IMPACT OF COAL MINING ON QUALITY AND QUANTITY OF FRESH GROUNDWATER IN THE UPPER SILESIAN COAL BASIN (POLAND)

Andrzej Różkowski

University of Silesia
Department of Hydrogeology and Engineering Geology
ul. Będzińska 60
41-200 Sosnowiec, Poland
E-mail: rozkowsk@us.edu.pl

ABSTRACT

The Carboniferous Upper Silesian Coal Basin (USCB) is located in the southern Poland. Intensive mining drainage associated with exploitation of sand, Zn-Pb ores and hard coal deposits is typical of the region studied.

Underground coal mining and intensive activity of associated industries have effected in disturbance of the natural hydrogeological condition in the mentioned MGWBs. The main phenomena causing the changes in hydrogeological environment include the drainage of rock massif, alteration of flow directions and water chemistry in the MGWBs as well as changes of physical parameters of the rock mass. These phenomena have led to the reduction of the groundwater resources and to the mine water pollution.

Coal mining being run within the Carboniferous strata result in the drainage not only of the Carboniferous rocks but also the overburden strata. The area of decreased piezometric pressure occurs within the north-eastern part of the USCB covering the area of about 1,100 sq.km.

Chemistry of coal mine waters have been formed in different geological formations and under circumstances of variable human impact hence their chemistry and quality are differentiated. Fresh mine waters require an intensive treatment. These waters are polluted bacteriologically, turbid, hard, often with high chlorides, sulphates, iron, manganese and suspension contents.

INTRODUCTION

The Carboniferous Upper Silesian Coal Basin (USCB), 7,500 sq.km in area, is located in the southern Poland. In the USCB the Quaternary, Triassic and Carboniferous aquifers are situated in the north-eastern part of the basin. They are the important sources of groundwater supply for the Upper Silesian urban-industrial agglomeration. These aquifers are intensively drained by mine workings. Intensive mining causes the large scale changes of water quantity and quality in the Quaternary, Triassic and Carboniferous aquifers.

GEOLOGICAL BACKGROUND

The USCB, is situated within the Upper Silesian Variscean depression. It is 7,500 sq. km in area. The basement of productive rocks of the USCB consist of the Precambrian, Cambrian, Devonian and Lower Carboniferous sequences.

The coal-bearing Upper Carboniferous formation of the USCB according to Kotas [1] and Jureczka and Kotas [2] includes 4 lithostratigraphic series, 8,500 m in total thickness, developed within the zones of the greatest basinal subsidence (Fig.1). These series are characterized by a gradual reduction of their thickness toward the east and south-east.

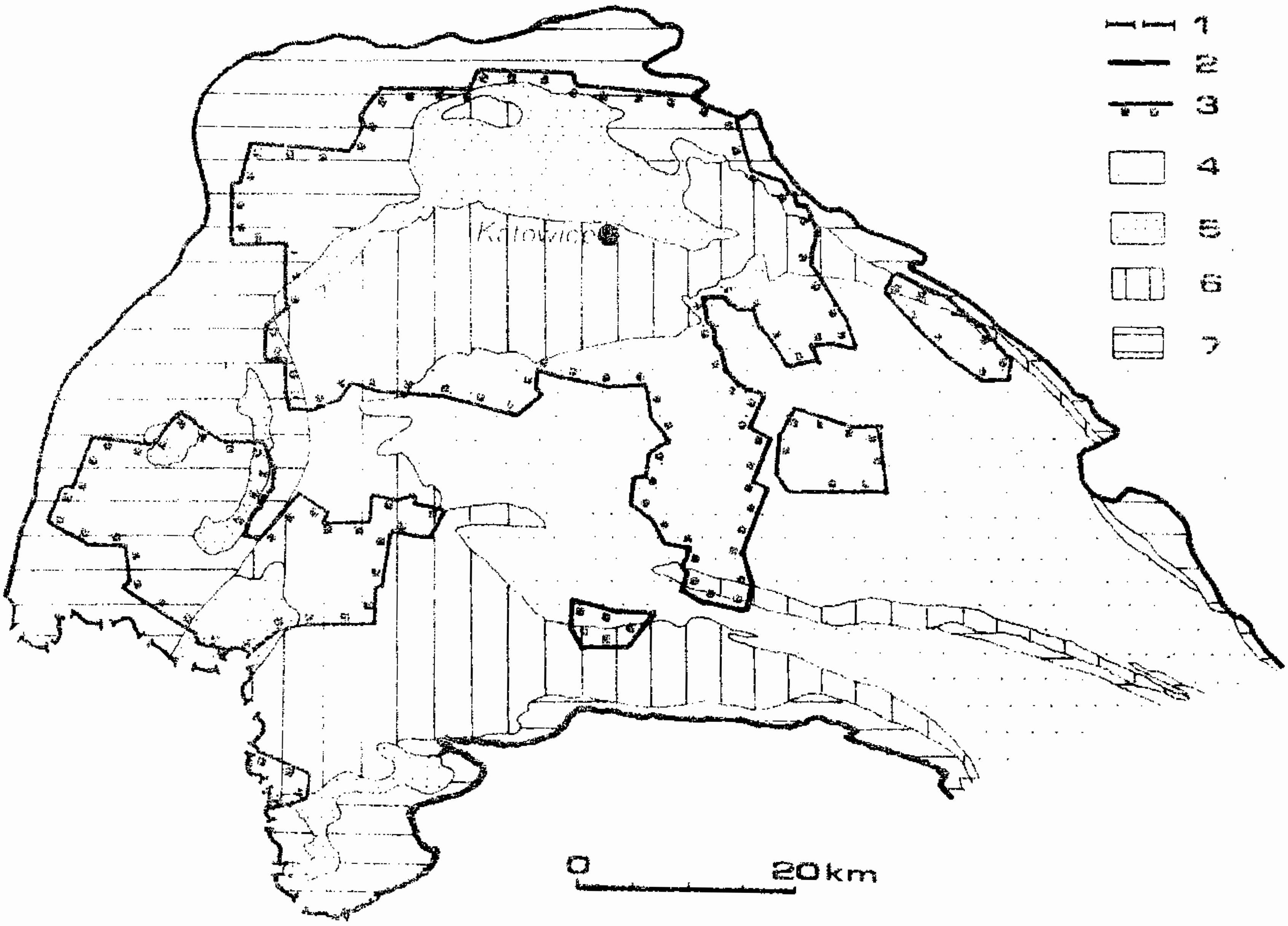

Fig. 1. Permian, Mesozoic and Cainozoic subcrop map of the Upper Silesian Coal Basin (USCB), with outlined of coal mine fields
1 - state boundary; 2 - extension of the USCB; 3 - mine areas; 4 - Cracow sandstone series; 5 - Upper Silesian sandstone series; 6 - Mudstone series; 7 - Paralic series

The Paralic Series embraces all paralic succession of sediments within the productive Carboniferous of the basin. The whole series belongs to the Upper Namurian A. The Paralic series is composed of conglomerates, sandstones, siltstones, claystones. The share of conglomerates and sandstones in the series profiles varies from 20% to 50%. The thickness of the Paralic series is variable: from 200 m to 3,780 m.

The Upper Silesian Sandstone Series (Namurian B-C) is characterized by a dominance of sandstones and conglomerates over claystones and siltstones. The share of coarse grained clastic rocks in the series is high but variable, commonly exceeding 50%. The total thickness of the series approaches 1,100 m; it pinches out in the eastern part of the basin.

The Mudstone Series (Westphalian A-B) is rather monotonous with fine grained clastic rocks being predominant. The share of sandstone in the whole series profile reaches to 16-23%.

The thickness of the series ranges from 100 m in the eastern part of the basin up to 2,000 m in the central part.

The uppermost sequence of the productive Carboniferous consists of the Cracow Sandstone Series (Westphalian C, D). A predominance of coarse-grained sandstones (up to 90%) over siltstones and claystones is the characteristic feature of the series. The thickness of the series is up to 1,640 m.

The coal-bearing Carboniferous formations of the basin are covered by Permian, Triassic, Jurassic, Tertiary and Quaternary deposits. Permian and Jurassic deposits cover very small portions of the basin, stretching along the north-east limit of the Carboniferous subcrops. The Triassic, Quaternary, and most of all, the Tertiary cover of the basin is significant for the hydrogeological problems (Fig.2).

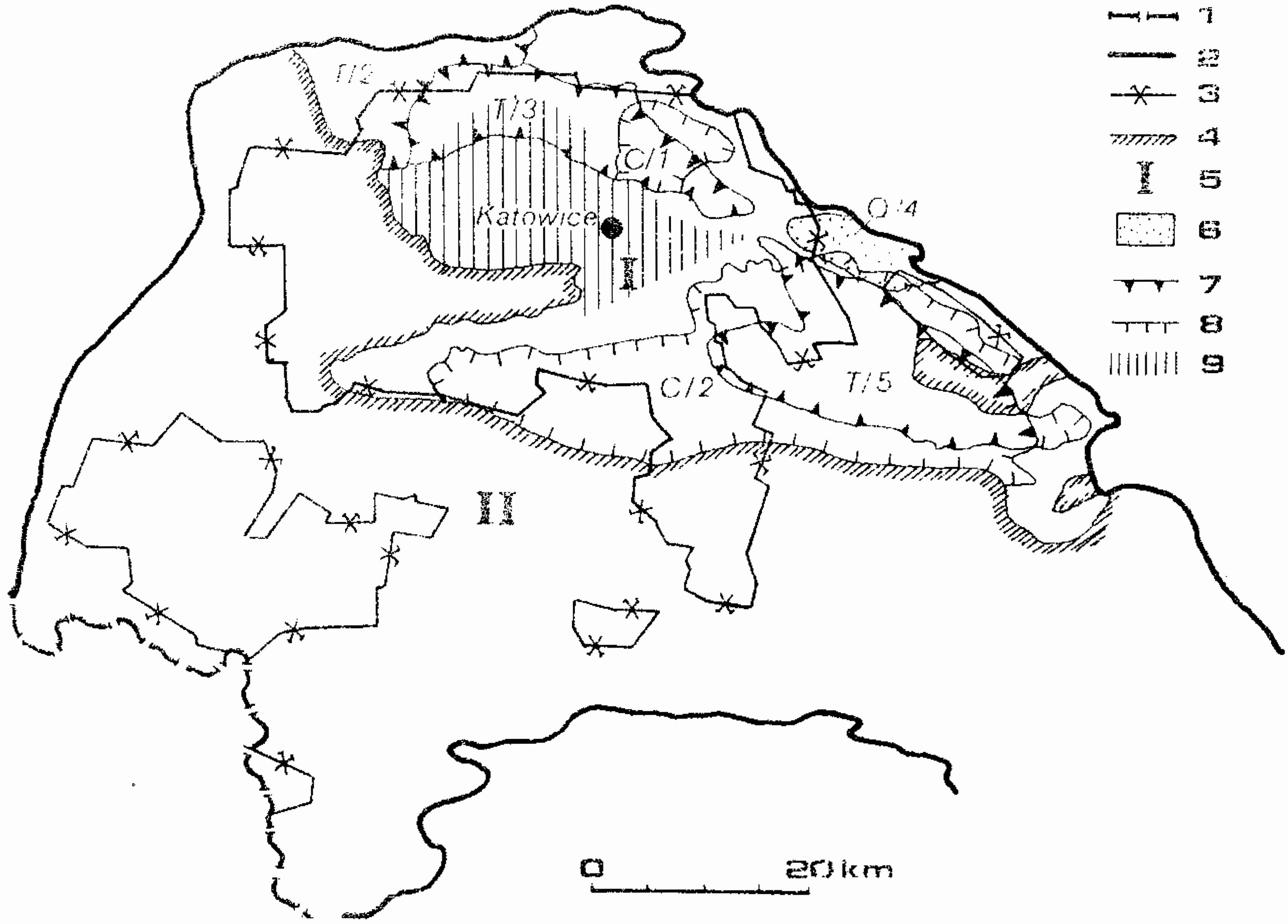

Fig. 2. Hydrogeological regions and Main Groundwater Basins (MGWBs)
1 - state boundary; 2 - extension of the USCB; 3 - mine areas; 4 - extension of the isolating series of the Tertiary formation; 5 - hydrogeological regions; 6 - the Quaternary MGWB; 7 - extension of the Triassic MGWBs; 8 - extension of the Carboniferous MGWBs; 9 - polluted mine water due to human activity in the Triassic (T/3) and Carboniferous formations

Triassic formations of the Upper Silesian Coal Basin reach up to 200 m in thickness. In general their sequence shows tripartite division (Fig.2). The basal part is formed by claystones and sandstones (the Lower Triassic Bunter Sandstone) passing upward into series of varied dolomites and organic limestones, among which the ore-bearing dolomites are the most significant. The series is Middle Triassic in age. Upper Triassic strata consist of claystones and mudstones with intercalations of dolomitic mudstones and gypsum.

The Jurassic formations, ranging in thickness up to 100 m, are known to occur only in easternmost part of the basin.

Tertiary sediments of Miocene age bury the complex lying over the erosional land-surface of the basin (Fig.2). The formation consists of argillaceous sediments with subordinate fine grained sand and sandstones intercalations. The thickness of that formation reaches up to 1,100 m in the southernmost area of the USCB.

The Quaternary sediments are significantly changeable through the basin. The older, Pleistocene part of the sequence consists of the glacial deposits: boulder clays, sands and gravels of morains and eskers, as well as sands and gravels of fluvioglacial accumulation, as well as periglacial loesses. There are also sands and gravels of several river accumulation terraces. The Holocene sediments confine fluvial silts and sands, as well as dune sands.

Two tectonic zones have been distinguished in the Carboniferous rocks of the basin: 1. the zone of fold tectonics and 2. the zone of disjunctive tectonics. The dominant part of the basin lies within the zone of disjunctive tectonics. Numerous faults, as well as very flat anticlines, domes, synclinal zones, or troughs represent the main structural elements.

HYDROGEOLOGICAL CONDITIONS

In the studied region, the USCB fresh groundwaters occur in the Quaternary, Tertiary, Cretaceous, Jurassic, Triassic, Carboniferous and Permian formations. Good conditions of occurring and extraction of groundwater have been detected only in the Quaternary and Triassic formations as well in the outcrops of the productive Carboniferous formation [3-7]. Carboniferous aquifers are recharged in zones of outcrops or through permeable cover rocks in the north-eastern part of the USCB, that is, in the area of Paleozoic epi-Variscean basement of the platform. Taking into consideretions the recharge conditions of the Carboniferous water-bearing sandstone, two hydrogeological regions (I, II) can be distinguished in the USCB. Their boundaries are delineated by the extent of the isolating series of the Tertiary (Fig. 2).

Aquifers which provide water suitable for drinking in high quantity occur only in the first hydrogeological region (Fig.2). However these aquifers are influenced by mining. Some of them comply with the following quantitative and qualitative basic criteria [8]: the potential yield of single well over 70 cub.m per hour, the abstraction of water intake over 10,000 cub. m per day, the transmissivity over 10 sq. m per hour, water quality suitable for drinking. They are numbered among the Main Groundwater Basins (MGWBs). In water deficiency areas individual quantitative criteria lower than the basic ones have been used. According to the mentioned criteria MGWBs have been specified in the studied region in Quaternary, Triassic and Carboniferous aquifers (Fig. 2).

The Quaternary MGWBs are located mainly in the system of buried valleys which generally only to small extent coincides with contemporary hydrographic system and directly refers to the Quaternary basement structure. In the first hydrogeological region (I) the MGWB occur in the Czarna Przemsza (Q/4) river valleys (Fig.2). The basin area is about 96 sq. km. large.

The basin occurs in the sandy-gravel, partly clayey, sediments. The thickness of aquifers ranges from several m to 80 m. Depths of wells are mostly from a dozen m to 60 m. Yield of single well reaches up to 100 sq. m per hour. The Quaternary MGWB is drained by sandy pit and coal mine workings. Renewable resources of the Quaternary basin are about 38 mln sq. m per year.

Negative feature of the Quaternary basins is their vulnerability to anthropogenic pollution due to high exposure. Therefore quality of drinking water in Quaternary basins is usually not too good.

Waters of the 3rd and 2nd classes predominate. Locally in areas of urban-industrial agglomerations waters beyond every classes of quality occur.

The Triassic MGWBs (Fig.2): Bytom (T/3), Chrzanów (T/5) and Gliwice (T/2) are built of dolomites and limestones of Muschelkalk and Roethian age and represent fissured-karst-porous aquifers. They are exploited by wells and drained by excavations of ore and coal mines. Locally they are drained by mineral material quarries too. Deep cones of depression are formed and the overexploitation of aquifers occurs due to intensive exploitation.

Taking into account resources of usable water, high yield of wells (up to several hundred cub. m per hour) and state of management, the Triassic aquifers are the main source of groundwater supply for urban-industrial agglomeration of Upper Silesia. The renewable resources of fresh groundwater in the Triassic MGWBs are about 65.8 mln m per year.

Because of intensive human activity in recharge areas aquifers' groundwater can be easily polluted. Waters of the Triassic carbonate series belong to the 1st, 2nd and 3rd classes of quality. Locally water of the Triassic MGWBs are submitted quality degradation and do not meet the sanitary regulations, particularly in the area of abandoned Zn-Pb ore mines in Bytom trough (Fig.2).

The Upper Carboniferous rocks consist of series of clays, mudstones and sandstones with coal seams. The Carboniferous confined aquifers of thickness from several to some tens meters are intercalated by impermeable claystones except for fault zones, zones of sedimentary wedging and areas of mining.

In the Upper Carboniferous formation TDS of groundwater ranges from 0.5 g/l to 372 g/l [5]. There is a general trend of TDS increasing with depth. The hydrochemical data demonstrate a vertical succession of hydrochemical zones in the Carboniferous formation of the USCB. Three hydrochemical zones have been distinguished: the zone of infiltrational waters, the intermediate zone of mixed waters and the lower zone of buried brines. These zones are defined on the basis of the hydrochemical and isotope data [5, 9-10].

The Upper Carboniferous aquifers with fresh water occur in the outcrop areas almost only in the NE part of the USCB. The zone of infiltrational waters of hydrochemical types: HCO_3-Ca, HCO_3-SO_4-Ca and SO_4-HCO_3-Ca-Mg and TDS below 1 g/l reaches the depth of about from 200 m to 250 m in the first hydrogeological region (I). The lower boundary of the intermediate zone lies at the depth ranging from 450 m to 650 m. The zone of buried brines of hydrochemical types Cl-Na and Cl-Na-Ca underlies the intermediate zone [5].

In the first hydrogeological region (Fig.2) two MGWBs have been specified in the Carboniferous formation: Czeladź C/1) and Tychy- Jaworzno (C/2). In the outcrop area of the Carboniferous formation in the central part of the first hydrogeological region there are any water resources suitable for consupmtion (Fig. 2). Because of high vulnerability of aquifers to anthropogenic pollution due to high exposure and mining activity the quality of infiltrated water is very low.

The region of direct recharge of Carboniferous aquifers extends in the northern and north-eastern part of the USCB, it means in the first hydrogeological region (Fig.2). The Carboniferous aquifers are recharged in the outcrop zones directly or through permeable cover rocks. Recharge intensity is predominantly related to the water-bearing Quaternary deposits presence which are especially abundant within buried valleys. Discharge of Carboniferous aquifers takes place in the areas of intensive mining.

Fresh waters from the Carboniferous belong mainly to the 3rd and 2nd classes of quality. They are pumped out by mine intakes, locally by wells with yield of some tens cub. m per hour.

In the Upper Carboniferous formation TDS of groundwater ranges from 0.5 g/l to 372 g/l.

The estimated renewable resources of fresh groundwater in the Carboniferous MGWBs are about 111.5 mln cub. m per year. Available resources, due to the negative impact of mining are much lower.

MINE WATERS

Mining in the USCB has been active since the second half of the 18th century. The coal fields cover the area of about 2,000 sq.km (Fig.1, 2). The depths of mining vary from 400 m to 1,200 m. The majority of coal mines lie in the area of shallow occurrence of productive Carboniferous series in the north-eastern part of the USCB.

Mine waters are pumped out from 65 coal mines in total quantity of 601.8 cub. m per min. TDS of natural mine waters ranges from 0.2 g/l to 372 g/l but TDS of the cumulative pumped out waters ranges from a few g/l up to 110 g/l [5].

Mine waters are highly variable in their chemical composition and TDS [11]. Pumped out mine waters belong to different chemical groups taking into account the following quantities:

1. waters with TDS below 1 g/l and Cl and SO_4 ion content below 0.6 g/l (fresh waters) - 220.2 cub. m per min;
2. waters with TDS from 1.0 g/l to 3.0 g/l and Cl and SO_4 ion content from 0.6 g/l to 1.8 g/l (industrial waters) - 148.5 cub. m per min;
3. waters with TDS from 3.0 g/l to 70 g/l and Cl and SO_4 ion content from 1.8 g/l to 42 g/l (saline waters);
4. waters with TDS above 70 g/l and Cl and SO_4 ion content above 42 g/l (brines).

Fresh waters with TDS below 1 g/l are mainly of the following hydrochemical types: HCO_3-Ca and HCO_3-SO_4-Ca. Brackish mine waters are enriched in sulphate ions in the mine workings due to oxidation processes of pyrites and sulphur from the coal seams. The saline waters and brines belong to Cl-Na and Cl-Na-Ca hydrochemical types.

In the first hydrogeological region the depth of the base of the low mineralised mine waters (below 1 g/l) reaches about 250-400 m.

Coal mines in the first hydrogeological region (I) are fed with waters from the Carboniferous aquifers consisting of numerous water-bearing layers. The local geological structure and the recharge condition of Carboniferous aquifers play decisive role in the quantity and quality of water flowing into coal mines [3, 12].

The inflow of waters into particular mines, situated in the north-eastern part of the USCB, varies from about 0.9 to 73 cub.m per min. Substantial inflow of low mineralised waters are recorded in areas where the coal exploitation takes place in the Cracow and Upper Silesian Sandstones series. In these series the sandstone layers predominate and the aquifers are recharged by waters from the thick Quaternary water-bearing formation.

The rate of the fresh water inflow to the coal mines located within the Carboniferous MGWBs: Będzin (C/1) and Tychy-Siersza (C/2) is about 130 cub. m per min. According to statistics they are used in 88% for industrial and communal purposes. About 12% of fresh mine waters are discharged into the rivers. The water supply system consumes about 14 cub.m per min [13]. Taking into account the quality of fresh mine water and costs of their intake in mines there is a possibility to use only about 27 cub.m per min for water supply system in the future [13-14].

IMPACT OF UNDERGROUND COAL MINING ON THE GROUNDWATER ENVIRONMENT

Underground coal mining and activities of associated industries have caused the disturbances of the natural hydrogeological condition in the Quaternary, Triassic and Carboniferous MGWBs within the first hydrogeological region of the USCB.

The main phenomena causing the changes in hydrogeological conditions include the drainage of rocks, alteration of water chemistry and flow directions in the MGWBs, as well as changes in the physical parameters of the rock mass. These phenomena result in the reduction of groundwater resources by lowering the water volume in the aquifers affected by mining and by water pollution [3-5, 7].

Slides, cracks and stressing of the rocks usually accompany mining activities. These processes cause increases of the rock permeability and the hydraulic connection of waters from different aquifers, producing the interruptions of isolating layers. Size of drainage is determined by geological structure, surface and depth of mining works and range of formed depression. The artificial hydraulic interconnection created by mine activities and deep drainage causes the changes in the natural chemistry and quality of groundwaters mainly due to water mixing processes.

The impact of mining on the groundwater resources in the area under consideration is of very complex nature and the differentiation of phenomena occuring here is very large.

The mining activity causes the changes of hydrogeological conditions. They are appearing as diminishing or even declining in surface outflow, changes of heads and quality of groundwater, directions and velocity of water flow, loss of water in wells.

The total mining activities within the first hydrogeological region may be classified as follows:

- exploitation of sand pits,
- underground mining of zinc and lead ores,
- underground mining of hard coal.

In the sand pits the Quaternary sand deposits are extracted causing the drainage of the subsurface Quaternary MGWB (Q/4). That is a rather large-scale phenomenon particularly in the area of backfilling sand pits characterised by the large excavation area. Coal mines drain about 400 sq.km of area covered by water-bearing Quaternary formation.

Underground zinc and lead ores mining is being run within the Bytom trough (T/3) as well as in Chrzanów syncline (T/5) (Fig.2). Zinc and lead ores mining combined with coal mining have effected in the permanent drop of water table occurring in the Triassic formation in the Bytom trough and partly in the Chrzanów syncline.

Mining of hard coal predominates in the first hydrogeological region (I). The direct impact of coal mining on the water resources is manifested by drainage of the Carboniferous MGWBs and the overburden aquifers. The drainage of these aquifers occurs mainly in areas where the Carboniferous sediments are overlain by the Quaternary or Triassic strata, with an insufficient isolation. In the first hydrogeological region the area of decreased piezometric pressure occupies about 1,100 sq. km. Pressure head of the Carboniferous aquifers have lowered from about 80 m to 150 m [15].

Within the Bytom trough the draining impact of the coal mining on the Triassic MGWB is due to the longwall with caving method being used under Triassic strata. It causes frequent breaking of the ledge forming the Triassic floor accompanied by outflows of water, sometimes very intensive. Such phenomena occur in the mines situated mainly in the eastern part of the Bytom trough. In the case of the „Saturn" mine the inflow to the mine excavations from the Triassic aquifer reaches up to 14.8 cub.m per min [16]. The total drainage rate of groundwater from the Triassic MGWB Bytom

(T/3) by coal mines and intakes is about 32 cub.m per min, while from the Triassic MGWB Chrzanów (T/5) is about 15 cub. m per min.

The chemistry of coal mine waters in formed in different geological formations and under circumstances of variable human impact, hence the chemistry and the quality of the fresh waters are differentiated. Under the cover of the Triassic formation, coal mine waters are of the HCO_3- Ca-Mg and HCO_3-SO_4-Ca-Mg hydrochemical types. Waters infiltrating to the coal mines from the Quaternary aquifers are usually of the HCO_3-Ca and HCO_3-SO_4-Ca types. In the areas of the maximum influence of the urban-industrial agglomeration on the environment, waters are degraded additionally by pollution migrating from the surface. From the chemical point of view these waters are mainly of SO_4-HCO_3-Ca-Mg and SO_4-Cl-Ca-Mg-Na types with TDS ranging from 1.5 g/l to 5.3 g/l (Fig.2).

Fresh mine waters require an intensive treatment. These waters are polluted bacteriologically, turbid, hard, often with high content of chlorides, sulphates, iron, manganese and suspension. According to Solik-Heliasz [13] 64% of the natural inflow of the fresh waters to mine workings is intaken. The scattered, small water effluents are difficult to be intaken and they are subjected to pollution during a long run-off to the main dewatering system of mines.

The wastes produced by the coal mining industry in the USCB represent the problem of unique environmental importance due to the enormous volumes that have already been accumulated in this region and are supplied each year by the operating mines. These wastes represent about 30-40% of total output of coal mines. Official statistical data for 1992 reveal that the USCB has accumulated, up to date, 663 Tg of wastes. In 1992 the hard coal mines yielded 52.5 Tg of wastes. According to Szczepańska and Twardowska [17] 38% of this amount is deposited in central and local dumps. The remaining 62% is utilised for land, common, and mine backfilling, in construction of roads, embankments, etc.

Coal mining is accompanied by two types of wastes: spoil rocks and flotation wastes. Salting of wastes increase with depth of mining. The investigations have shown that the salting of Carboniferous spoil rocks resulted in presence of the groundwaters of different salinity in rock pores. Chloride concentration in spoil rocks is therefore also varying from 0.15% to 1.0 %, while in flotation wastes from 0.003% to 0.009% [18].

All the deposition and utilisation methods introduce wastes as anthropogenic components to the vadose zone. Here, the wastes are exposed to the atmospheric conditions and consequently subjected to physical, chemical and biochemical processes. These processes generate contaminants. They are released into water systems in the vicinity of dumps and constructions and cause degradation of the water environment [17]. Soluble components leached from the wastes: sodium, potassium, chlorides, sulphates, iron, manganese, zinc, lead, aluminium, nickel and copper, change chemistry of groundwater and cause decreasing of groundwater quality in the areas adjacent to the waste disposal sites. Such phenomena have been observed in the Quaternary (Q/4), Triassic (T/3, T/5) and Carboniferous (C/1, C/2) MGWBs (Fig.2).

Another source of the most hazardous contamination to the water environment is the leakage of saline-polluted mine waters from the settling tanks. Release of approximately 700,000 cub.m of polluted coal mine waters from the three settling tanks in the Bytom area (T/3) during the years 1975-1981 is an good example of such contamination [19].

REFERENCES

1. Kotas A., sc. ed., 1994, Coal-Bed Methane Potential of the Upper Silesian Coal Basin, Poland. Prace Państwowego Instytutu Geologicznego, Warszawa, 142: 81 p.

2. Jureczka J., Kotas A., 1995, Upper Silesian Coal Basin. In: The Carboniferous System in Poland. Prace Państwowego Instytutu Geologicznego, Warszawa, 148: 164-173
3. Rogoż M., Różkowski A., Wilk Z., 1987, Hydrogeologic problems in the Upper Silesian Coal Basin. In: Hydrogeology of Coal Basins. Intern. Symposium. Katowice, Poland 14-18 September 1987: 365-382. Kraków: Wyd. AGH
4. Różkowski A., 1989, Impact of mining on the water environment in the Upper Silesian Coal Basin (Poland). W: Impact of mining on environment: International Workshop. Tallinn-Leningrad June 18-25, 1986: Proceedings Part UNEP/UNESCO/USSR. Project Geology and Environment. Part 1 Moscow, 1989: 119-136
5. Różkowski A., 1995, Factors controlling the groundwater conditions of the Carboniferous strata in the Upper Silesian Coal Basin, Poland. An.Soc.Geol.Pol., vol. 64: 53-66
6. Różkowski A., Kowalczyk A., Witkowski A., 1996, Występowanie, zasoby i użytkowanie zwykłych wód podziemnych w zlewni górnej Odry i górnej Wisły w zasięgu województwa katowickiego i bielskiego. Prz.Geol., vol. 44, 8: 834-839
7. Wilk Z., Adamczyk A.F., Nałęcki T., 1990, Wpływ działalności górnictwa na środowisko wodne w Polsce. Warszawa: The Agricultural University: 220 p.
8. Kleczkowski A.S., 1991, The map of the critical protection areas (CPA) of the Major Groundwater Basins (MGWB) in Poland 1:500 000 (Explanations). Academy of Mining and Metallurgy, Kraków: 44 p.
9. Kleczkowski A.S., Vu-Ngoc-Ky, 1970, Chemical Properties of Ground Waters in the Babice-Spytkowice Area. Bull. Acad. Pol. Sc. Sér. Sc. géol. géogr. vol. 18 nr 3: 189-198
10. Pałys J., 1966, O genezie solanek w górnym karbonie na Górnym Śląsku. An. Soc. Geol. Pol., vol. 36, 2: 121-154
11. Rogoż M., 1995, Aktualne problemy hydrogeologii górniczej węgla kamiennego. W: Współczesne problemy hydrogeologii. 7, cz. 2: 21-30. Kraków-Krynica 1995
12. Rogoż M., Staszewski B., Wilk Z., 1987, Impact of mining activities upon the aquatic environment within the Upper Silesian Coal Basin (USCB). In: Hydrogeology of Coal Basins. Intern. Symposium. Katowice. Poland 14-18 September 1987: 553-566. Kraków: Wyd. AGH
13. Solik-Heliasz E., 1992, Możliwości zwiększenia wykorzystania wód słabo zmineralizowanych z kopalń węgla kamiennego. W: 4 Konf. Postęp naukowy i techniczny w geologii górniczej węgla kamiennego. Szczyrk, 7-10 października 1992 r: 162-167. Katowice
14. Posyłek E., Wawerska B., 1988, Wody o niskiej mineralizacji w kopalniach węgla kamiennego Górnośląskiego Zagłębia Węglowego. Prace Głównego Instytut Górnictwa 748: 15 p.
15. Nałęcki T., 1990, Górnośląskie Zagłębie Węglowe. Wpływ działalności górnictwa na środowisko wodne w Polsce. The Agricultural University, Warszawa, 27: 19-53
16. Kropka J., Rogoż M., Różkowski A., 1989, Ujmowanie wód użytkowych w rejonie drenażu górniczego kopalni węgla kamiennego. Prace Naukowe Instytutu Geotechniki Politechniki Wrocławskiej, nr 58, Konferencje 29: 221-226
17. Szczepańska J., Twardowska I., 1995, Dynamics of contaminant leaching from coal mine waste dump Smolnica. In: Guide to Excursion II: Ecological Impact of Underground Coal Mining and Activities of Associated Industries. Polish Geological Institute: 16-22
18. Herzig J., 1985, Charakterystyka zasolenia chlorkowego pokładów węgla i skał otaczających w Górnośląskim Zagłębiu Węglowym. Phd Thesis. Academy of Mining and Metallurgy Kraków: 103 p.
19. Kropka J., 1995, The influence of the coal mining activity on groundwater in the Triassic carbonate series (Bytom). In: Guide to Excursion II: Ecological Impact of Underground Coal Mining and Activities of Associated Industries. Polish Geological Institute: 9-12.