds even 40 m.

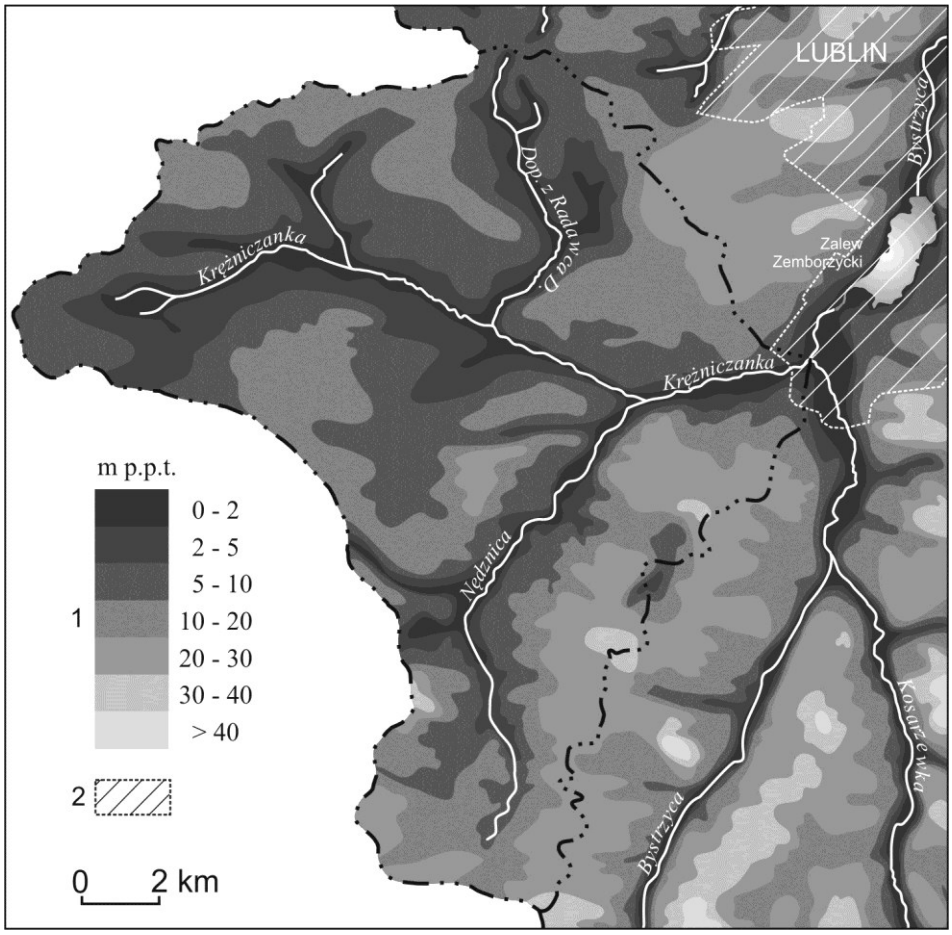

Fig. 3. Depth of occurrence of groundwater table: 1 – depth of occurrence of groundwater table, 2 – territory of Lublin

Groundwater table in the lowest part of the catchment is maintained at a height of approximately 179 m a.s.l. In the central part of the catchment, it increases to 200 m, and in the western and northern part to 232 m a.s.l. In the southern and central part of the catchment, unconfined waters of the first aquifer are retained in marls, opokas, and gaizes at a height of 200–220 m a.s.l. In the zones of plateaus, the existence of perched Quaternary waters with low volumes is locally recorded, retained on weathered Cretaceous rocks or on boulder clays (Fig. 4). Formerly, they were commonly used for individual water supply in homesteads. Their existence was recorded in the watershed zone in different parts of the catchment.

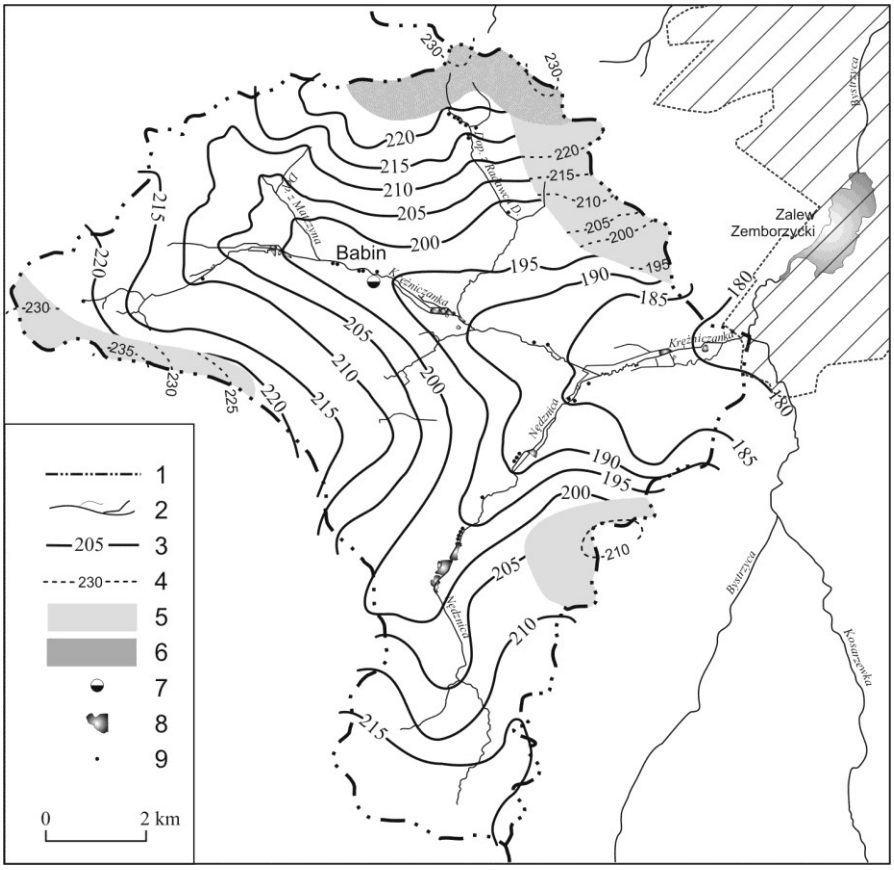

Fig. 4. Groundwater table levels: 1 – watershed, 2 – rivers, 3 – groundwater contour map of the main aquifer, 4 – groundwater contour map of the upper aquifer, 5 – area of occurrence of the upper aquifer in Cretaceous rocks, 6 – waters of the perched aquifer, 7 – groundwater monitoring station of the Polish Hydrogeological Survey, 8 – ponds and water bodies, 9 – springs

SURFACE WATER RESOURCES AND WATER BALANCE

The Krężniczanka catchment occupies a weakly hypsometrically varied plateau area slightly dissected by valleys of different ranks. Their majority is dry. Water continuously flows in Krężniczanka, Nędznica, and stream from Radawiec. Up to the point of connection of both rivers, their length amounts to approximately 17.5 km each. Krężniczanka has a somewhat larger catchment of 116.8 km^2, and Nędznica 82.8 km^2. The valleys are quite narrow – their floors reach a width of 100–400 m. The width of the river channel, weakly indented into the flood terrace, varies from 2 to 5 m. In both catchments, small surfaces of ponds occur: in the Krężniczanka River valley 0.274 km^2, and in the Nędznica River valley 0.209 km^2. In the entire catchment stagnant surface waters occupy 0.57 km^2.

Krężniczanka flows out of a small spring in Krężnica Okrągła above Bełżyce at an altitude of 221 m a.s.l. It flows into the Bystrzyca River in the southern part of Lublin, above the Zemborzycki Reservoir, at an altitude of 178.6 m a.s.l. According to the map of MPHP, its total length amounts to 23 km, and mean inclination 1.8‰. In its middle course, it is fed by waters of the tributary from Radawiec Duży with a length of approximately 9 km, and in the lower course it is supplied with the waters of the Nędznica River. According to names used by the local community, the rivers are often ascribed the name Ciemięga.

Nędznica, a river with a length of 17.5 km, takes its origin in the vicinity of Obroki at an altitude of approximately 229 m a.s.l., and then flows northwards through Sobieszczany and Niedrzwica. Below Niedrzwica Duża, where it flows through a complex of ponds, it changes direction to north-east until connecting with Krężniczanka at an altitude of 184.5 m a.s.l.

The gauging profile Krężnica Jara accounts for an area of 218.9 km^2, i.e. 97.3% of the catchment. The collected hydrometric materials document low variability of water stages, and suggest quite stable river alimentation with groundwaters. In hydrological years 2010–2016, extreme discharges ranged from 0.28 to 4.85 $m^3 \cdot s^{-1}$.

The compared values of the mean and minimum monthly discharge (Fig. 5) show a multiannual variability of water resources. In the years 2010–2016, discharges above the mean value were maintained over several subsequent months. Particularly high discharges occurred in the years 2013–2014. The lowest values were recorded in summer months of 2012 and 2016. Similar terms corresponded with the lowest monthly discharges, reflecting the volume of groundwater alimentation of the catchment. The comparison of mean and minimum monthly discharges directly suggests a very high contribution of groundwaters in total runoff, estimated for 81.5% in the study period. This results from good infiltration conditions of the ground which retains atmospheric precipitation in the aeration and saturation zone. Runoff from the catchment does not show a direct response to atmospheric precipitation, even in the conditions of increased intensity. Retained precipitation and melt waters are supplied to rivers in the following months. Almost parallel changes in groundwater discharge and resources are suggested by a similar rhythm of changes in water discharge and stages. In addition to discharge values, Fig. 6 presents mean monthly groundwater stages in Babin. It is a groundwater monitoring station of the Polish Hydrogeological Survey, located in the Krężniczanka River valley, uptaking water from the rocks of the Cretaceous and Quaternary horizon. The depth of occurrence of the water table varied from 2.3 m in 2010 to 3.44 m in 2013 (Fig. 5).

In the seasonal approach, a quite high degree of equalisation of discharges is observed. Mean annual discharge for the years 2010–2016 amounted to 0.872 $m^3 \cdot s^{-1}$. Mean discharge of the cool half-year was maintained at a similar level (XI–IV) of 0.876 $m^3 \cdot s^{-1}$, and warm half-year 0.868 $m^3 \cdot s^{-1}$. The lowest monthly

discharges decreased to 0.3 $m^3 \cdot s^{-1}$, i.e. to approximately 1.4 $dm^3 \cdot s^{-1} \cdot km^2$. Their highest values occurred in March, and lowest in June and July (Fig. 6). Maximum discharge in the observation period amounting to 4.85 $m^3 \cdot s^{-1}$ occurred in May 2014 after very high precipitation, reaching a monthly total of 240 mm in Radawiec. In the cold half-year, the maximum discharge slightly exceeded 2.0 $m^3 \cdot s^{-1}$ in 2010 (Fig. 6).

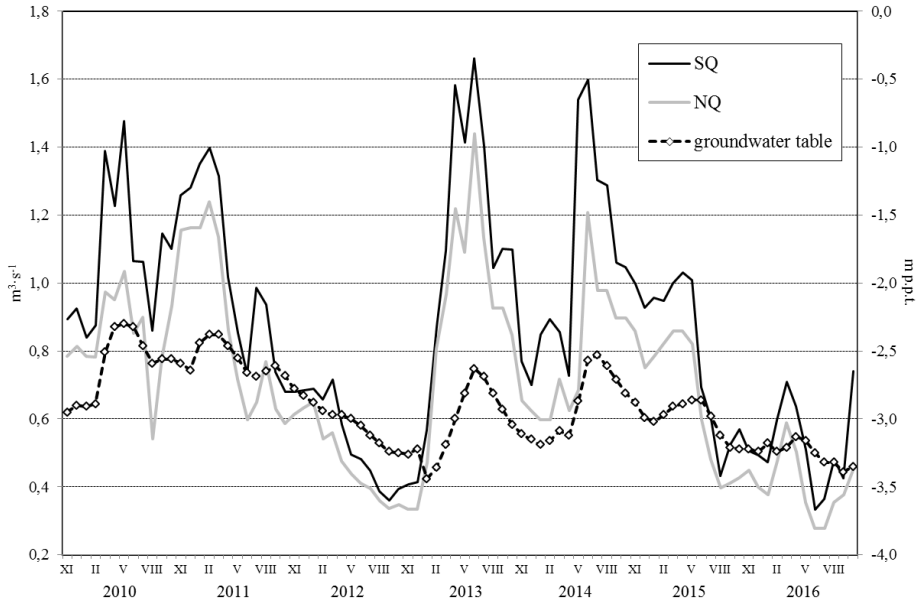

Fig. 5. Mean (SQ) and minimum (NQ) monthly discharge in the Krężniczanka River in Krężnica, and mean monthly groundwater table in Babin

Mean specific runoff reaches almost 3.98 $dm^3 \cdot s^{-1} \cdot km^2$, and is maintained on the level of the mean value for the upland area of the Lublin Region. Its value is lower by approximately 1.6 $dm^3 \cdot s^{-1} \cdot km^2$ than the value for Poland. The highest daily specific runoff reached only 22 $dm^3 \cdot s^{-1} \cdot km^2$ – a low value at the scale of the Lublin Upland.

Based on the collected hydrometeorological data, the water balance equation was developed for the Krężniczanka catchment for the years 2010–2016.

$$\text{Precipitation} = \text{runoff} + \text{evapotranspiration}$$

$$629.4 = 125.7 + 503.7 \text{ mm}$$

Annual values of the components of the water balance are presented in Fig. 7. It also presents the state of retention, calculated from monthly balance values. Annual balance surpluses of water were determined in 2010, 2014, and 2016. In the remaining years, the annual balances showed a deficit.

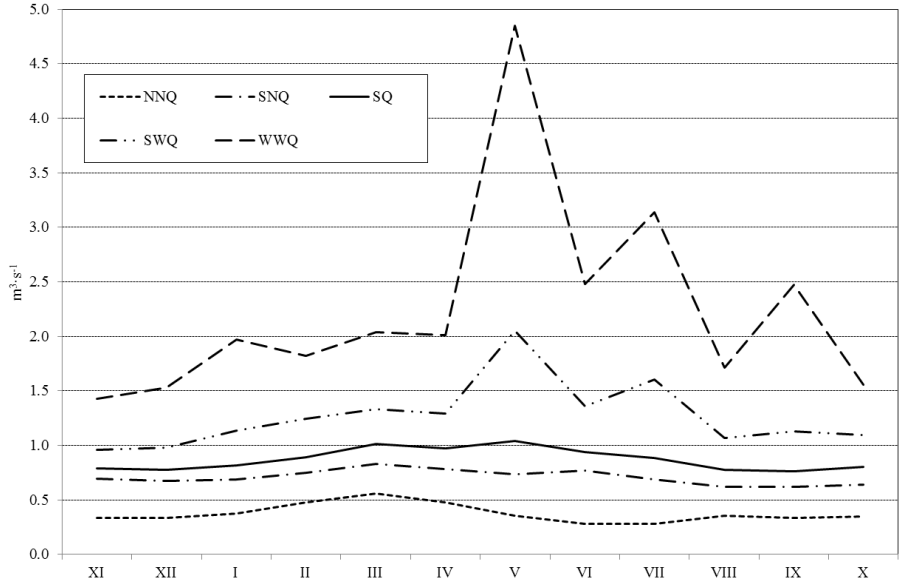

Fig. 6. Characteristic discharges of the Krężniczanka River in Krężnica in the years 2010–2016. Monthly discharge: NNQ – the lowest, SNQ – mean from the lowest values, SQ – mean, SWQ – mean from the highest values, WWQ – the highest

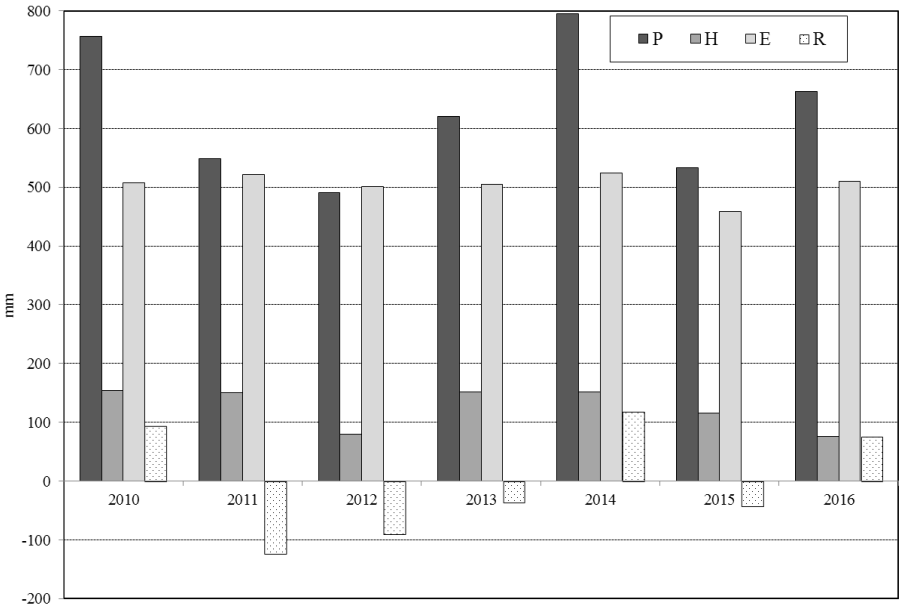

Fig. 7. Annual components of the water balance of the Krężniczanka River catchment: P – precipitation in Radawiec, H – runoff from the catchment to Krężnica, E – evapotranspiration, R – calculated state of retention

The annual precipitation total calculated based on data of IMGW for station Lublin-Radawiec varied from 490 mm in 2012 to 795 mm in 2015. Mean atmospheric alimentation for the years 2010–2016 reached 629.4 mm. It was higher by 40 mm in comparison to the period 1951–2016. The runoff layer in the period of seven years of observation reached 125.7 mm. The highest runoff occurred in the years 2013–2014, and the lowest in 2016. Mean value of evapotranspiration calculated by the Konstantinow method based on data from station Lublin-Radawiec amounted to 503.7 mm. Its annual values varied from 501 mm to 524 mm. The lowest stages of retention calculated from monthly values of water balance occurred at the end of 2012.

SUMMARY

In the Krężniczanka catchment, rocks of the Cretaceous horizon developed as marls with different degrees of resistance, as well as gaizes and opokas, have the primary importance for the conditions of water circulation and retention. They are covered with a thin layer of permeable Quaternary sediments, and in the northern part gaizes and aeolian formations. Groundwaters occurring in rocks of the Cretaceous, Palaeocene, and Quaternary develop a single surface declining to river valleys. Only locally, in watershed zones, higher water stages and perched waters occur. The pattern of groundwater contours points to concentric flow of groundwater to the lower section of Krężniczanka – below the mouth of the Nędznica River. Wells of the prospective water uptake for Lublin "Strzeszkowice" were established in the area.

Good conditions of infiltration of precipitation waters permit water retention in the bedrock. This feature determines a high degree of discharge equalisation and high contribution of groundwater supply in total runoff. Overland flow occurs sporadically, and its higher contribution in runoff occurs during a longer period of high precipitation or overland flow of meltwaters on frozen ground. Groundwater reaches rivers through direct channel drainage of the resources of the Cretaceous-Quaternary horizon. The contribution of springs in river alimentation is low. Synchronic changes in groundwater tables and discharge in Krężniczanka were recorded. Mean specific runoff from the Krężniczanka catchment amounts to almost 4 $dm^3 \cdot s^{-1} \cdot km^2$. The value is comparable to the mean value of runoff from the upland area of the Lublin Region.

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CHARAKTERYSTYKA HYDROLOGICZNA KRĘŻNICZANKI

Streszczenie. W pracy przedstawiono zasoby wodne dorzecza Krężniczanki opracowane na podstawie materiałów hydrologicznych i hydrogeologicznych Zakładu Hydrologii UMCS. Jej zlewnia o powierzchni 224,9 km^2 położona jest na południowy zachód od Lublina, głównie na obszarze Równiny Bełżyckiej. Sieć rzeczna jest stosunkowo rzadka, co wynika z dobrej przepuszczalności podłoża skalnego. Rzeki są zasilane głównie wodami podziemnymi krążącymi w marglach, opokach i gezach górnej kredy, a lokalnie również skałach paleocenu i czwartorzędu. W 2009 r. założono w dolnym biegu rzeki automatyczny rejestrator stanów wody, z którego dane umożliwiły opracowanie dynamiki i reżimu odpływu. Średni odpływ w latach 2010–2016 wynosił 125,7 mm, opad 629,4 mm, a ewapotranspiracja 503,7 mm. Stwierdzono dużą zgodność rytmu odpływu i zmian stanów wody podziemnej. Wielkość zasilania podziemnego w odpływie całkowitym wynosiła 81,5%.

Słowa kluczowe: wody podziemne, odpływ, bilans wodny, Krężniczanka, Wyżyna Lubelska