Quantitative analysis of supply from anthropogenic sources to mine workings of closed zinc-lead ore mines in the Bytom Trough (southern Poland)

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Abstract. The central pumping station Bolko in Bytom enables continuous dewatering of mined-out workings in lead-zinc ore mines in the Triassic Bytom Trough. Water of anthropogenic origin is of great importance in the balance of water flowing into workings and pumping stations: leakage from water supply networks and sewerage systems and seepage from rivers and collector trenches. The average total amount of supplying ore workings from analysed anthropogenic sources of water and sewer in the years 1999-2000 was 12.2 m^3/min, equivalent to a recharge rate of 341 mm/y. Its share in total water inflow was 40%.

Introduction

The Bytom Trough constitutes a complicated, multi-layer (Quaternary, Triassic, Carboniferous) aquifer system, which is the location of a system of two-level mining exploitation. The upper one, in the Middle Triassic beds, was for the exploitation of zinc-lead ore deposits, finished in 1989; while the lower one if for active exploitation of hard coal deposits in the layer of productive Carboniferous. Difficult mining conditions result from the fact that areas of the mentioned coal mines were or are located beneath a densely developed building setting belonging to the urban area of Bytom and Piekary Śląskie cities. The cities have an approximate population of 200,000. It is necessary to drain ore workings in closed mines since there are active coalmines situated beneath. Otherwise, exploiting coal deposits in the layer of productive Carboniferous would be endangered by groundwater inflow. Atmospheric precipitation, 801 and 915 mm in the years 1999 and 2000 respectively, together with waters of anthropogenic origin constitute the main supplying source. Anthropogenic sources comprise water that seeps from surface watercourses during the breakdown of water mains and urban water supply and sewerage systems. It is extremely complicated to specify clearly anthropogenic components in the balance of water flowing into ore workings.

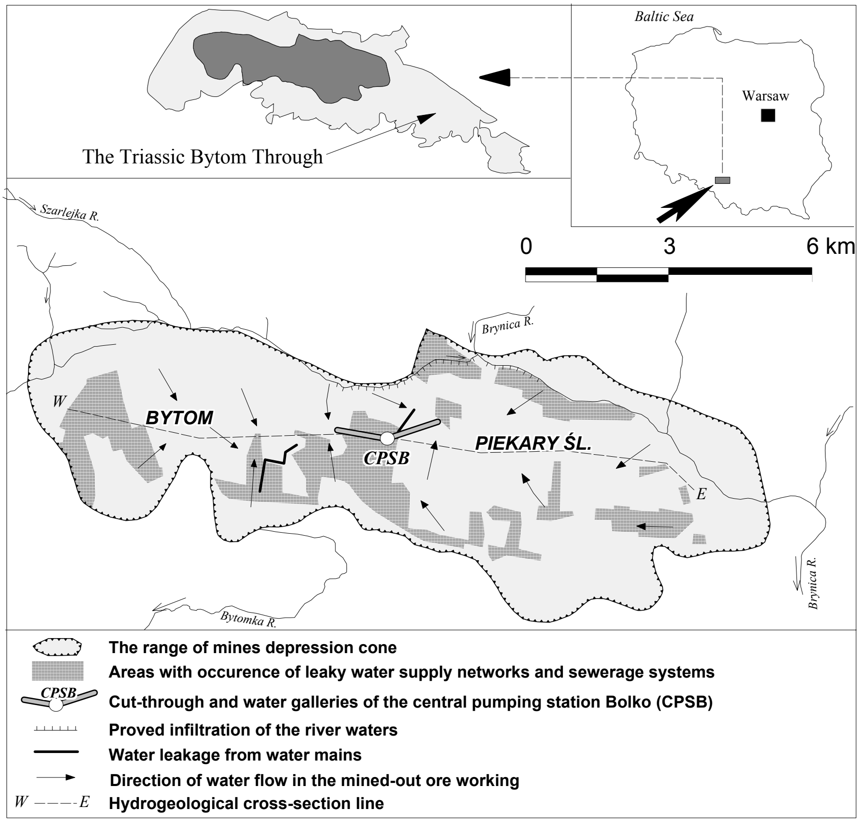

Fig. 1. Hydrogeological sketch of the mined-out workings in lead-zinc ore mines in the Triassic Bytom Trough.

Geology, mining operation and hydrogeology of the study area

The study area is located in the southern part of Poland, as indicated in Fig. 1. The Bytom region of ore mining is situated in the western part of Silesian–Cracow area where zinc-lead ore deposits occur (Wilk et al. 1990). The Triassic Bytom Trough is one of several fold-block alpine structures of lower strata within the border of Silesian-Cracow monocline. The northern, northern-eastern and southern borders are tectonic-erosive, while the western is hydrodynamic (Fig.1). In the

Triassic profile, with total thickness from several to maximum ca. 230-250 metres, terrigene deposits of Lower and Middle Bunter Sandstone and carbonate deposits of Roethian and Muschelkalk occur. The Triassic cover consists mainly of Quaternary deposits, greatly differentiated as far as thickness and lithological development are concerned (Fig.2).

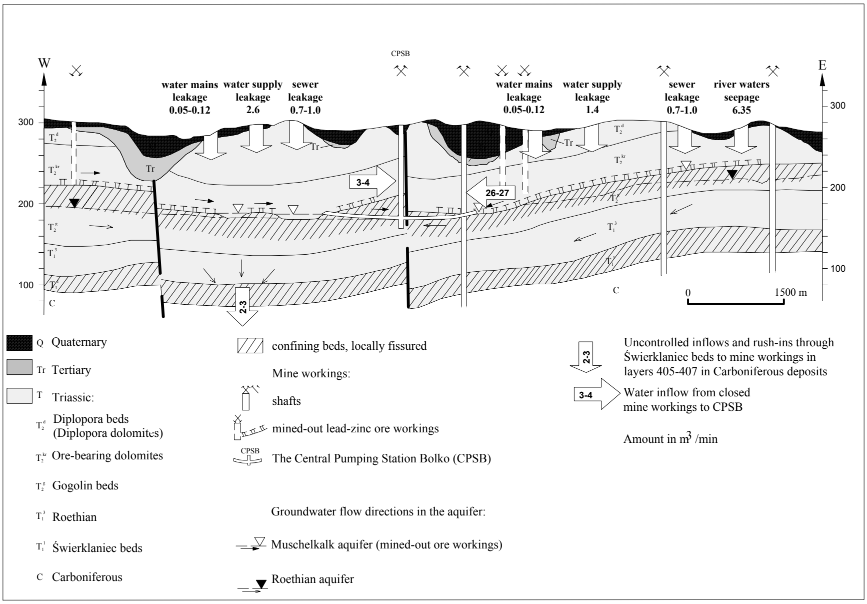

Fig. 2. Hydrogeological cross-section.

The first documented historical reports on zinc and lead ores mining activity within the discussed area date back early 12th century (Majorczyk 1985). Industrial mining exploitation, started in the late 19th century, reached the depth of ca. 110 metres under the surface level, and caused intensive transformations in water relationships. In the mid-seventies of the 20th century there were five active zinc and lead ore mines. Zinc and lead ore deposits within the discussed area are related to the so-called ore bearing Dolomite series of the Middle Triassic. The subject of exploitation was both oxidized ore deposits (galmei) and sulphide ores (zinc blende and galenite) (Baranowski 1980; Gałkiewicz 1980). Thickness of exploited deposits ranged from 2.0 to 6.5 m, 3.0-4.0 m on average. The main exploitation levels were situated at the depth (from surface) from 90-100 in the western and central and 64-96 m in eastern part of mining area (Fig.2). Mines not working at present are connected with each other by means of underground workings. The area of mine workings in the last few years of exploitation (1983-1989) was ca. 39.0-40.0 km². Mine workings were situated within the borders of a mining area of 61.4 km². Total range of draining influence of ore mines on groundwaters in Quaternary and Muschelkalk deposits is ca. 57.8 km² (Fig.1).

Exploitation of hard coal deposits is performed in productive Carboniferous, within the influence of zinc-lead ore exploitation. The period of intensified hard coal exploitation started in the seventies of the 19th century. Ten hard coal mines were still working 11 years ago, when zinc-lead ore mining was definitely finished. Currently, according to the state for 1 Jan. 2002, five coalmines are still active. Generally, below ore workings, the present deposits of Orzesze Beds (Westphalian A) and Ruda, Saddle and Poruba Beds (Namurian C, B and A accordingly), with thickness from 1.2-9.0 metres, there were, and still are, exploited. Intensive, mainly roof caving exploitation of hard coal, within the level of 180-930 deep (under the area surface), leads to serious disturbances and deformations in Carboniferous rock mass, which are then transferred to carbonate Triassic rocks lying above, and finally to the surface. Surface deformations play a role in the breakdowns of urban water supply and sewerage systems on areas of dense building settings, as well as the loss of tightness in watercourse beds and basin resulting in no water runoff.

Basically, three independent aquifers were distinguished in the natural hydrogeological profile of the Triassic multi-aquifer formation (Kropka 1996). The main Muschelkalk and Roethian aquifers, consisting of dolomites and limestone, are karst-fissured aquifers. The first of them is of great significance for inflow to workings of liquidated zinc-lead ore mines (Fig.1, 2). Muschelkalk aquifer comprises a series of dolomitic limestone, ore bearing limestone, and minor marly dolomites. This series is highly porous and cavernous, partially brecciated, providing advantageous conditions for receiving, storing and transmitting water. This layer is isolated from the lower one by vitriolic clays and marly-limestone clays, and from the upper one by part of Gogolin strata. In natural conditions, the water table in Muschelkalk aquifer occurs at the ordinate +265 m above the sea level, while thickness ranged from several up to maximum ca. 50-55 metres. Recharge conditions in Muschelkalk aquifer within the Triassic Bytom Trough are greatly differentiated. Long lasting ore exploitation in the central part of the Bytom Trough caused lowering of the water table up to the level of ore workings, i.e. to the ordinate 170-240 m.a.s.l. (metres above sea level). At present, the Triassic rock mass above ore workings level is drained (Fig.2).

Abandoning mining exploitation in 1989 and final liquidation of ore mines in the Bytom Trough (years 1990-1991) did not stop drainage of ore workings. Ceasing drainage and, in consequence, flooding ore workings and Triassic rock mass would cause a real water inflow danger for active hard coal mines. This is why the system of central drainage in liquidated mines was introduced, which is designed to operate until hard coal deposits lying below are completely exploited. The main role in the centralised system of draining abandoned ore workings is played by the Bolko shaft, 129.3 m deep, with a newly built central pumping chamber, with pumping capacity ca. 36.0 m^3/min, and hollowed drainage workings directed to the west and east (Fig.2). Central pumping station at Bolko shaft (CPSB) started to work in 1988, and in the period from March 1989 to August 1990, by means of the two mentioned workings, it took over waters coming from liquidated pumping stations in the five ore mines. In the period from August 1990 to December 2000 water flowing into CPSB was ca. 30.0 m^3/min on average. The main factors that differentiate the share of water inflow from the western and eastern parts to CPSB are following:

- cover, predominantly occurring in the western part, from several to ca. 70 metres thick, consisting of clay and loamy Tertiary and Quaternary deposits, while in the eastern part the dominant role is played by areas of advantageous supply; and
- entering a part of water from ore workings through Bunter Sandstone beds to the workings in coal mines in 1991, at the western side of CPSB.

Anthropogenic sources supplying mine workings

The factors that decide the amount of anthropogenic water supplying inflow to mine workings in abandoned ore mines is water and sewer infiltration from the following sources:

Rivers and collector trenches

The problems connected with water seepage from surface watercourses to mine workings in ore mines were presented, among others, by Plotnikov and Roginets (1989), Sawicki (2000) and Wilk et al. (1990). Rivers and collector trenches flowing through mining areas belonging to ore mines created, until 1989, the most serious water inflow danger to mining works in the Bytom Trough. The reasons for subsidence and damage to tightness of river beds, resulting in water infiltration and as a consequence an increase in the amount of water flowing to workings, was mining exploitation of hard coal deposits in a direct neighbourhood of watercourses. Among other factors, seepage from the Brynica and Szarlejka rivers intensified in the 1970s, caused temporary increase in waterflow to two ore mines, from 1.6-2.7 m^3/min to 10.7 m^3/min, and from 7.0 m^3/min to 13.0 m^3/min, respectively (Kropka, in press). River waters, highly polluted, flow in regulated and partly self-tightened river and stream beds. However, three series of hydrometric measures performed in 1999-2000, proved that water escaped in two sections of the mentioned rivers in total amount of ca. 6.35 m^3/min (Fig.1, 2).

Water mains

Large diameter water main pipelines (several hundred mm dia.) transect the Triassic Bytom Trough from north to south. Intensive deformation of the rock mass has caused two sections of pipeline to be particularly vulnerable to cracking and leakage (Fig.1). It is estimated that, as a result of several breakdowns of the mentioned pipelines, ca. 0.1 up to ca. 0.25 m^3/min of water infiltrated to the rock mass and then to ore workings.

Leaky water supply networks in Bytom and Piekary Śląskie cities

Leakage from water supply is a major source of urban recharge (Lerner 1997). Often cited average values of groundwater recharge rate from this source in the suburbs of Lima (Peru), Tokyo (Japan) and Birmingham (England) are 360, 440 and 180 mm/y respectively (Foster et al. 1997; Lerner 1997). According to Lerner (1997) loss rates of 20-25% are considered normal in the UK. The cities of Bytom and Piekary Śląskie take water for consumption purposes from outer sources. Leakage from water supply is intensified by old, highly exploited network with many worn-out connections, which are easily affected by changes of pressure in water mains and activity of underground mining. In the early 1990s, loss resulting from infiltration within the area of discussed cities amounted to 35-40%. The amount of loss is the difference between the amount of water pumped into the district and the amount of water bought by single users of the water supply network. In the period 1996-2000, water supply agencies allocated significant financial resources to rehabilitating infrastructure of urban water supply network. Thanks to the effectiveness of these actions the number of breakdowns has fallen and infiltration has decreased. Infiltration rates are presented in Table 1.

Leaky sewerage systems (urban and industrial waste water)

Although sewer leakage occurs, there are almost no estimations of quantities, and no proved methods of identification and quantification. Some publications suggest that an average leakage rate should be no lower than 5% (Lerner 1997). Much higher standards are possible in areas where the provision of waste water disposal is performed by sanitation without sewerage network (e.g. septic tanks) and ductile-iron pressurized sewage systems (Foster et al. 1999). Over 99% of all households in the analysed districts of Bytom city are connected to a complete sewer system to remove waste water for further treatment in water treatment stations. The districts in Piekary Śląskie, within the borders of mining activity are covered with sewerage system in ca. 70%. The leakage of sewers is not well documented within the discussed area. The analyses made so far suggest that an average leakage rate ranges from 7-12% in areas with sewerage system and 30-50% in areas where provision of waste water disposal is performed by sanitation without sewerage network (Table 1).

Discussion and conclusions

The average total water inflow from closed mine workings to CPSB in the years 1999-2000 amounted to ca. 30.0 m³/min. Total closed workings recharge in the western part of the system remains on the level of 5.0-7.0 m³/min, out of which 3.0-4.0 m³/min flows into the pumping station, while the remaining 2.0-

3.0 m³/min infiltrates to shallow mine workings in hard coal mines. Inflow of water from the eastern part to the pumping station was 26.0-27.0 m³/min (Fig.2).

The average total amount of ore workings recharge in the western region (within two districts of the Bytom city) from analysed anthropogenic sources of water and sewer in 1999-2000 was 3.4-3.7 m³/min. Its share in total recharge was 53-68%. The average amount of analogous recharge from anthropogenic sources in the eastern region (mainly in four districts of the Piekary Śląskie city) in the years 1999-2000 was 8.5-8.9 m³/min. Its share in total water recharge was 33%.

Table 1. Major anthropogenic sources of mine-out ore workings recharge (m^3/min/mm).

Mined-out ore workings	Year	Water mains leakage	Water supply leakage	Sewer leakage	River waters seepage	Total recharge
The western part	1999	0.05-0.12	2.7	0.7-0.9	-	3.4-3.7
		-	337	87-112	-	(424-449)
	2000	0.05-0.12	2.4	0.7-1.1	-	3.2-3.6
			299	87-137	-	(387-436)
The eastern part	1999	0.05-0.12	1.5	0.6-0.9	6.35	8.5-8.9
		-	172	69-103	-	(241-275)
	2000	0.05-0.12	1.3	0.7-1.1	6.35	8.4-8.9
		-	149	80-126	-	(229-275)
The average total amount in the years 1999-2000		0.1	4.0	1.7	6.35	12.2
		-	239	102	-	(341)

Annual summaric maintenance costs of CPSB in the analysed period ranged from 8.8 to 9.3 million zloty. It must be emphasized that 22-23% of these costs results from expenditure on electric energy. It is extremely complicated to specify clearly anthropogenic components in the balance of water flowing into CPSB and it requires further examination. The author realises that generalisations and estimations made during calculations were necessary. Results indicate that for average meteorological-hydrogeological conditions, the contribution of water from anthropogenic origin as inflow to closed ore workings is about 39-42%, i.e. from ca. 11.6 to ca. 12.6 m³/min. Waters of anthropogenic origin leads to deterioration of water quality and an increase in the cost of maintaining pumping stations. This increase is best illustrated in a one-year period from 1 Sept. 1998 to 31 Aug. 1999, in which the unit cost of electric energy of pumping 1 m³ water out to the surface was 0.1295 złoty. Sealing the whole system by means of, first of all limiting water seepage from anthropogenic sources, and simultaneously limiting water inflow by 20-30% as compared to present amount, will contribute to savings in expenditure (on electric energy alone) by the sum of 408,000—613,000 zloty per year.

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