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# PARTICIPATION OF QUATERNARY AQUIFERS IN GROUNDWATER INFLOW TO MINES IN THE UPPER SILESIAN COAL BASIN (USCB)

# UDZIAŁ WODONOŚNYCH UTWORÓW CZWARTORZĘDOWYCH W PROCESIE ZAWODNIENIA KOPALŃ GÓRNOŚLĄSKICH

The Upper Silesian Coal Basin (USCB) is situated within Variscean depression in the southern Poland. Mining of the hard coal, ore and sand deposits in the USCB has a long-lasting tradition. Exploitation has been carried out with both – open pit and mainly underground operations. The intensity of water inflows to mines depends on geogenic and technological factors. Among geogenic factors the main one is occurrence of thick water – bearing Quaternary sediments in the roof of Carboniferous ore deposits. Among technological factors the essential influence on the inflows to the mine workings have: time, depth and surface of exploitation, as well as drainage intensity.

**Keywords:** USCB, Quaternary sediments, mining of hard coal, ore and sand deposits, water inflow to mines

Górnośląskie Zagłębie Węglowe (GZW) jest niezależnym regionem hydrogeologicznym. W jego zasięgu wydziela się dwa subregiony hydrogeologiczne: północno-wschodni ( I) i południowo-zachodni (II), o odmiennych układach i warunkach hydrogeologicznych. Granicę między subregionami wyznacza zasięg występowania zwartej pokrywy ilastych, izolujących podłoże, utworów miocenu. W zasięgu subregionu I czwartorzędowe poziomy wodonośne znajdują się w więzi hydraulicznej z poziomami wodonośnymi karbonu lub triasu. W subregionie II więź hydrauliczna między karbońskimi i czwartorzędowymi poziomami wodonośnymi występuje tylko w zasięgu erozyjnych okien hydrogeologicznych w utworach miocenu. Na obszarze GZW obserwuje się wyraźne zróżnicowanie miąższości i wykształcenia litologicznego pokrywy utworów czwartorzędowych. Wspomniane utwory są reprezentowane przez piaszczysto-gliniaste osady, których miąższości wahają się w granicach od dziesiętnych metra do ponad 120 m.

W zasięgu rejonów górniczych czwartorzędowe poziomy wodonośne są intensywnie drenowane przez wyrobiska górnicze kopalń głębinowych węgla i rud cynkowo-ołowiowych oraz odkrywkowych surowców okruchowych. Eksploatacja górnicza prowadzona jest na skalę przemysłową przez okres ponad dwustu lat. Zawodnienie kopalń jest zróżnicowane i uzależnione od czynników geogenicznych oraz górniczo-technicznych prowadzonej eksploatacji. Przeprowadzone badania wykazały, iż w zawodnieniu

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kopalń głębinowych podstawowe znaczenie posiada infiltracja wód z czwartorzędowego nadkładu w przepuszczalne podłoże. Aktywność procesu przesączania się wód w podłoże jest uwarunkowana przepuszczalnością, miąższością i wodonośnością utworów czwartorzędowych, udrożnieniem skał serii złożowej długotrwałą eksploatacją oraz odwadnianiem skał aktywnym drenażem górniczym.

Utwory czwartorzędowe w obrębie GZW podlegają drenażowi nie tylko w wyniku pośredniego wpływu górnictwa węgla kamiennego, czy rud cynku i ołowiu, ale także są bezpośrednim obiektem eksploatacji, podlegając koniecznemu odwodnieniu. Nagromadzenia bilansowe piasków podsadzkowych udokumentowano, bądź tylko wstępnie rozpoznano dla potrzeb górnictwa węgla kamiennego, wskazując jako najzasobniejsze rejony kopalnych i współczesnych dolin rzecznych Białej i Czarnej Przemszy. Fragmenty dolin i kotlin wypełnionych plejstoceńskimi osadami klastycznymi o wysokiej przewodności objęto granicami Głównych Zbiorników Wód Podziemnych: GZWP nr 453 Biskupi Bór, GZWP nr 455 Dąbrowa Górnicza.

**Słowa kluczowe:** Górnośląskie Zagłębie Węglowe (GZW), czwartorzęd, eksploatacja górnicza, zawodnienie kopalń

## 1. Geologic background

The USCB covers an area of 7500 km$^2$ (including 5500 km$^2$ in Poland). The coal basin is situated within the Upper Silesian Variscean depression. Geologic development of the basin has been affected by the Variscean and Alpine orogenesis (Kotas, 1985). The southern and the north – western parts of the USCB are within the reach of the Carpathian Foredeep, where the Carboniferous sediments are covered by the clayey formation of Miocene (Fig. 1, 2).

The northern part of the USCB area lays in range of the Epi – Variscean platform as well as Mesozoic platform cover (Cracow – Silesian Monocline). The overlying formations of Carboniferous are of the Quaternary, Triassic and locally Jurassic age (Fig. 1, 2).

Coal bearing formation of the coal basin is connected with molasses deposits of the Upper Carboniferous (Namurian-Westphalian). It includes four lithostratigraphic series: 1) paralic (PS) (Namurian A), 2) Upper Silesian sandstone (USS) (Namurian C-D), 3) mudstone (MS) (Westphalian A-B), and 4) Cracow sandstone (CSS) (Westphalian C-D) series (Fig. 2). These series are represented by clay-silt and sandstone complexes with coal seams. Proportion of macroclastic to fine-grained rocks in profiles of these series vary, which influences their diverse ability for water accumulation and hydraulic conductivity.

During Quaternary the USCB has been covered by the Southern Polish glaciation deposits, the Middle Polish glaciation deposits, and partly it was a peryglacial zone of the Northern glaciation (Mojski, 2005). Conditions of the Pleistocene deposits sedimentation in the USCB has been described by G. N. Kotlicka (1964), J. Lewandowski (1996), J.E. Mojski (2005).

At the area of USCB, visible differentiation in thickness and lithology of Quaternary sediment cover has been observed (Doktorowicz-Hrebnicki & Kaszyńska-Makowska, 1975; Kotlicka, 1964; Lewandowski, 1996). Thickness of Quaternary deposits changes from less than one meter to over 120 m (Fig. 3). Their lithology differs too. Pleistocene deposits are built by sandy-clay peryglacial sediments deposited at glacial front. Glacial sediments are represented by clay ground and frontal moraines as well by sandy glacial rivers deposits and loess formed during glacial recession.

Sequence of Quaternary sedimentation and erosion exactly refers to configuration of the older background. Lithologically differentiated Quaternary deposits of considerable thickness fill depressions of tectonic, denudative and erosive origin. The northern part of Silesian Upland,

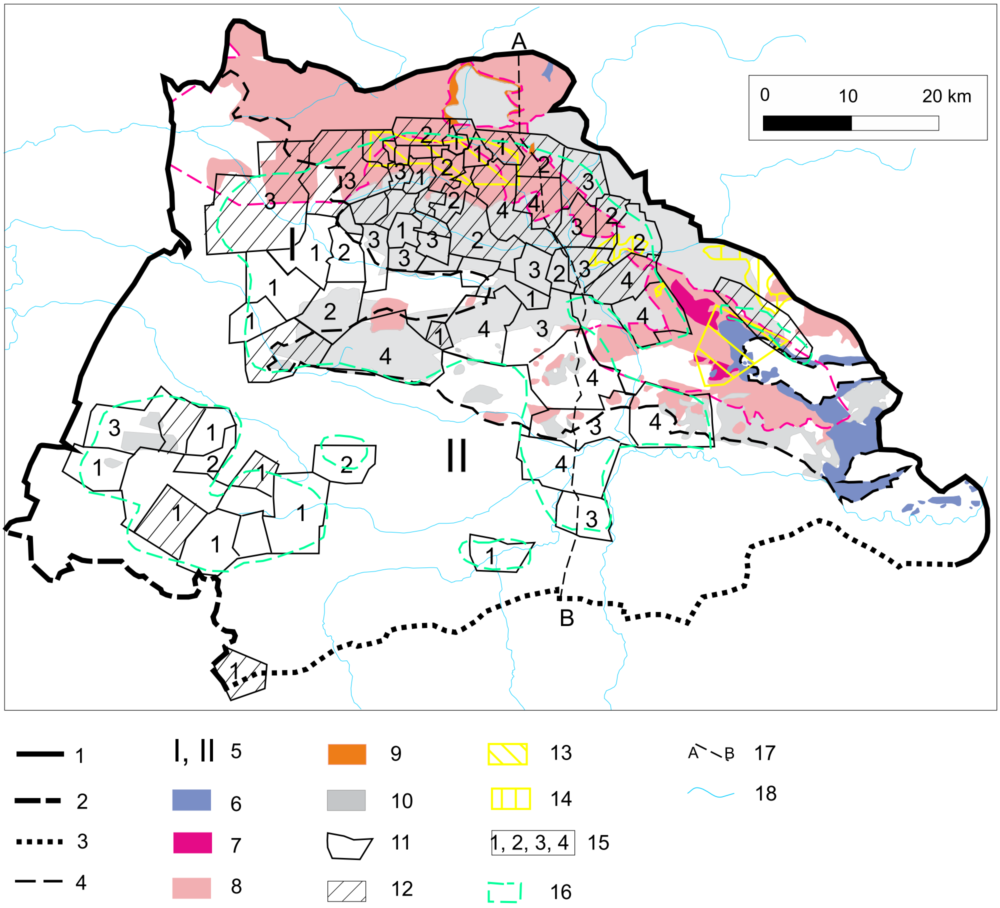

Fig. 1. Map of mining areas and classes of water inflow into mines on the background of geological conditions 1 – extension of the USCB, 2 – state boundary, 3 – Carpathian overthrust boundary, 4 – hydrogeological subregion boundary, 5 – hydrogeological subregion; sediments underlying Quaternary: 6 – Jurassic, 7 – Upper Triassic, 8 – Triassic carbonate series, 9 – Lower Buntsandstein, 10 – Carboniferous; mining areas: 11 – mining areas of the operating coal mines, 12 – mining areas of the abandoned coal mines (by Jureczka et al., 2005), 13 – mining areas of the abandoned Zn – Pb mines, 14 – boundaries of documented sand deposits, 15 – class of water inflow into coal mines, 16 – extension of the mining drainage (according to the data from 1986), 17 – hydrogeological cross–section line, 18 – main rivers

morphologically uplifted, has been strongly altered by denudation processes. Quaternary formation profiles overlying Mesozoic or productive Carboniferous are thin and incomplete here. Considerable thickness is observed in area of buried valleys and in low-lying areas of Oświęcim and Racibórz basins where erosion processes have been considerably less active and therefore thickness of Quaternary sediments overlying Neogene deposits is significant in these areas. The highest thickness of sandy sediments are observed within contemporary and buried valleys of the rivers: Olza, Ruda, Bierawka, Vistula, Kłodnica, Czarna and Biała Przemsza, Przemsza (Fig. 3).

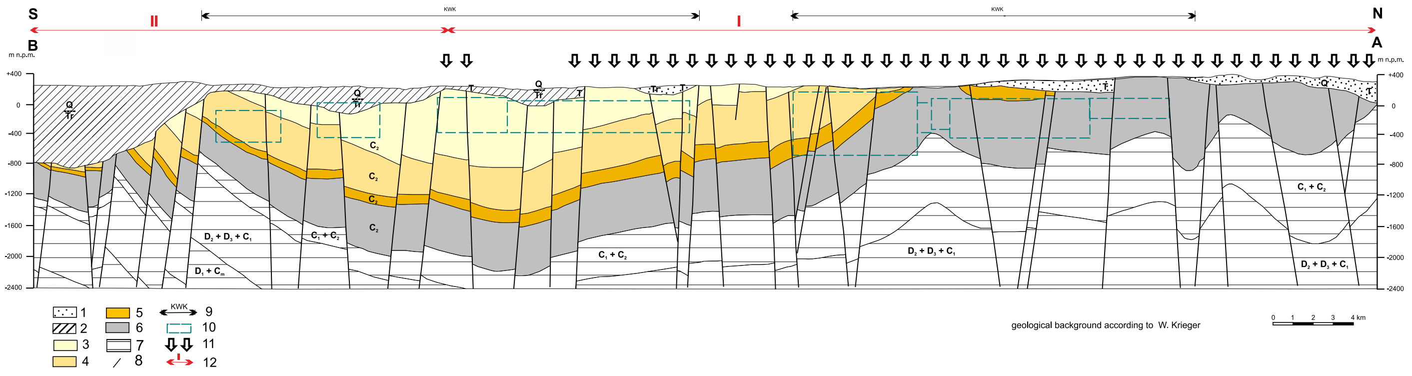

Fig. 2. Hydrogeological cross–section through USCB

Overburden of the Upper Carboniferous: 1 – permeable sediments, unseparated: Quaternary (Q – sands, gravels), Neogene (Tr – sands of thickness <50 m), Triassic (T – limestone, dolomite), Jurassic (J – limestone), Permian (P – conglomerates), 2 – impermeable sediments, unseparated: Quaternary (Q – clays, silts), Neogene (Tr – clays of thickness > 50 m), Triassic (T – marl, siltstone); sediments of Productive Carboniferous: 3 – the Cracow Sandstone Series (CSS), 4 – Mudstone Series (MS), 5 – Upper Silesian Sandstone Series (USS), 6 – Paralic Series (PS), 7 – sediments underlying Productive Carboniferous: $C_2$ – Upper Carboniferous, $C_1$ – Lower Carboniferous, $D_3$ – Upper Devonian, $D_2$ – Middle Devonian, $D_1$ – Lower Devonian, $C_m$ – Cambrian, 8 – faults, 9 – extension of the coal mine mining areas, 10 – scheme of deposit panelling adopted at a mining area, 11 – recharge areas of the Upper Carboniferous, 12 – hydrogeological subregion

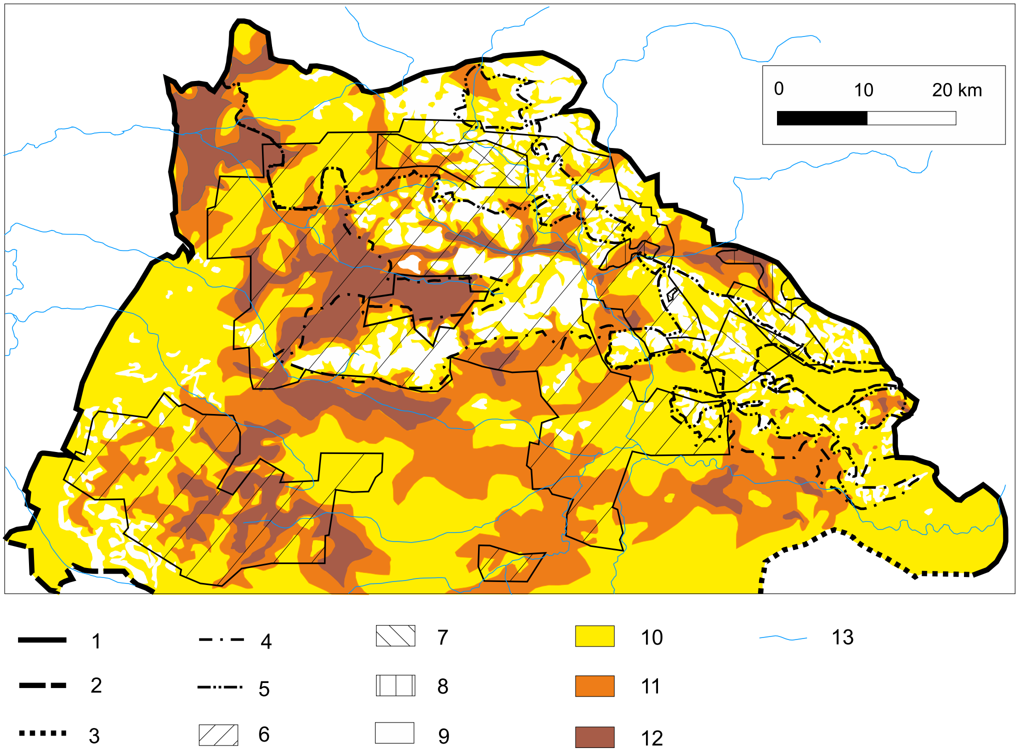

Fig. 3. Map of distribution and thickness of Quaternary sediments in the USCB
1 – extension of the USCB, 2 – state boundary, 3 – Carpathian overthrust boundary, 4 – extension of the Neogene formation, 5 – extension of the Triassic sediments, 6 – mining areas of the coal mines, 7 – mining areas of the Zn – Pb mines, 8 – boundaries of documented sand deposits; extent and thickness of Quaternary sediments (according to Doktorowicz – Hrebnicki, Kaszynska – Makowska, 1975), 9: < 0.5 m, 10: 0.5–25 m, 11: 25–50 m 12: > 50 m, 13 – main rivers

## 2. Hydrogeological characteristics of the area

The USCB hydrogeological region is situated in Variscean basin. Taking into account geological structure of the USCB two hydrogeological subregions can be identified: the north-eastern (I) and south-western (II). Hydrogeological conditions differ in both of them (Różkowski, 1995). A boundary between these two subregions forms the extent of the continuous cap of clayey Miocene deposits isolating basement (Fig. 1).

In the first subregion (I) two hydrogeological systems occur. The first system covers the area of main saddle structures and the NE fold-block structures situated within young Paleozoic platform as well as the northern part of Fore-Carpathian depression. In this system Quaternary sediments lay directly on productive Carboniferous roof. Quaternary aquifers are in hydraulic connection with Carboniferous aquifers. Within the second system there are situated two syncline forms of Chrzanów and Bytom. They occur in the range of Mesozoic platform (Fig. 1). Triassic deposits locally covered by Jurassic sediments lay directly on Carboniferous roof. In within the

Triassic geological profile of Muschelkalk zinc-lead ores occur. Muschelkalk and Quaternary aquifers are in hydraulic connection only within their outcrops areas. In other parts of this complex they are isolated from each other by clay sediments of Upper Triassic (Fig. 1, 2).

In second subregion (II) within Carpathian Foredeep, the roof of productive Carboniferous is isolated by Miocene deposits. Hydraulic connection between Carboniferous and Quaternary aquifers is present only in erosional hydrogeological windows (Fig. 1).

Quaternary sediments are characterized by a range of permeabilities and thicknesses. Quaternary aquifers occur in sandy-gravel deposits of Pleistocene and Holocene age. Thickness of these aquifers varies from less than one to about 80 meters. Useful parts of the aquifers occur mainly in the erosion basins and in river and buried river valleys. Their distribution and resources are significantly diversified (Kotlicka, 1964; Kotlicki, 1958; Kropka & Rubin, 1989; Pikuła, 2007; Różkowski et al., 1997).

Quaternary aquifers have porous character. Water table is free or slightly confined when covered by clay deposits. Hydraulic conductivity varies from $1.13 \times 10^{-5}$ to $6.5 \times 10^{-3}$m/s. These aquifers are characterized by diversified water-bearing capacity. Discharge of a single well varies from 4.9 to 200 $m^3/h$ dependent on drawdown. Specific discharge varies from 0.3 to 124.5 $m^3/h/1$ mS (Chmura, 1997; Pikuła, 2007).

Sandy-gravel Pleistocene aquifers of the buried valleys of: Czarna and Biała Przemsza, Przemsza, Kłodnica, Mała Panew, Bierawka, Ruda, Wisła and Odra rivers play significant part as groundwater basins (Fig. 3). Buried valleys system is only partly in agreement with current hydrographic system. In hydrogeological profile of the valleys usually 1 or 2 aquifers are present. Their thickness vary from few to 80 meters.

Geogenic and anthropogenic factors have an influence on chemistry of waters in Quaternary aquifers. Total mineralization of waters varies from 81 to 3100 $mg/dm^3$. Low mineralized waters predominate (95% of analyzed population). Natural waters are mainly of $HCO_3$-Ca, $HCO_3$-Ca-Mg and $HCO_3$-$SO_4$-Ca-Mg hydrochemical types (Chmura, 1997). A close relationship between water quality, chemical composition and Quaternary formation exposure, spatial management of surface area and specially mining management can be observed.

Recharge of Quaternary aquifers takes place on whole surface directly by rainfall. The Quaternary aquifers of deep cut buried valleys can be recharged also by ascending water in the drainage areas of basement aquifers. Quaternary aquifers are drained by rivers and water infiltration in the recharge area of basement aquifers. The last process is especially active in the NE, tectonically lifted part of the coal basin, on areas of Paleozoic horst structures as well as Silesia-Cracow Mesozoic monocline (subregion I). In Carpathian Foredeep (subregion II) Quaternary aquifers are usually isolated by Miocene clay sediments. Recharge of Carboniferous aquifers takes place only through local hydrogeological windows.

In the mining areas Quaternary aquifers can be intensively drained by mine workings of open-pits and in the case of hydraulic connection with basement aquifers, also by workings of underground mines. In conditions of intensive mining drainage rivers can change their character from draining into recharging. Quaternary aquifers are drained also by wells.

Intensive recharge and active drainage by rivers, mine workings and wells result in short water circulation pathways and significant flow velocities of groundwater in Quaternary sediments. Hydraulic gradients vary between a few per mille, up to tens of per mille in areas of mining drainage.

# 3. Participation of Quaternary aquifers in process of groundwater inflow to the USCB mines

Quaternary aquifers in an area of the USCB and its direct surroundings are subject to special anthropopressure in active mining areas. They are drained by open-pit workings and by underground mines (Fig. 3). Influence of mining drainage is especially intensive in case of concentrated coal mining within an area of the first hydrogeological subregion (Fig. 1). Mining drainage has regional character (Rogoż & Posyłek, 2000; Różkowski & Różkowski, 2011; Wilk, 2003; Wilk & Bocheńska, 2003).

Raw deposits, namely carbonate rocks, clay and clastic rocks (sand and gravel) are exploited in open-pits. Significant amount of deposits is mined over local drainage base of Quaternary aquifer. Quaternary aquifer drainage takes place in all sandpits operating below the water table, where the groundwater inflow is characterized by steady drainage rates.

Hard coal deposits and Zn-Pb ores are exploited by underground mines. Intensity of water inflow to mine workings depends on geological structure and hydrogeological conditions of deposit areas as well as technological conditions of exploitation. Water inflow to mines changes in time depending on altering geological conditions of mining areas and progress of mining exploitation (Różkowski & Różkowski, 2011; Wilk, 2003).

## 3.1. Participation of Quaternary aquifers in process of water inflow to hard coal mines

Within the USCB mining exploitation has been led on industrial scale since 18th century. In history of hard coal mining development can be distinguished by stages of growing intensity of exploitation since 18th till 20th century. This intensity of mining diminished from 1989 when the process of mining restructurization has begun (Różkowski & Różkowski, 2011; Wilk, 2003).

Opencast exploitation of hard coal carried out within the first subregion in the first half of the 18th century influenced hydrogeological regime only marginally. In the period between the second half of the 18th century and the first half of the 19th century underground mining was usually carried out below the water table. The depth of mining did not exceed 70-100 m, causing drainage of Quaternary formation and changing hydrographical network and river discharge regime in the mining areas. During the second half of the 19th and the beginning of the 20th century mining developed very fast. Quaternary formation was deeply drained and water inflow to mines was growing.

Intensive development of hard coal mining and active drainage of Quaternary formation took place after the Second World War, reaching its maximum in the seventies and eighties of the 20th century. Coal exploitation at a level of 201 mln t/year, was carried out by 68 coal mines. Total surface of the coal fields covered about 2000 km$^2$ (Fig. 1). Water inflows into mining drainage/systems creased to 760 m$^3$/min (Różkowski, 1999). Groundwater inflow originated from dynamic and static groundwater resources. Mining drainage covered an area of about 1750 km$^2$ (Fig. 1). The range of drainage reached regional scale. Coal mining activity resulted in reduction in piezometric water pressure from 0,8-3,0 MPa.

Economic reasons related to the depletion of shallow coal deposits forced the process of coal mining restructuring which started in 1989. It resulted in connection of particular neighboring coal fields or their total liquidation. Currently, the coal deposits are exploited by 31 mines at the depth from 270 to 1050 m. The surface of the coal fields covers about 1100 km$^2$. In the 2009 total production reached 71 mln t/year. All mines produce together about 486 m$^3$/min of water.

Cessation of full or partial dewatering of mine galleries in liquidated plants reduced activity of Quaternary aquifer drainage and decreased water inflow into mines. These processes affect all mine areas located in the first subregion (Bradecki & Dubiński, 2005; Rogoż & Posyłek, 2000; Różkowski & Różkowski, 2010; Wilk, 2003).

In the year 2003 all hard coal mines pumped out together about 489 m$^3$/min of water of varying mineralization, including 367 m$^3$/min of fresh or low mineralized (below 3.0 g/dm$^3$) water. Groundwater inflow to individual mine (also to joined ones) varies from 0.68 to 55.8 m$^3$/min. According to Z. Wilk (2003) classification, mines can be divided into four classes taking into account water inflow: 1) small – less than 3.0 m$^3$/min, 2) middle – 3.0 to 6.0 m$^3$/min, 3) high – 6.0-18.0 m$^3$/min, 4) very high – over 18 m$^3$/min. Classes of water inflow to mines in the first and second hydrogeological subregions, respectively to particular hydrogeological arrangement, are shown at Fig. 1.

Observations and studies carried on for many years shown that intensity of water inflow to coal mines depends on geogenic and technological factors (Bukowski, 2002; Grabara, 2006; Rogoż & Posyłek, 2000; Różkowski & Różkowski, 2011; Szczepański 2004**;** Wilk, 2003). Among geogenic factors occurrence of thick permeable Quaternary sediments in a roof of Carboniferous as well as lithostratigraphic structure of series are the main ones. Structural arrangement of beds and tectonic engagement are of lesser importance. Among technological factors the following are of essential influence: time, depth and surface of exploitation, increase of rock massif water holding capacity due to mining exploitation and its intensive drainage connected with dewatering of workings. Analysis of data shows that 38% of active mines belong to the first class of water inflow, while the second, third and fourth represent: 23%, 26% and 13% respectively.

In the first subregion in the range of Epi – Variscean platform where Carboniferous formation is overlain directly by Quaternary deposits, coal exploitation for many centuries caused cracking of rock massif, intensifying variability of water inflow into mines. Inflow ranges from 2.5 m$^3$/min (Śląsk mine) to 55.8 m$^3$/min (Sobieski-Jaworzno III mine) (Różkowski, 2004; Wilk, 2003). The volume depends mainly on thickness and permeability of the Quaternary overburden (Fig. 1, 2).

In the area of main saddle, where Quaternary deposits of some meters thick are of low permeability, inflow to mines changes from a few to several m$^3$/min. These mines belong to the first and second, partly the third class of water inflows (Wilk, 2003).

Very high inflow is characteristic for mines situated in the NE fold-block area where outcrops of productive Carboniferous occur under Quaternary sediments and in the area of the northern decline of main basin. In these parts of USCB buried and contemporary river valleys increase Quaternary aquifer retention. To mentioned rivers belong: Czarna and Biała Przemsza, Przemsza, Brynica, Rawa, fragmentary Drawa and Kłodnica (Fig. 1, 3). Mines extract there coal from well permeable Carbonifrerous complexes of CSS and USS series. High inflow (about 80%) is related to intensive infiltration from Quaternary aquifers which are fed in turn by infiltrating river water (Różkowski, 2004). Most of these mines belong to the highest – fourth class of water inflow.

In the area of Silesia-Cracow monocline structures, within Bytom and Chrzanów troughs (the second hydrogeological system), Triassic deposits were identified in a roof of the Carboniferous. In natural conditions they isolate Quaternary aquifers from direct hydraulic contact with aquifers of Carboniferous productive series (Fig. 1, 6). Mines situated in this area belong to the second and third classes of water inflow (Fig. 1, 5).

Significant negative hydrogeochemical anomaly was identified in the area of the first hydrogeological subregion (Różkowski, 2004; Różkowski & Siwek, 2008). It is caused by deep, long-lasting and intensive mine drainage of rock massif with simultaneous active infiltration of water from Quaternary formation. Mines situated in the area of the anomaly pump water of varying mineralization in amounts of 380 m$^3$/min. Intensive water drainage by coal mining caused lowering of piezometric pressure (0.8 to 3.0 MPa). Anomaly area within mining drainage area reaches about 1100 km$^2$ (Fig. 1). Active drainage of Quaternary aquifers occurs over an area of approximately 460 km$^2$. Ongoing research show dynamic changes of anomaly creation conditions. Its shape and size depends on changing in time: depth and size of exploitation as well as drainage intensity.

It can be observed in Carboniferous formation, in the zone of the negative hydrogeochemical anomaly, that deep water becomes fresher with time (Fig. 4). Fresher mine water originates from present day recharge infiltration, as documented by its chemical and isotopic composition (Table 1). Values of stable isotopes characteristic for current infiltrating water vary in limits from $\delta^{18}$O –11.7 to –9.43 and δD from –84.0 to –68.1 (Różkowski, 2004). Present day infiltrating waters are observed at the depths up to about 600 m, and very young waters positively dated by tritium (5 TU) are observed to the depths of about 300 m (Różkowski, 1999; Różkowski & Sołtysiak, 2004). Total mineralization of infiltration waters, as documented by isotopes, changes in the range from 0.3 to 1.0 g/dm$^3$, locally reaching 3.0 g/dm$^3$. Increased water mineralization is associated with the impact of anthropogenic processes in areas of mining (Szczepańska, 1987). Hydrogeochemical characteristics of mine water in the anomaly area is shown in Table 1.

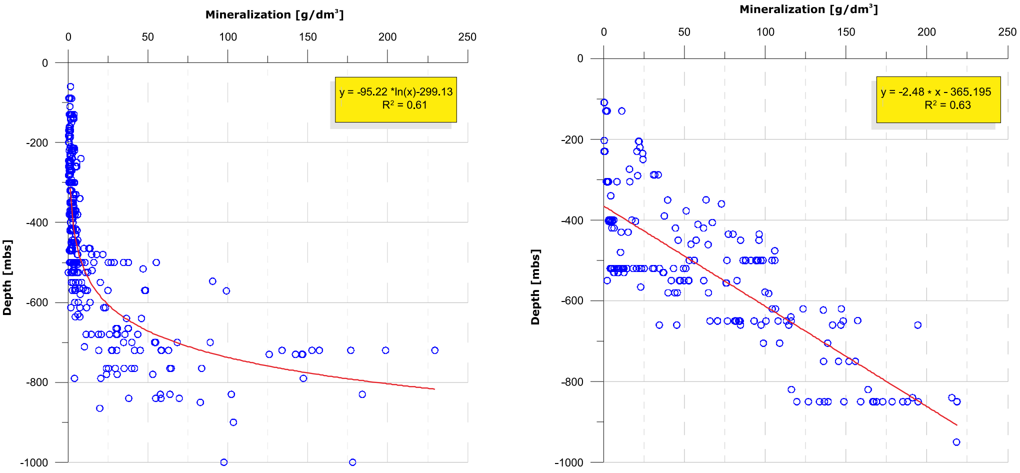

Fig. 4. Changes of groundwater mineralization with depth in the hydrogeological subregions of the USCB (after: A. Różkowski ed., 2004)

TABLE 1

Hydrogeochemical parameters of coal mine water in range of negative hydrochemical anomaly region (according to Różkowski & Sołtysiak, 2004)

| **Interval of sampling [mbs]** | **Mineralization – median [g/dm$^3$]** | **Dominant hydrochemical types of mine waters** | **r Na/r Cl** | **ð$^{18}$ O [%$_o$]** | **ðD [%$_o$]** |
|---|---|---|---|---|---|
| 0-200 | 0,87 | $HCO_3$-$SO_4$-Ca-Mg<br>$SO_4$-$HCO_3$-Ca-Mg<br>$SO_4$-Ca<br>$SO_4$-Cl-$HCO_3$-Na | 0,61 | –10,71÷–9,70 | –73,3÷–68,4 |
| 200-400 | 1,17 | $SO_4$-Ca<br>$SO_4$-Cl-Na<br>$HCO_3$-$SO_4$-Ca-Mg<br>$SO_4$-Ca-Mg | 0,97 | –11,17÷9,43 | –84,0÷68,8 |
| 400-600 | 2,04 | $HCO_3$-$SO_4$-Ca-Mg<br>$SO_4$-$HCO_3$-Na<br>Cl-$SO_4$-Na | 0,94 | –10,7÷9,52 | –76,0÷68,1 |

Hydrological investigations carried out by Kowalski (1993) showed increase of groundwater subsurface runoff index in the area of anomaly in the range from 4 to 5 dm$^3$/s/km$^2$, reaching 8.5 dm$^3$/s/km$^2$. Index values in the areas with no active mining change approximately from 2.5 to 3.0 dm$^3$/s/km$^2$ only. Higher values of this index indicate intensive infiltration of rain water into Quaternary sediments and further drainage by mine workings. As a result of high groundwater runoff water flow decreased in the following rivers: Biała and Czarna Przemsza, Brynica, Przemsza, Kłodnica.

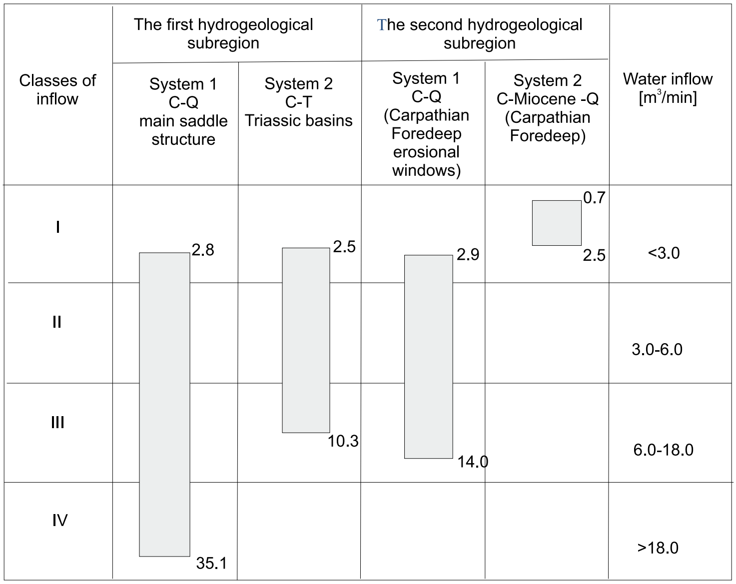

Fig. 5. Classes of water inflow into mines in various hydrogeological flow systems of the USCB (according to the state in the year 1996; Różkowski, 2004)

In the second subregion intensive drainage of Quaternary aquifers as a result of coal mining activity occurs only locally within the limits of hydrogeological erosional windows. Mines situated there belong to the second and third classes of water inflow (Fig. 1, 5). For example water inflow to Brzeszcze mine reaches 9.2 $m^3$/min, while to Dębieńsko mine – 12.6 $m^3$/min. In case of full isolation of Carboniferous formation by clay Miocene series inflow into mines becomes very low and is related to dewatering of groundwater static resources only. In such hydrogeological conditions mines belong to the lowest first and second classes of water inflow (Fig. 1, 5) (Różkowski, 2004; Wilk, 2003).

## 3.2. Participation of Quaternary aquifer in inflow to underground zinc and lead ore mines

Extraction of zinc and lead ores is concentrated in the Upper Silesian Coal Basin within partly isolated patches of Triassic sediments which occur in the form of synclinal – tectonic depressions along the southern edge of the Silesia – Cracow monocline (Fig. 1, 6). Within the Basin were distinguished two ore regions, presently abandoned – within troughs of Bytom and Chrzanów. Ore mineralization is associated with epigenetic dolomites of variable thickness. They are present in a profile of Muschelkalk, within Górażdże, Terebratula and Karchowice beds. The origins of exploitation, extending to the twelfth century, are associated with the Bytom region. Initially work was carried out within the aeration zone, reaching down to the groundwater table. Over time, with the development of science and technology, mining progressed deeper. In the twentieth century mining works were carried out in successively extended and opened mines. In the second half of the last century four plants remained, which ceased the production in the following sequence: Nowy Dwór (1978), Waryński (1981), Marchlewski (1985), Orzeł Biały (1989). They continued groundwater drainage however.

Cessation of production was associated with the depletion of reserves and economic instability, related as well to the mines operating in structure of Chrzanów trough. Successively the following mines were closed: Galmany (1958), Matylda (1973), Trzebionka (2010). Despite cessation of the production, drainage of parts of mining areas is still carried out, due to the demand for water (mainly Chrzanów trough area) or the need of hard coal mines protection, which are operating under the Triassic formation.

Hydrogeologically Triassic structures of Bytom and Chrzanów troughs belong to respectively exposed and partly covered aquifers. Quaternary sediments predominate within the overburden of the first one, in addition to appearing in local Miocene's depressions. In the region of Chrzanów additionally appear semipermeable sediments of Upper Triassic, as well as Middle and Upper Jurassic. Mentioned overlaying sediment of variable thickness cover structural elements of Chrzanów trough (Fig. 6). Assumed area of Chrzanów aquifer is 273 $km^2$, within which, the total area covered with semipermeable sediments reaches about 150 $km^2$, area equal to 55% of the aquifer extent. Outcrops of Triassic carbonate series cover approximately 47 $km^2$ (17%), enabling direct contact with Quaternary sediments on one-third surface of the aquifer (Witkowski et al., 2003).

The youngest sediments of Pleistocene and Holocene age consist among others of sands and gravels of glacial and fluvioglacial origin, as well as clays and decomposed rocks. Despite similar profile, the hydrogeological meaning of the overburden in particular regions is slightly different.

Quaternary overburden is characterized by the variable thickness. While slopes and elevations of the structural base are deprived of sediments, within depressions of surface deposits

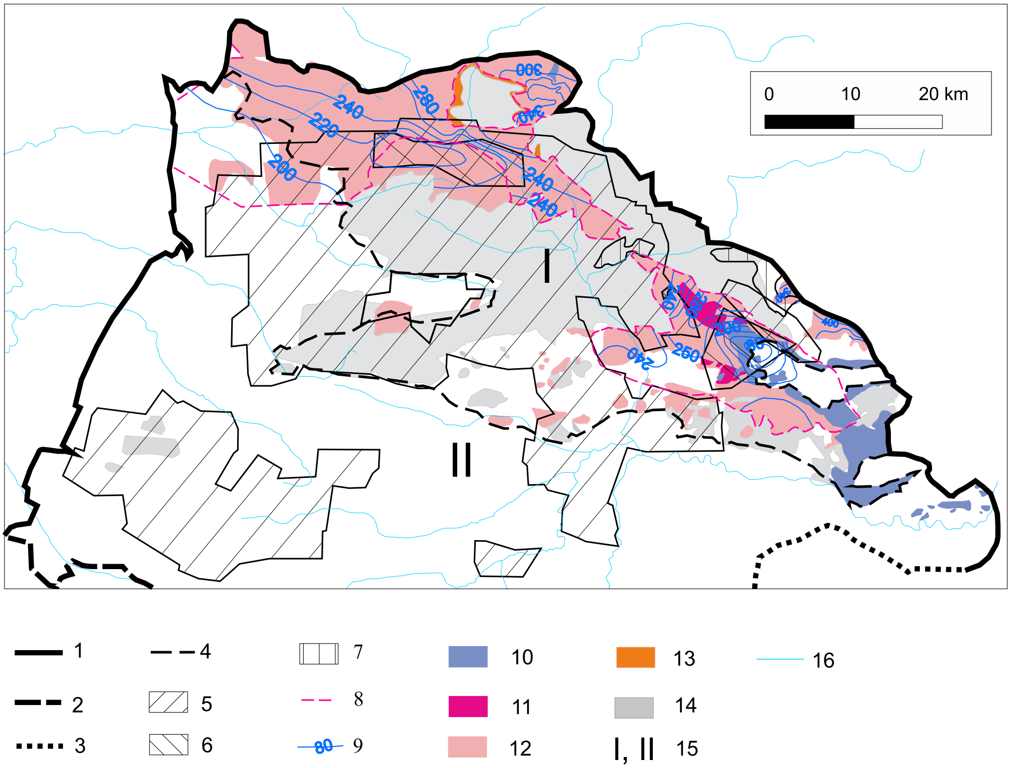

Fig. 6. Hydrodynamic field in the Muschelkalk aquifer of the Upper Silesia region influenced by mine drainage
1 – extension of the USCB, 2 – state boundary, 3 – Carpathian overthrust boundary, 4 – hydrogeological subregion boundary, 5 – mining areas of the coal mines, 6 – mining areas of the Pb – Zn mines, 7 – boundaries of documented sand deposits, 8 – extension of Triassic Major Groundwater Basin, 9 – hydroisohypses of Triassic aquifer; outcrops or underquaternary outcrops of: 10 – Jurassic, 11 – Upper Triassic, 12 – Triassic carbonate series, 13 – Lower Buntsandstein, 14 – Carboniferous, 15 – hydrogeological subregion, 16 – main rivers

reach tens of meters. The maximum thickness of up to 60 m was identified by drilling within the sub-structure of Chrzanów – Dąb trench. Even higher number of about 70 m were identified in the Bytom trough (Różkowski & Wilk, 1980). At the region of Bytom Triassic the thickness is in the range of 0 to 20 m, increasing towards the west of up to 10-30 m. Simultaneously the Quaternary thickness within Chrzanów Triassic varies from a few to several meters (Różkowski, 1986).

Typically for Quaternary, the highest thickness of sediments appear within valleys of present rivers: Chechło, Łużnik in the region of Chrzanów trough or Brynica, Szarlejka and Mikulczycki flowing through Bytom trough, or past erosional forms, buried valleys and tectonically descended structures. The arrangement of the layers in the profile, especially those of low permeability is essential for Quaternary water-bearing capacity under conditions of mine drainage.

In the Bytom region, the lens of permeable clastic rocks of different sizes are separated by loamy and clay layers, creating local usually unconfined aquifers. Aquifers remain most often independent, sometimes appearing as perched (Różkowski & Wilk, 1980). Within the zinc and lead mining areas were identified two erosive structures – gullies of Karb and Dąbrówka Wielka.

Both are characterized by a meridional course, with a depth of up to 45 m in the axial and 5-7 m in coastal parts. Quaternary sediments are generally weak and of low permeability, demonstrating additionally considerable variability of parameters. In the area of direct contact with dewatered Triassic sediments, aquifers are drained to the extent which is difficult to determine.

In the Chrzanów region water-bearing deposits (except river valleys) fill base tectonically descended structures: Chrzanów, Wilkoszyn troughs and Chrzanów – Dąb trench, underlained by sediments of low permeability. In the mentioned regions, Quaternary aquifers are of unconfined character, recharged by rainfall, as well as river water infiltration within the valley structures of Chechło or Łużnik rivers. Among the layers occurring lower in the profile, isolating function have poorly permeable sediments of Lower Jurassic, Keuper, Boruszowice layers, and clays or loams of the same age. The discontinuous spread of the particular layers, results in presence of areas without isolation. Most often they are associated with side blocks of the main descended structures, as Wilkoszyn trough or with elevated forms. In such conditions, the thickness of the Quaternary substantially reduces. Quaternary sediments covering outcrops are in the form of weathered clays, rubble, rarely sand, and are practically poorly water-bearing. However they have an important role in alimentation of underlying aquifers, reducing surface runoff and retentioning part of the water. Studies characterizing the hydrogeology of Chrzanów Triassic document depth to the water table within the Quaternary aquifer from 0.5 to 5 m below ground level, with significant variations depending on the meteorological conditions (Wilk & Bocheńska, 2003). The river network of the region is dependent on the youngest sediments. Most of the rivers, including Chechło and Łużnik, start its course from springs fed by the Quaternary aquifer water, which also forms vast wetlands.

Quaternary aquifer underlained by impermeable sediments are utilised in vicinity of Trzebinia and Bolęcin and between Chrzanów, Libiąż and a valley of Przemsza river. Within the Chrzanów trough it is regarded, due to the favorable conditions, as an important source of groundwater – useful aquifer (UPWP) Bolęcin of total area 48.5 km$^2$ and 160 m$^3$/d/km$^2$ of disposable resources (Kawalec & Patorski, 1998).

Quaternary aquifer, except in the mentioned regions, is not considered as groundwater resource, either because of the generally low transmissivity or poor chemical quality, especially in highly urbanized areas. Additionally is a subject to the variable intensity indirect drainage associated with the exploitation of raw materials in underlying sediments of Lower Triassic or Carboniferous age. Many years of mining activities initially involving extraction of lead and zinc ore followed by coal extraction from lower Carboniferous sediments, within practically entire Bytom trough, and on the periphery of the Chrzanów trough, led to the creation of a network of cracks and fissures in solid carbonate sediments of the Triassic age, opening connections and increasing the permeability of the formation. Subsidence resulting from shallow roof – fall exploitation caused, mainly in the Bytom region, numerous transformations of land surface morphology and partial remodeling of the river network. The process of indirect drainage began in areas of direct contact of Quaternary and Triassic. Intensity and spatial structure of the drainage differ quite significantly in mentioned aquifers, mainly due to significant aerial coverage of low permeability sediments.

The Bytom aquifer had much greater intensity of mining operations and at the same time the exploitation went below the water table of Triassic aquifer. Consequently, the drainage of groundwater storage from Triassic and Quaternary aquifers resulted in intensive inflows to mine galleries. Over time, after dewatering of water accumulated in voids within sediments, it turned to self stabilizing inflow hydraulically connected to groundwater renewable resources. According to the estimates the maximum area of Muschelkalk covered by drainage reached 60-70 km$^2$, at a large area reaching almost to the lowest layers (Wilk & Bocheńska, 2003). Aggregate inflow to the mines of the region reached its maximum at 56,3 m$^3$/min in 1949, along with the unflooding of the mine section Nowy Dwór and large water infiltration rates from gradually sealed Brynica river. Along with defiltration of free groundwater and regulation of rivers at the beginning of the 70's inflows decreased to the level of 24,5 m$^3$/min. Afterwards the construction of Dąbrówka mine section in the 80's the inflow increased to about 45 m$^3$/min. At the end of the century and interception of inflows by the shaft Bolko, in conditions of the gradual shutdown of particular drainage systems of mined sections, total inflow showed a downward trend again, reaching about 20 m$^3$/min in 2008. Lower than expected values are associated with groundwater escaping during redirection of water to operating beneath coal mines (Kropka, 2009).

The most intense inflows from Quaternary sediments originate from alluvial filling of riverbeds of present rivers and older erosion forms filled with a mixture of younger sediments. The highest volumes were associated with Brynica river valley. During the works aimed at reducing the water hazard in mines were sealed parts of the riverbeds, partially redesigning the river network layout. It is estimated, that after the regulatory work in the years 1948-1952 and later additional works at the turn of 70's and 80's, inflows to the mine section Orzeł Biały decreased by about 50%.

Direct significant inflows from the Quaternary aquifer have also been reported within the deep erosion structure – Dąbrówka, generating local water hazard, including the possibility of quicksand.

The needs of growing urban – industrial agglomeration of Śląsk supported mine drainage through the construction of new groundwater intakes or reconstruction and adaptation of abandoned fragments of mine galleries for the purpose of water supply. Priority was given to the abandoned mine shafts such as Rosalie, which were adapted for groundwater intake purposes.

Along with the regulation of the river system, elimination of some surface reservoirs and depletion of free groundwater, inflows remained dependent in practice only on the renewable groundwater resources formed as a result of the precipitation infiltration from the surface, and indirectly through the Quaternary sediments. Despite the termination of the zinc and lead ore exploitation in 1989, drainage of the Triassic aquifer and consequently the Quaternary aquifer continued. In order to protect the coal mines operating beneath the abandoned workings of zinc and lead mines, it was decided to continue dewatering, allowing for elimination of prospective water hazard associated with the possibility of accumulation of water in the abandoned workings. Since 1990 restructured drainage system has been reduced to one central pumping station in the Bolko shaft.

The structure of the Chrzanów trough, thanks to lead and zinc mining operations, and conducted in the marginal zone coal extraction, is subject to variable in time and space drainage. Exploitation of zinc and lead ores was carried out in three mines: Galmany, Matylda, Trzebionka. They were successively closed with depletion of resources. On the outskirts of the Triassic structure there are few mines exploiting coal from the underlying Carboniferous strata: ZG Sobieski, ZG Janina and already closed ZG Siersza. Hydrogeological analyzes suggest direct influence of the activities of the Sobieski mine on the water resources of Triassic aquifer. Relations of the others have not been unambiguously determined.

The severity of the mining drainage was variable over time. Partial restoration of groundwater conditions since the 30's was associated with cessation of mining operations and flooding of mines Galmany and Matylda. Resumption of production after World War II and later construction of Trzebionka mine between 1954-1957, led to maximization of inflows in the early sixties. The total inflow reached about 77 m$^3$/min in 1962, and then began to fall (Wilk & Bocheńska, 2003). Stabilization of water rates at the level of 12-14 m$^3$/min, drained by galleries of Matilda mine began with the culmination of inflow to Trzebionka mine, about the year 1962. Approximately ten years later inflow to the second mentioned mine at about 34 m$^3$/min stabilized as well. Further decreases in the 80's and 90's resulted in the total volume of pumped out water dropping to below 40 m$^3$/min in the year 2000.

Within the limits of the Chrzanów Triassic trough axial parts of decreased structures are filled in a substantial part with younger than Muschelkalk low permeability sediments separating Quaternary aquifer from the Triassic aquifer. Such lithology of strata in a profile resulted in the directions of groundwater flow from alimentation zones at the outcrops located in the marginal areas, mainly the side blocks of troughs, towards the axial zones, as in the case of Trzebnionka mine. As a result, draining impact of mining on Quaternary sediments is limited spatially to the marginal zones. The location of the mine workings at the outcrops of ore bearing layers, as in the case of Galmany Mine in the north – western part of the Wilkoszyn trough, influenced drainage of the directly overlying part of Quaternary sediments. Low impact on Quaternary aquifer results from low water resources dependent on the lithology.

Termination of the mining activity in the Chrzanów region, was not synonymous with the cessation of drainage. It altered only a purpose, transforming activity towards the water supply. To this day in the area of mines Galmany and Matylda Triassic and indirectly Quaternary aquifer are still drained. Built on the basis of dewatering mine systems well intakes serve as a water supply for cities of Chrzanów and Jaworzno.

### 3.3. Participation of Quaternary aquifer in generating water inflows into open pit mines extracting aggregate

The aggregate production in the Upper Silesia region is dominated by the average quality crushed stone: dolomite, limestone and sandstone, as well as commonly occurring and in bulk mined natural aggregates. The vast majority, especially of small deposits, are exploited without disturbing natural water conditions, above the local groundwater table, or using special techniques from under the water table. Different in this context, although conducted on a relatively small scale, is filling sands operation (Fig. 1).

During peak demand in 1978, filling sands production reached 35,3 million m$^3$ (Kozłowski, 1986), and then began a systematic decrease, forced by economic factors. In 1989, at the beginning of political and economic changes, production exceeded 22,6 million m$^3$, and after a further decline in 2010 reached 5.1 million m$^3$. From the largest of mines – Szczakowa, according to the estimates, excavated more than 650 million m$^3$ of sand until 2005 (Haładus et al., 2007).

Identification and documentation phase carried out prior to the exploitation, identified the richest deposits areas in parts of the modern or buried river valleys of Biała and Czarna Przemsza. Eroded usually 40-60 m to a maximum of more than 70 m valleys, are filled with clastic sediments, mostly made up of sands and gravels of Odra and Warta glaciations (Lewandowski, Zieliński, 1988).

The historic operation was initially associated with small pits situated near coal mines. After the World War II, with the development of the coal mining industry, the following mines were developed: Szczakowa (1954), Maczki Bór (1961), Kotlarnia (1966), Kuźnica Warężyńska (1967), all of which exist to this day, the first three. The last ceased in 2002. Surface of the biggest excavation – Szczakowa mine exceeded 31 km$^2$. Due to the location of outside of the USCB border, Kotlarnia mine was excluded from further characterization.

Despite the interbeddings of clayey character existing among sands, gravels and all-in aggregates, Quaternary deposits on a scale of a glacial valleys form one consolidated aquifer of high water – bearing capacity. Obtained from the pumping tests hydraulic conductivity is in the range of 1.6-5.6 × $10^{-4}$ m/s, characterizing sediments as of good permeability. The valley structures form hydraulically open and simultaneously poorly isolated aquifers. Within the identified deposits thickness of the permeable sediments reaches 25 m in Maczki – Bór Mine, 32 m in Kuźnica Warężyńskiej and 55 m in Szczakowa Mine, with the conductivity from several to 1500 m$^2$/d (Kropka & Wróbel, 2001; Różkowski et al., 1997; Zimny, 1995; Haładus et al., 2007).

Under natural conditions, the water table in Quaternary aquifer fluctuated on average, at a depth of 3-5 m below the ground, up to several m below the surface. Quaternary sands form open pore aquifers, recharged by rainfall infiltration. In case of deeply incised buried valleys lateral recharge from older formations becomes significant. Particular fragments of valleys and basins with high transmissivity were delimited with the boundaries of Major Groundwater Reservoirs: MGB no. 453 Biskupi Bór, MGB no. 455 Dąbrowa Górnicza. Their estimated disposable resources are respectively: 108 and 46 thousands m$^3$/d (Kleczkowski ed., 1990).

Intercepted by mine water drainage systems water is partly collected for the water supply system of the Upper Silesian agglomeration. At the end of the eighties almost all of the inflow to the Szczakowa Mine (120 m$^3$/min) and about 50% (12-15 m$^3$/min) of water from dewatering of the eastern party of the Maczki – Bór deposit was transferred to the water supply network (Wilk et al., 1990). At the moment Szczakowa supplies water to MPWiK Jaworzno, GPW Katowice and Power Plant "Siersza" in Trzebina (Bielec & Tomaszewska, 2010). Due to the lack of stability of the chemical composition, water is no longer collected from sandpit Maczki – Bór (Nowicki ed., 2009).

Beginning of dewatering have changed the original hydrogeological conditions of deposits in the neighborhood. Initially small inflows increased with time and were supported by increasing share of renewable resources of the flow stream migrating through structures of buried valleys. Conducted by J. Kropka and J. Wróbel (2011) investigations at the sandpits showed high and very high precipitation infiltration percentage from 8.3 to 50.5%, i.e. 2.0-14.0 dm$^3$/s/km$^2$. Opening of new operational levels lead in case of ZG Kotlarnia or ZG Maczki Bór into extraction practically to the thill of the deposit, forcing takeover of most of the filtration stream. The total inflow from the beginning showed great variability, being greatly dependent on hydrometeorological conditions. In the analysis done by J. Kropka (2007) for the period 1984-2005, the highest inflows were documented at Szczakowa mine. In 1984 maximum inflows slightly exceeded 120 m$^3$/min. Inflows to the other four mines reached four to five times lower values. In 2005, except Kuźnica Warężyńska mine, which was in the final stage of flooding, the total inflow to the remaining mines slightly exceeded 100 m$^3$/min, less than ZG Szczakowa in the phase of maximum inflow growth.

Panelling of the successive parts of deposits and most of all descending with exploitation into ever deeper levels, resulted in lowering naturally formed groundwater level of up to about 30 m in the central parts of the workings (Kropka & Wróbel, 2001). Due to the high transmissivity of the Quaternary sediments formed cones of depression occupied relatively small areas of asymmetrical shapes. The observed range of influence reached according to J. Kropka and J. Wróbel (2000) between tens of meters to over 1300 meters from the edge of the excavations, covering an area from 18.5 km$^2$ in case of the Kuźnica Warężyńska pit, 22 km$^2$ in surrounding of ZG Maczki – Bór, and up to 88.9 km$^2$ around the Szczakowa mine (Kropka, 2006; Kropka & Wróbel, 2001). In the neighborhood of the latter it is also apparent that drainage influenced the near zinc and lead ore Olkusz – Pomorzany mine (Haładus et al., 2007; Wilk et al., 1990). In the case of a MGB Biskupi Bór, in the vicinity of Maczki – Bór mine, to drainage contributed in a lesser extent coal mines: Jan Kanty, Kazimierz – Juliusz, Niwka – Modrzejów, Porąbka – Klimontów (Kropka, 2006).

Direct drainage of high water – bearing parts of the Quaternary aquifer has led to local depletion of available groundwater resources, including areas covered by the limits of MGB: no. 453 Biskupi Bór and activity of Szczakowa Sand Mine, no. 455 Dąbrowa Górnicza. With a small area of the latter MGB of about 21 km$^2$, Kuźnica Warężyńska mine and earlier Pogoria, intercepted the majority of the filtrating stream, depleting disposable resources. At present, reservoirs formed in place of the pits increase retention within Quaternary aquifer.

To disturbance of water circulation conditions within the Quaternary aquifer contributed as well the interception of infiltrating surface water by mining drainage systems. Water seepage has been observed from Biała Przemsza, Jaworznik, Kozi Bród, Sztoła, Czarna Przemsza and Trzebyczka rivers (Kropka & Wróbel, 2001).

The progressive decline in demand and a large supply of filling sands, began the process of gradual reduction of mining production. As a result of the efforts to reclaim the postmining areas and pass them to local governments were intensified. One of the ways to utilize the existing voids was the placement of waste products in postmining excavations, like in the Maczki Bór Mine. Since 1976 it began collecting waste rocks, slag and fly ash from power stations, construction wastes and later the municipal wastes. Conducted by mine personnel water quality monitoring studies show decreased quality of water discharged from the sector Bór – Zachód, associated with elevated levels of chlorides, sulphates, calcium and total mineralization.

In the recent history of local mining, production was terminated in Kuźnica Warężyńska mine. After analyzing all determinants and possible directions of reclamation, water direction was decided to be the best option. That created a reservoir for flood control, which was finally filled in 2006 (Jakóbczyk & Kowalczyk, 2009). The newly created reservoir joined three more Pogoria reservoirs located to the south, which were formed after the water reclamation of older sandpits.

## References

Bielec B., Tomaszewska B., 2010. *Operat wodnoprawny w związku z przełożenie koryta potoku Jaworznik do rowu WIII/1a w rejonie sektora 3 Pola Siersza Kopalni Piasku DB Schenker Rail S.A. w Jaworznie*. Maszynopis.

Bradecki W., Dubiński J., 2005. *Wpływ restrukturyzacji polskiego górnictwa węgla kamiennego na poziom zagrożeń naturalnych*. Arch. Min. Sci., Vol. 50, No 1.

Bukowski P., 2002. *Chłonność wodna górotworu karbońskiego i jej wpływ na przebieg zatapiania wyrobisk górniczych kopalń węgla kamiennego w GZW*. Arch. Min. Sci., Vol. 47, No 3.

Chmura A., 1997. *Poziomy wodonośne czwartorzędu*. [W:] Użytkowe wody podziemne Górnośląskiego Zagłębia Węglowego. PIG, Warszawa: 51-53.

Doktorowicz-Hrebnicki S., Kaszyńska-Makowska B., 1975. *Mapa geologiczna Górnośląskiego Zagłębia Węglowego*. skala 1:100 000. Wydanie H – Mapa grubości nadkładu czwartorzędowego. Wyd. Geol., Warszawa.

Grabara M., 2006. *Zawodnienie kopalń węgla kamiennego w Górnośląskim Zagłębiu Węglowym i warunki je kształtujące*. Arch. WNoZ – U. Ś., Sosnowiec.

Haładus A., Kania J., Kulma R., 2007. *Badania modelowe zmian stosunków wodnych w obrębie złoża piasków na obszarze górniczym Szczakowa III*. Gospodarka Surowcami Mineralnymi, t. 23, z. 1, 139-152.

Jakóbczyk S., Kowalczyk A., 2009. *Skład chemiczny wód podziemnych w rejonie zatopionej Kopalni piasku Kuźnica Warężyńska w świetle badań modelowych*. Biuletyn PIG, nr 436, 165-173.

Jureczka J., Dopita M., Gałka M., Krieger W., Kwarciński J., Martinec P., 2005. *Atlas geologiczno-złożowy polskiej i czeskiej części Górnośląskiego Zagłębia Węglowego*. skala 1:200 000. PIG, Warszawa.

Kawalec T., Patorski R., 1998. *Dokumentacja hydrogeologiczna dyspozycyjnych zasobów wód podziemnych dla obszaru triasu chrzanowskiego*. Krakowskie Przedsiębiorstwo Geologiczne „ProGeo” Sp. z o.o., Kraków.

Kleczkowski A. S. ed., 1990. *Główne zbiorniki wód podziemnych w Polsce – własności hydrogeologiczne, jakość wód, badania modelowe i poligonowe*. Wyd. AGH, Kraków, 120 s.

Kotas A., 1985. *Structural evolution of the Upper Silesian Coal Basin (Poland)*. Congress Int. Strat. Geo. Carb. Rend. 3, Madrid, 459-469.

Kotlicka G.N., 1964. *Mapa wodonośności czwartorzędu Górnośląskiego Zagłębia Węglowego*. Arch. PIG, Oddział Górnośląski, Sosnowiec.

Kotlicki S., 1958. *Wodonośność utworów czwartorzędowych w świetle zagadnienia gospodarki wodą na Górnym Śląsku*. Przegląd Geologiczny, nr 2, 64-66.

Kowalski J., 1993. *Mapa odpływu podziemnego zlewni Górnej Wisły*. Arch. Inst. Hydrogeol. i Geol. Inż. AGH, Kraków.

Kozłowski S., 1986. *Surowce skalne Polski*. Wydawnictwa Geologiczne, Warszawa.

Kropka J., 2006. *Infiltracja efektywna w rejonie odkrywkowej kopalni piasku Maczki Bór*. Przegl. Górn., nr 12, 45-53.

Kropka J., 2007. *Dopływy do odkrywkowych kopalń piasku w rejonie Górnośląskiego Zagłębia Węglowego*. [W:] XIII Sympozjum „Współczesne problemy hydrogeologii”, Kraków – Krynica. Wyd. AGH, 813-820.

Kropka J., 2009. *Changes in the water inflow to the Central Pumping Station Bolko in Bytom*. Biul. PIG, nr 436, 301-308.

Kropka J., Rubin H., 1989. *Czwartorzędowe zbiorniki wód podziemnych regionu górnośląskiego i problemy ich ochrony*. [W:] Mat. Konf. Pr. Nauk. Inst. Geot. Polit. Wrocławskiej, nr 58.

Kropka J., Wróbel J., 2000. *Hydrogeological problems concerning open digging of filling sands in the area of Upper Silesian Coal Basin (southern Poland)*. 7th IMWA Congress. Mine Water and Envirnoment, Ustroń, Poland: 555-564.

Kropka J., Wróbel J., 2001. *Przekształcenie warunków hydrogeologicznych w obszarach odkrywkowej eksploatacji piasków podsadzkowych w rejonie Górnośląskiego Zagłębia Węglowego*. Przegl. Geol., nr 7, 631-638.

Kropka J., Wróbel J., 2011. *Infiltracja efektywna w obszarach odkrywkowej eksploatacji piasków*. Biuletyn Państwowego Instytutu Geologicznego, nr 445, 345-354.

Lewandowski J., 1996. *Główne czynniki neogeńskiej i czwartorzędowej ewolucji morfogenetycznej regionu ślasko-krakowskiego*. Acta Geogr., Łódź, nr 71, 131-148.

Lewandowski J., Zieliński T., 1988. *Środkowoplejstoceńskie osady dolnego regionu górnośląskiego – dorzecze Przemszy (południowa Polska)*. Problemy paleogeografii czwartorzędu – zlodowacenie środkowopolskie, Katowice, 49-63.

Mojski J.E., 2005. *Ziemie Polski w czwartorzędzie. Zarys morfogenezy*. PIG, Warszawa, 404 s.

Nowicki Z. ed., 2009. *Wody podziemne miast Polski. Miasta powyżej 50 000 mieszkańców*. Państwowy Instytut Geologiczny, Warszawa, 532 s.

Pikuła A., 2007. *Środowisko hydrogeologiczne utworów czwartorzędowych w Górnośląskim Zagłębiu Węglowym*. Arch. WNoZ., U. Ś., Sosnowiec.

Rogoż M., Posyłek E., 2000. *Problemy hydrogeologiczne w polskich kopalniach węgla kamiennego*. Główny Instytut Górnictwa, Katowice, 402 s.

Różkowski A. ed., 1986. Zadanie 09.01.02.02L *Koncepcje alternatywne ochrony wód podziemnych dla wydzielonych regionów hydrogeologicznych*. Region XVIIIb i trias śląski centralny, rejon – niecka bytomska – piętro serii węglanowej triasu. Etap I: Koncepcja wstępna wyznaczenia obszarów chronionych, maszynopis.

Różkowski A., 1995. *Factors controlling the groundwater conditions in the Carboniferous strata in the Upper Silesian Coal Basin, Poland*. Annales Soc. Geol. Poloniae, Vol. 64, 53-66.

Różkowski A., 1999. *Origin of mine waters based on the isotopic and hydrochemical composition (Upper Silesian Coal Basin, Poland)*. [In:] Mine Water and Environment. Intern. Mine Water Assoc., Sevilla, 99-105.

Różkowski A. ed., 2004. *Środowisko hydrogeochemiczne karbonu produktywnego Górnośląskiego Zagłębia Węglowego*. Wyd. U. Ś., 174 s.

Różkowski A., Chmura A., Siemiński A. ed. 1997. *Użytkowe wody podziemne Górnośląskiego Zagłębia Węglowego i jego obrzeżenia*. Pr. PIG, 152 s.

Różkowski A., Różkowski K., 2010. *Hydrogeological conditions of the Cracow Sandstone Series influenced by mining activity in Upper Silesian Coal Basin*. Biuletyn PIG, Hydrogeologia, nr 441, 131-138.

Różkowski A., Różkowski K., 2011. *Wpływ działalności górnictwa węglowego na środowisko wodne Górnośląskiego Zagłębia Węglowego w wieloleciu*. Biul. PIG., Hydrogeologia, nr 445, 583-592.

Różkowski A., Siwek P., 2008. *Czynniki kształtujące ujemną anomalie hydrochemiczną w utworach karbonu produktywnego w północno-wschodniej części Górnośląskiego Zagłębia Węglowego*. Zeszyty Naukowe Politechniki Śląskiej, nr 285, 259-272.

Różkowski A., Sołtysiak M., 2004. *Rejony hydrochemiczne obszarów górniczo zagospodarowanych i ich charakterystyka*. [W:] Środowisko hydrogeochemiczne karbonu produktywnego Górnośląskiego Zagłębia Węglowego, Wyd. U.Ś., 122-141.

Różkowski A., Wilk Z. ed., 1980. *Warunki hydrogeologiczne złóż rud cynku i ołowiu regionu śląsko-krakowskiego*. Prace Instytutu Geologicznego. Wydawnictwa Geologiczne, Warszawa.

Szczepańska J., 1987. *Zwałowiska odpadów górnictwa węgla kamiennego jako ogniska zanieczyszczeń środowiska wodnego*. Wyd. AGH, Kraków, 122 s.

Szczepański A., 2004. *Wpływ górnictwa na środowisko wodne*. Przegl. Geol., nr 10, 968-971.

Wilk Z. ed., 2003. *Hydrogeologia polskich złóż kopalin i problemy wodne górnictwa*, tom 1. AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków, 611 s.

Wilk Z., Adamczyk A. F., Nałęcki T., 1990. *Wpływ działalności górnictwa na środowisko wodne w Polsce*. SGGW – AR w Warszawie, Centralny Program Badań Podstawowych 04.10 Ochrona i Kształtowanie Środowiska Przyrodniczego. Wydawnictwo SGGW – AR, Warszawa.

Wilk Z., Bocheńska T. ed., 2003. Hydrogeologia polskich złóż kopalin i problemy wodne górnictwa, tom 2. AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków: 478 s.

Witkowski A., Rubin K., Kowalczyk A., Różkowski A., Wróbel J., 2003. *Groundwater vulnerability map of the Chrzanów karst-fissured Triassic aquifer (Poland)*. Environmental Geology, Vol. 44, No. 1.

Zimny J., 1995. *Dokumentacja hydrogeologiczna Kopalni Piasku „Szczakowa" według stanu na 1.01.1995 r. (w granicach posiadanej koncesji KP „Szczakowa", Jaworzno*. Maszynopis.

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