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Groundwater circulation in the Miechów Trough and the central part of the Carpathian Foredeep (Poland): a hydrogeological conceptual model

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Abstract

The Miechów Trough and the central part of the Carpathian Foredeep in southern Poland have a highly complex geological structure and numerous fault zones. These features play a significant role in hydrogeological conditions of the area. In this area drinking water, medicinal groundwater or thermal groundwater occur, so recognition of their circulations is basic for reasonable groundwater management. In this note, a hydrogeological conceptual model, created for the purpose of regional scale mathematical modelling, is presented. This conceptual model illustrates the geology of the hydrogeological system modelled, as well as hydrogeological conditions and characteristics of groundwater circulation, as determined by tectonics. Typical of the research area is the wide diversity of geological and hydrogeological conditions. The Busko-Zdrój area, a region with a long history of exploitation of medicinal groundwater, presents the best example.

Key words: regional aquifer systems, groundwater modelling, central Europe

1. Introduction

The Miechów Trough and the central part of the Carpathian Foredeep are regions with drinking water, medicinal groundwater and thermal groundwater. Sulphurous medicinal groundwater is exploited in the town of Busko-Zdrój and in the villages of Las Winiarski, Dobrowoda and Cudzynowice (Fig. 1). The same water in the northern part of Busko-Zdrój and at Cudzynowice is also considered as thermal groundwater on account of temperatures above 20°C (PGG, 2017).

The presence of sulphurous medicinal groundwater and thermal groundwater offers opportunities for use and economic development for many regions in the Miechów Trough and the central part of Carpathian Foredeep. Interest in medicinal or thermal groundwater exploitation has led to growth of research efforts and reconnaissance activities. This activity should be implemented with awareness of relationships between economic growth, environment protection and quality of life, according to the notion of sustainable development (Bhattacharya & Bundschuh, 2015; UN, 2015). The basis should consist of reliable information on groundwater, hydrogeological conditions and possibilities of exploitation. The hydrogeological conditions in this area have been outlined in papers by Barbacki (2004a), Paczyński & Sadurski (2007), Lisik (2010), Oszczypko & Oszczypko-Clowes (2010), Górecki (2012) and Lisik & Szczepański (2014). Papiernik (2010) described the specific geology of the Kazimierza Wiel-

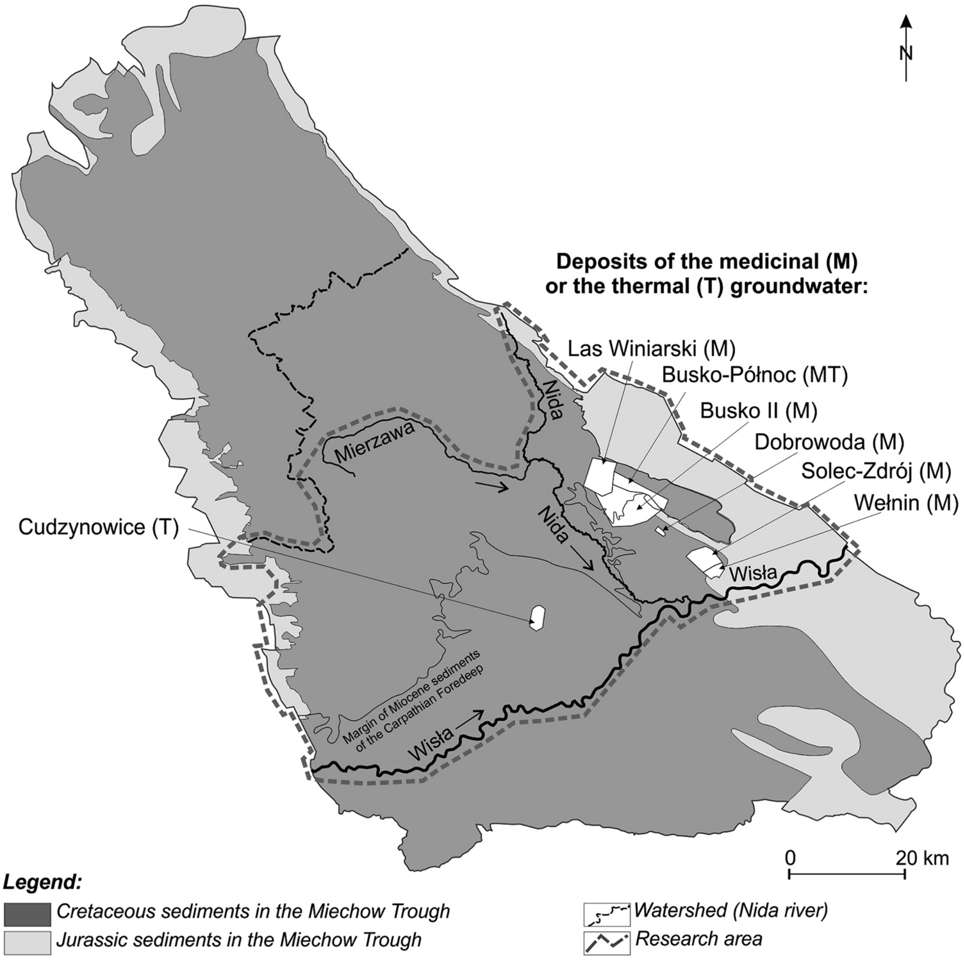

Fig. 1. The study area on the Miechów Trough structure (based on Dadlez et al., 2000).

ka–Pińczów–Busko-Zdrój region, while a detailed characterisation of thermal groundwater in the Cudzynowice region was published by Wiktorowicz et al. (2015) and Wiktorowicz & Nowak (2016). Specifically, the Busko-Zdrój and Solec-Zdrój areas were studied in detail (Lisik, 2010; Lisik & Szczepański, 2014; Gorczyca et al., 2017). The main goal of the present paper is to present results of studies in the Miechów Trough and the central part of the Carpathian Foredeep. This research was the basis for the design of our hydrogeological conceptual model.

2. Characterisation of the study area

2.1. Location

The study area is located in the southeastern part of the Miechów Trough where Upper Cretaceous strata overlie Jurassic and Triassic rocks. According to the newest tectonic mapping of Poland (Żelaźniewicz et al., 2011) this area is situated on the Miechów Segment, a part of the Szczecin-Miechów Synclinorium.

The extent of the study area has been determined on the basis of natural, hydrostructural and hydrodynamic elements. The northwestern border was located in the valley of the River Mierzawa and the northeastern border was set on the valley of the River Nida (Fig. 1). The western border was taken as the line of intersection of Upper Cretaceous sedimentary rocks in the western part of the Miechów Trough. Part of the valley of the River Vistula was adopted as the southern border. The extent of Jurassic rocks was taken as the border line in the eastern part of the study area.

2.2. Lithology

The valley of the River Nida divides the study area into two parts, a western and an eastern. The former is covered by Pleistocene loess (Lindner, 1998) and divided by river valleys consisting of silts, sands, gravels, alluvial soils, peat and fluvial sediments (Jurkiewicz & Woiński, 1977; Kaziuk & Lewandowski, 1978). In the northwestern part mainly Cretaceous rocks occur, e.g., marlstones, opoka with gaizes and Maastrichtian or Campanian limestones. In the northeastern part Jurassic strata occur, e.g., Kimmeridgian and Oxfordian limestones, marlstones and coquinas (Jurkiewicz & Woiński, 1977). North of the town of Busko-Zdrój, there are Neogene clays, sandstones or sands, Pleistocene gravels, sands and glacial deposits. To the south and east of Busko-Zdrój are found Neogene clays ('Krakowiec clays') with mudstones and sandstones (Herman & Gągol, 2000). The valleys of the rivers Vistula and Nida mainly have alluvial soils with mudstones, sands and gravels. In the valley of the latter river also zones with Miocene deposits occur, such as anhydrite, limestones with sulphur, gypsum with clay and halite (Kasprzyk, 2005).

Underneath the Quaternary, in the northern part of the study area, Upper Cretaceous deposits, mainly marlstones, limestones and opoka with gaizes, of Maastrichtian and Campanian age have been noted (Jurkiewicz & Woiński, 1977). The southern part of the area (i.e., the outer part of the Carpathian Foredeep) has a cover of Neogene strata (Peryt, 2012), e.g., clays and sands ('Grabowiec beds') or clays ('Krakowiec clays') with mudrocks and sandstones (Jurkiewicz & Woiński, 1977). The eastern part of the study area is covered by deposits of Cretaceous age, e.g., marlstones and limestones (Santonian), limestones with flints and limestones with glauconite (Coniacian), glauconitic marlstones and limestones with flints (Turonian) and sands and sandstones with glauconite and phosphorite of Cenomanian date (Jurkiewicz & Woiński, 1977). The Jurassic succession represents two series of carbonates of Oxfordian and Kimmeridgian age (Romanek, 1982).

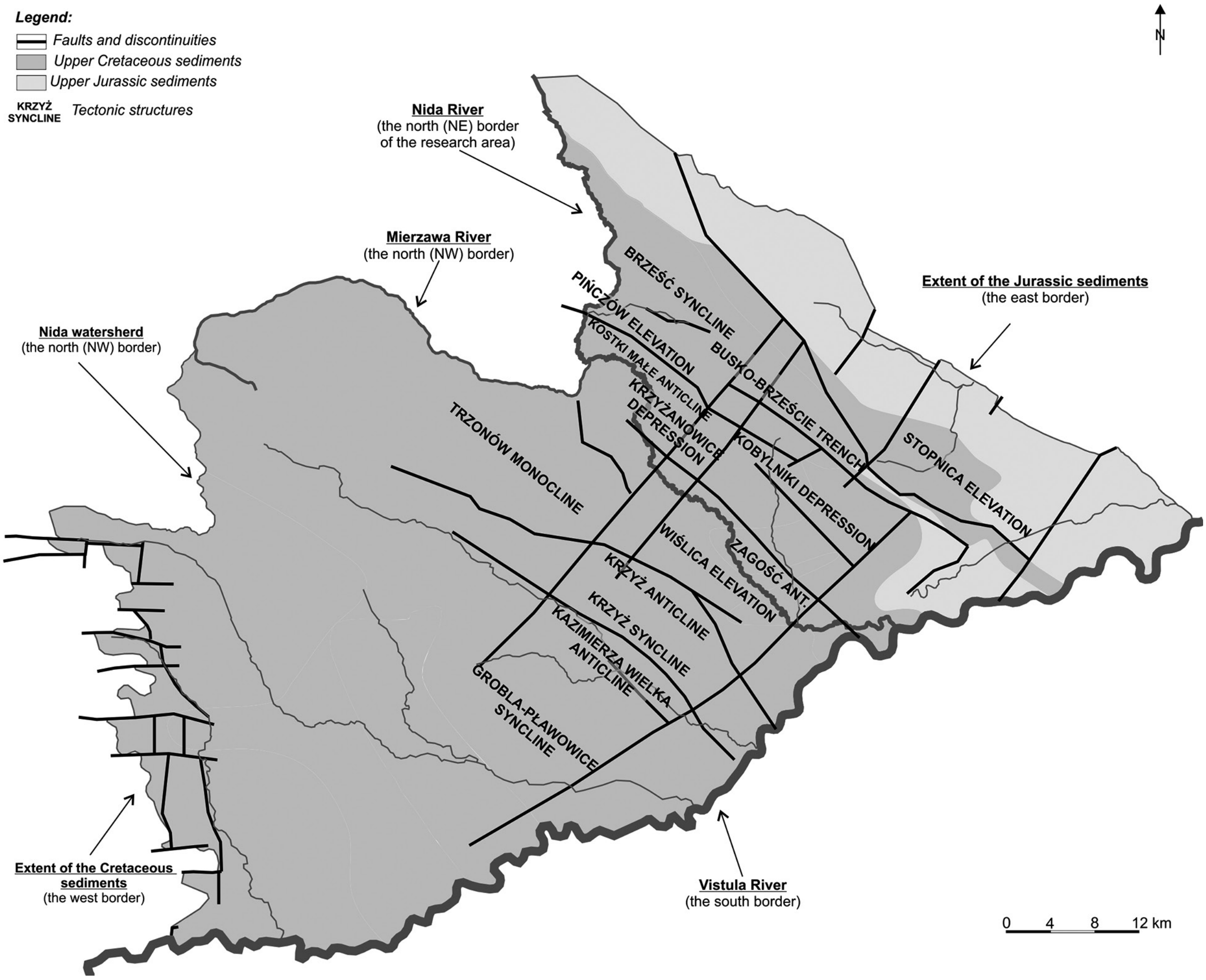

Fig. 2. Tectonic structures of the Miechów Trough (based on Porwisz & Mądry, 2000; Papiernik, 2010).

2.3. Tectonics

Sediments of the Miechów Trough accumulated in a syncline, the form of which was determined by northwesterly-southeasterly directed faults. The second fault system has a southwesterly-northeasterly trend, which is why the Miechów Trough tectonic system is referred to as a "fold-block structure" (Oszczypko & Oszczypko-Clowes, 2010; Różkowski & Różkowski, 2010; Lisik & Szczepański, 2014). Structures related to the northwesterly-southeasterly faults are the main blocks, crossed by southwesterly-northeasterly faults. On account of these faults, the Miechów Trough structural blocks sank in a southerly and easterly direction and created a stair-like structure (Różkowski & Różkowski, 2010). This also explains the differences in the thickness of layers and in sediment parameters. The block structure explains differences in geological sections, even in nearby areas. Lots of evidence of that were demonstrated in boreholes at Busko-Zdrój and Las Winiarski (Zuber et al., 2010). A characteristic feature of the study area is also the occurrence of elevated (e.g., elevations, anticlines) and depressed structures (e.g., synclines) (Fig. 2).

3. Material and methods

A hydrogeological conceptual model presents information on water circulation and allows to create a mathematical model (Przybyłek & Hermanowski, 2016). A conceptual model is a description of a geological structure and contains characteristics of the hydrogeological system, e.g., lithostratigraphy, tectonic structure, hydrogeological conditions with aquifers, etc. (Dąbrowski et al., 2010). Such a model should also contain a hypothesis on groundwater circulation in aquifers.

During preparation of a hydrogeological model on a regional scale the most important is aggregation of geological layers and aquifers into the main model layers. Basic to the conceptual model are ideas which "map" real phenomena into simple equivalents. The conceptual model is also a set of individual interpretations and hypotheses tested in the mathematical model.

For creating a conceptual model the following data were used (Table 1):

- single point information, e.g., geological sections, results of hydrodynamic tests, data on groundwater tables and surface water flow, measurements of temperature, infiltration of precipitation, well location and groundwater intake rates;

Table 1. Data sources.

Sources of data	Type of data
Polish Geological Institute-National Research Institute	Geological Maps of Poland in scale 1:200 000 (Jurkiewicz & Woiński, 1977 – Tarnów; Kaziuk & Lewandowski, 1978 – Kraków)
	Detailed Geological Maps of Poland in scale 1:50 000 (Senkowicz, 1955 – Pińczów (884); Romanek, 1979 – Chmielnik (885); Łyczewska, 1971 – Busko-Zdrój (917); Walczowski, 1973 – Stopnica (918))
	Hydrogeological Maps of Poland in scale 1:200 000 (Kowalczewska, 1981 – Tarnów; Jóźwiak & Kowalczewska, 1984 – Kraków)
	Hydrographic Maps of Poland in scale 1:50 000 (MPH, 2015)
	Data of the Polish Hydrogeological Survey (PSH, 2015)
	Information from database "Mineral, thermal and medicinal water" (PSH, 2015)
	Information from database „Exploitation" (PSH, 2015)
	Information from database „Groundwater monitoring" (PSH, 2015)
	The balance of mineral resources deposits in Poland (PIG, 2015)
	Central Geological Database (CBDG, 2013-2016)
Institute of Meteorology and Water Management-National Research Institute	Hydrological data – state and flow for IMGW stations (IMGW, 2015)
	Meteorological data – precipitation quantity for IMGW station (IMGW, 2015)
Central Office of Geodesy and Cartography	Topographic maps in scale 1:200 000
	Topographic maps in scale 1:50 000
	Topographic maps in scale 1:25 000
	Digital Elevation Model 100×100 m (CODGiK, 2015)
Hydrogeotechnika Company	Hydrogeological Documentation of medicinal groundwater resources

- line information, e.g., geological and hydrogeological cross sections, results of geophysical surveys;
- areal information: geological and hydrogeological maps, topographical maps, digital elevation model.

In addition to the data presented in Table 1, publications of the Polish Geological Institute-National Research Institute on about 1,035 boreholes were used, as well as:

- explanations to Geological Maps of Poland, scale 1:200,000 (Jurkiewicz & Woiński, 1977; Kaziuk & Lewandowski, 1978) and explanations to Detailed Geological Maps of Poland, scale 1:50,000 (Łyczewska, 1972; Walczowski, 1976; Romanek, 1982);
- information on boreholes in papers by Barbacki (2004a) and Lisik & Szczepański (2014);
- internet data bases of the Polish Geological Institute-National Research Institute (CBDG, 2013–2016).

4. Hydrogeological model

4.1. Structure and aquifers

The top of layers in the conceptual model has been mapped as a surface morphology. The bottom boundary has been set according to data from the boreholes Pawęzów 2, Pawęzów 5 and Łukowa 2. The base of the Upper Jurassic strata has been found in these boreholes at depths below 1,800 m and there was the deepest level of the Upper Jurassic sediments in the study area. The hydrogeological system has been mapped as five layers (Table 2; Fig. 3).

Surfaces of layers division has been adopted on the basis:

- data on 560 deep wells (drilled through more than two stratigraphical levels) and 475 shallow boreholes (drilled through no more than two);
- data on 3,506 boreholes from data bases of the Polish Hydrogeological Survey (PSH, 2015).

The Jurassic aquifer consists of Callovian and Oxfordian limestones. This is fractured-porous aquifer with a great diversity of hydrogeological parameters (Barbacki, 2004b). Fractures are particularly characteristic in zones where the Jurassic rocks occur at the surface, e.g., in the western and eastern part of the study area and in the upper parts of the structural floor. The aquifer recharge in the study area boundary zones goes through infiltration of precipitation or through groundwater leakage from Quaternary, Miocene or Cretaceous rocks of limited thicknesses.

The Cenomanian aquifer is formed by sands and sandstones, its extent being limited because of the absence of Cenomanian strata in the south-

Table 2. Geological section and data on model levels.

Number of model layer	Hydrogeological structure	Surface elevation (m a.s.l.)
I	Aquifer (Quaternary sands and graves, Jurassic, Cretaceous and Miocene fractured carbonate sediments)	top elevation: +435.00 ÷++99.10
II	Aquifer zones (divided by aquifuge zones) (aquifers – Santonian-Maastrichtian sediments and Miocene sands and limestones; aquifuges – Miocene clays)	+424.00 ÷++81.00
III	Aquifuge (Upper Cretaceous marlstones)	+340.00 ÷–872.00
IV	Aquifer (Cenomanian sands and sandstones and Upper Jurassic carbonate sediments)	+357.50 ÷–906.50
V	Aquifer (Jurassic carbonate sediments)	+334.00 ÷–1017.50 +327.20 ÷–1837.00

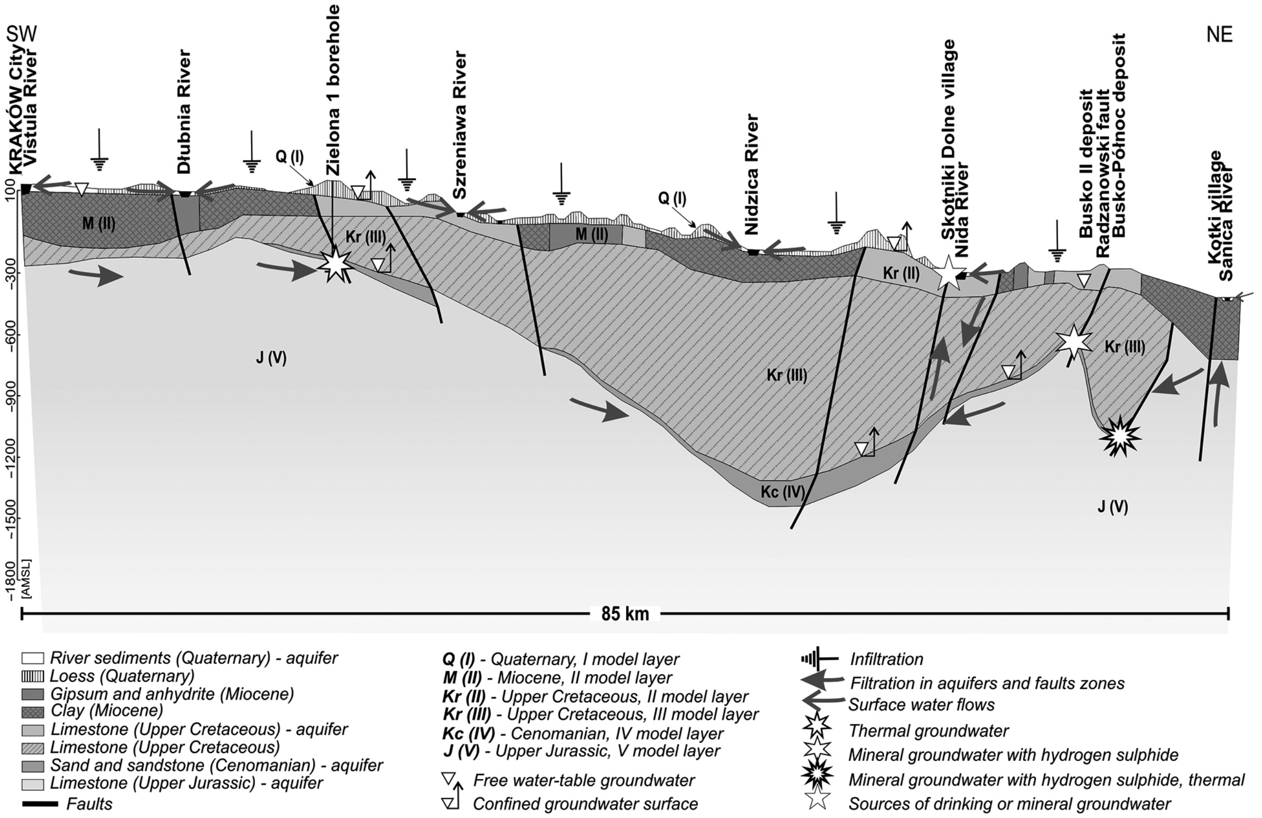

Fig. 3. Hydrogeological conceptual model for the study area.

western, southeastern and eastern part of the study area. In the Cenomanian aquifer take place confined groundwater surface. Infiltration from precipitation is possible only in a limited area, i.e., between the villages of Sobków and Kije and the nearby village of Stopnica. Another possibility of recharge could be a tectonic discontinuity. It might be a way of filtration for groundwater from aquifers younger than Cenomanian and from the Upper Jurassic.

The Santonian-Maastrichtian aquifer is formed by marlstones that occur across the entire study area. There is the fractured type aquifer to a depth of about 100–120 m. In deeper zones groundwater circulation disappears because of compression (Różkowski & Różkowski, 2010). The groundwater table is free in the locations where aquifer is elevated to the ground surface. The groundwater-table surface is confined under Quaternary and Miocene sedimentary rocks. Aquifer recharge is possible as infiltration of precipitation in places where Santonian-Maastrichtian strata in surface-near zones. The second possibility is vertical leakages form the Quaternary and Miocene sediments. The third option concerns horizontal flow between the Santonian-Maastrichtian and Jurassic aquifer in contact zones, especially in the marginal zones of the study area. In the Carpathian Foredeep the Santonian-Maastrichtian strata underlie Miocene levels; these sediments form hydraulic isolation also for other aquifers because it is a marlstone complex with less good hydrogeological parameters.

The Neogene aquifer zones occur in limestones, sands and sandstones in the northeastern part of the study area, representing a porous-fractures-karst type. The Neogene aquifer zones occur also in a gypsum and anhydrite zones in the valley of the River Nida. The groundwater table could either be a free or a confined type. Recharge of the Neogene aquifer zones is possible by infiltration of precipitation in zones where strata extend to the ground surface and as a result of the leakage from Quaternary strata. Other infiltration possibilities could occur in discontinuity zones crossing sandstone complexes (Barbacki, 2004c).

The Quaternary aquifer is a noncontinuous structure, divided by zones of outcrops of Miocene, Cretaceous or Jurassic strata and zones of Quaternary strata of weak or non-filtration type. The Quaternary aquifer is formed by gravels and fluvial sands of the porous type. The groundwater table is free and recharge is connected to infiltration of precipitation.

4.2. Hydrogeological parameters

According to Różkowski & Różkowski (2010), the permeability of Upper Jurassic sediments shows significant variation. The Upper Jurassic aquifer is fractures-porous-karst type with hydraulic conductivities value ranges from 10^{-7} to 10^{-4} m/s. The Cenomanian aquifer hydraulic conductivity values ranges from 10^{-6} to 10^{-5} m/s. The capacity of Santonian-Maastrichtian aquifer permeability is higher and reaches values ranging between 10^{-6} and 10^{-4} m/s. Below a depth of 120 m, fractures are compressed and filtration possibilities decrease to a range from 10^{-9} to 10^{-7} m/s (Różkowski & Różkowski, 2010).

According to Polish Hydrogeological Survey data (PSH, 2015), distribution of the hydraulic conductivity value of sediments in the research area has been mapped out (Table 3). These parameters have been calculated on the basis of data from hydrogeological pumping tests executed for wells in the study area.

To this purposes data, from 695 well registers with data on hydraulic conductivity values in different aquifers were used; results are shown in Table 3. The variability of hydraulic conductivity in the study area is substantial and their value is about 99%. For marlstones, the coefficient of variation reaches 216.5%, with a difference between minimum and maximum values from 1.20×10^{-6} to 8.85×10^{-4} m/s. The reasons for this could be depositional and tectonic processes that had an impact on the lithology in different parts of the study area. Occasionally, marlstones could crop out at the surface and be subject to erosional processes. On the other hand, the Cretaceous strata could underlie Neogene and Quaternary deposits and be subject to extensive compression. According to PSH data (2015), the groundwater table in Cretaceous marlstones could appear at a depth of 0.5 m to 189 m and this causes the vertical change of filtration conditions. The smallest variation of hydraulic conductivity has been documented in Quaternary cobbles, boulders

Table 3. Statistics of hydraulic conductivity variation aquifers in the study area (based on PSH, 2015).

Lithology	Age	Number of observation	Minimum	Maximum	Average	Median	Dominant	Standard variation	Coefficient of variation (%)
Hydraulic conductivity *k* (m/s)									
Gravels	Q	111	2.70×10^{-6}	9.41×10^{-4}	2.61×10^{-4}	2.42×10^{-4}	1.22×10^{-4}	2.09×10^{-4}	80.3
Rubbles	Q	7	8.09×10^{-5}	4.55×10^{-4}	2.80×10^{-4}	3.00×10^{-4}	No data	1.42×10^{-4}	50.6
Sands	Q	117	1.60×10^{-6}	9.48×10^{-4}	1.72×10^{-4}	1.25×10^{-4}	2.50×10^{-6}	1.82×10^{-4}	106.0
Boulders	Q	12	1.40×10^{-4}	8.79×10^{-4}	3.21×10^{-4}	2.34×10^{-4}	2.32×10^{-4}	2.02×10^{-4}	62.9
Limestones	M	6	3.87×10^{-5}	1.93×10^{-3}	8.27×10^{-4}	7.49×10^{-4}	No data	6.90×10^{-4}	83.4
Sandstones	M	17	3.80×10^{-6}	3.16×10^{-4}	7.76×10^{-5}	3.10×10^{-5}	No data	9.01×10^{-5}	116.2
Sands	M	15	1.60×10^{-6}	1.54×10^{-4}	4.01×10^{-5}	1.52×10^{-5}	No data	4.33×10^{-5}	107.9
Gypsum	M	3	1.10×10^{-6}	1.80×10^{-6}	1.33×10^{-6}	Not calculated			
Clay-shales, clay-marlstones	M	2	6.70×10^{-6}	8.80×10^{-6}	7.75×10^{-6}	Not calculated			
Lithothamnium limestones	M	2	1.03×10^{-4}	3.45×10^{-4}	2.24×10^{-4}	Not calculated			
Detrital limestones	M	4	9.50×10^{-6}	6.75×10^{-5}	2.73×10^{-5}	Not calculated			
Limestones with flints	C	6	1.16×10^{-5}	6.81×10^{-5}	3.27×10^{-5}	3.18×10^{-5}	No data	1.85×10^{-5}	56.5
Marlstones-limestones	C	21	3.20×10^{-6}	8.41×10^{-4}	1.40×10^{-4}	6.35×10^{-5}	5.10×10^{-6}	2.06×10^{-4}	147.7
Limestones	C	21	1.25×10^{-5}	6.59×10^{-4}	1.76×10^{-4}	1.42×10^{-4}	No data	1.56×10^{-4}	88.9
Clay-marlstones	C	61	1.20×10^{-6}	8.85×10^{-4}	6.76×10^{-5}	1.25×10^{-5}	1.50×10^{-6}	1.46×10^{-4}	216.5
Marlstones	C	265	1.10×10^{-6}	9.47×10^{-4}	1.24×10^{-4}	5.50×10^{-5}	1.05×10^{-4}	1.73×10^{-4}	140.0
Marlstones with flints and opoka	C	5	1.52×10^{-5}	4.74×10^{-5}	2.98×10^{-5}	2.95×10^{-5}	No data	1.03×10^{-5}	34.6
Limestones with flints	J	7	3.40×10^{-6}	3.78×10^{-5}	1.54×10^{-5}	1.35×10^{-5}	No data	1.08×10^{-5}	70.1
Limestones	J	13	2.20×10^{-6}	2.30×10^{-4}	6.29×10^{-5}	1.60×10^{-5}	No data	7.58×10^{-5}	120.4
Sum		695							

Age: Q – Quaternary, M – Miocene, C – Cretaceous, J – Jurassic.

and gravels, possibly because geological conditions of Quaternary aquifers are quite homogeneous. Gravels usually are the ground surface sediments, appearing mainly in river valleys to depths of a few metres and of limited thickness. A slight variability was also observed in Jurassic and Cretaceous marlstone-type strata with flints.

4.3. Groundwater recharge and drainage

According to Różkowski & Różkowski (2010), deep gravitational systems of groundwater infiltration in Jurassic and Cretaceous strata nowadays are formed outside the Carpathian Foredeep, i.e., in the northern part of the Miechów Trough. The Kraków-Częstochowa Upland area in the west and the Holy Cross Mountains in the east should be considered the main recharge zones of the Upper Jurassic and Cenomanian aquifers. Recharge could be also a slow precipitation leakage through Upper Cretaceous carbonates of the Miechów Upland and filtration occurring in the fault zones.

The base of the drainage of groundwater in the Miechów Trough is the River Vistula (Różkowski & Różkowski, 2010) and this causes a groundwater flow into the direction of this Vistula valley (Zuber et al., 2010). In part, the base of the regional drainage system could also be the valley of the River Nida. The local base of the groundwater drainage could also be formed by smaller rivers, permeable fault zones and permeable deposits. To the east of the valley of the River Nida natural groundwater drainage was found in the form of numerous springs of mineral waters. Probably, their origin is related to a vertical groundwater flow in the tectonic discontinuity zones (Dowgiałło et al., 2002). Historical information, archive data and contemporary research (Migaszewski, 2010, 2013) show that in the Busko-Zdrój and Solec-Zdrój area there are numerous springs.

4.4. Faults, discontinuous zones and groundwater circulation

The presence of numerous faults and discontinuity zones is significant for the formational processes of groundwater circulation. According to Dowgiałło et al. (2002), two types of faults could be distinguished, namely aquifuge or permeable. Generally, faults could determine groundwater flow in three different ways (Sitek & Kowalczyk, 2014). The faults and discontinuities could be: 1) zones for easy groundwater flow; 2) zones acting as hydraulic barriers; 3) combined-type zones. To date, no studies have been carried out to answer queries which types of faults are represented in the Miechów Trough. Assessment of the character of faults and their impact on conditions of groundwater circulation was done only during hydrodynamic pumping tests (Lisik & Szczepański, 2014).

In the aquifuge fault zones, an increase of hydrodynamic pressure could occur (Różkowski & Różkowski, 2010). The path for easy groundwater filtration could be also fault zones and zones with a natural growth of permeability, for example, in zones of erosion and denudation in the top parts of Upper Jurassic and Cretaceous floors. In the fractured fault zones migration and accumulation of deposit fluids are possible. Characteristic of this zone, according to Barbacki (2009), are fewer accumulation possibilities and groundwater storage due to limited capacity.

An example of a hydraulic barrier for groundwater flows and exchanges between aquifers is the Radzanowski fault and orthogonally located faults, occurring between the town of Busko-Zdrój and the village of Las Winiarski. Hydrogeological research carried out for the LW-1 and LW-2 boreholes at Las Winiarski and the C-1 borehole at Busko-Zdrój has shown the hydrodynamic barrier character of these faults (Szczepański & Porwisz, 2007; Lisik & Szczepański, 2014). Simultaneously, this has mapped out possibilities of mixing mineral groundwater from different aquifers in tectonic blocks due to ascent or descent along tectonic discontinuities (Szczepański & Porwisz, 2007).

4.5. Groundwater exploitation

The Quaternary and Santonian-Maastrichtian aquifers are the basis for extraction of drinking groundwater for economic and municipal purposes in the study area. In the marginal zones also Jurassic aquifers are exploited. Medicinal sulphurous groundwater occurs in Cenomanian and Jurassic aquifers at Busko-Zdrój and Las Winiarski and at the nearby Cudzynowice (Zuber et al., 2010; Lisik & Szczepański, 2014; Wiktorowicz & Nowak, 2016). At the nearby town of Solec-Zdrój and the village of Wełnin medicinal groundwater occurs in the Jurassic aquifer. In some places, medicinal groundwater is found in combined Jurassic-Cretaceous aquifers which could have a cover of Miocene strata of a huge thickness and aquifuge, for example clays, marlstones and gypsum. In the village of Dobrowoda groundwater occurs in the local tectonic-erosional structure which is the Neogene-Cretaceous-Jurassic aquifer zone.

5. Conclusions

The main goal of the present paper is to characterise conditions of groundwater circulation in part of the Miechów Trough and the central part of the Carpathian Foredeep in a hydrogeological conceptual model. Natural structural and hydrodynamic borders were adopted as the confines of the study area. The southern border was placed at the River Vistula, the northern by the rivers Mierzawa and Nida. The western and eastern borders were set at the extent of Jurassic deposits in the Miechów Trough.

Investigations conducted on a regional scale have led to identification of geological and hydrogeological conditions in the study area. On the basis of numerous analyses have allowed to create a conceptual model of groundwater circulation on a regional scale. The most important conclusions are that aquifers in the Miechów Trough and the central part of the Carpathian Foredeep occur in geological structures with an unconfirmed hydrodynamic role of faults. Fault zones and block structures could have an impact on differences in flow directions of groundwater, recharge and drainage conditions and quantity of groundwater in various geological structures (blocks).

Proper hydrogeological recognition is the basis of effective projects and allows opportunities for sustainable development in places where thermal and medicinal groundwater is explored. At present, the Miechów Trough and the central part of the Carpathian Foredeep are areas with a high level of geological recognition. However, many problems related to hydrogeology still should be explained in future. This means that additional research efforts should be made all across the Miechów Trough and the central part of the Carpathian Foredeep for purposes of responsible groundwater management and assessment of exploitation possibilities of medicinal sulphurous groundwater. Lisik & Szczepański (2014) demonstrated that it was particularly significant in new places and this has been confirmed in the Cudzynowice borehole.

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