CHAPTER

17

Mine Water Discharges in Upper Silesian Coal Basin (Poland)

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17.1 INTRODUCTION

The Upper Silesian urban-industrial agglomeration is one of the most impacted and transformed areas in Europe. The intense industrialization results mostly from the presence of coal and other mineral deposits and their extraction. Mining areas of hard coal mines comprise approximately 25% of the total catchment area of watercourses in the Upper Silesian Coal Basin (USCB), including the river basin of the Upper Odra (Oder) River and the Little Wisła River. The mining, its scope and depth, duration of mining works, extraction systems being used and the total volume of the drainage fundamentally affect the conditions of groundwater and surface water in the area being studied (Bondaruk et al., 2016). Surface transformation due to mining waste dumps and soil degradation occur on large areas in the USCB. Fig. 17.1 shows the location of the Upper Silesian collieries and their current status, as well as the zones of potential mining impacts.

Hard (or bituminous) coal mining is the largest branch of the Polish mining industry. Polish bituminous coals are associated exclusively with the Carboniferous period. Three types of productive formations occur in connection with three known Polish coal basins (Nowak, 2004), as follows: (i) Lower Silesian Coal Basin (an intermontane depression); (ii) Upper Silesian Coal Basin (a foredeep); (iii) Lublin Coal Basin (a platform depression).

The USCB is the largest of the three and is the subject of the current study. The USCB is located in the southern part of Poland, where historical dependency on industry reflects the character of the whole region. Coal mining is the main branch of industry that has affected every aspect of societal life, environment and economy in the USCB for over two centuries. The USCB is located across the country border: in southern Poland and in the Ostrava-Karvina region in the Czech Republic. It covers an area of about 7400 km^2 (about 5800 km^2 within Polish territory).

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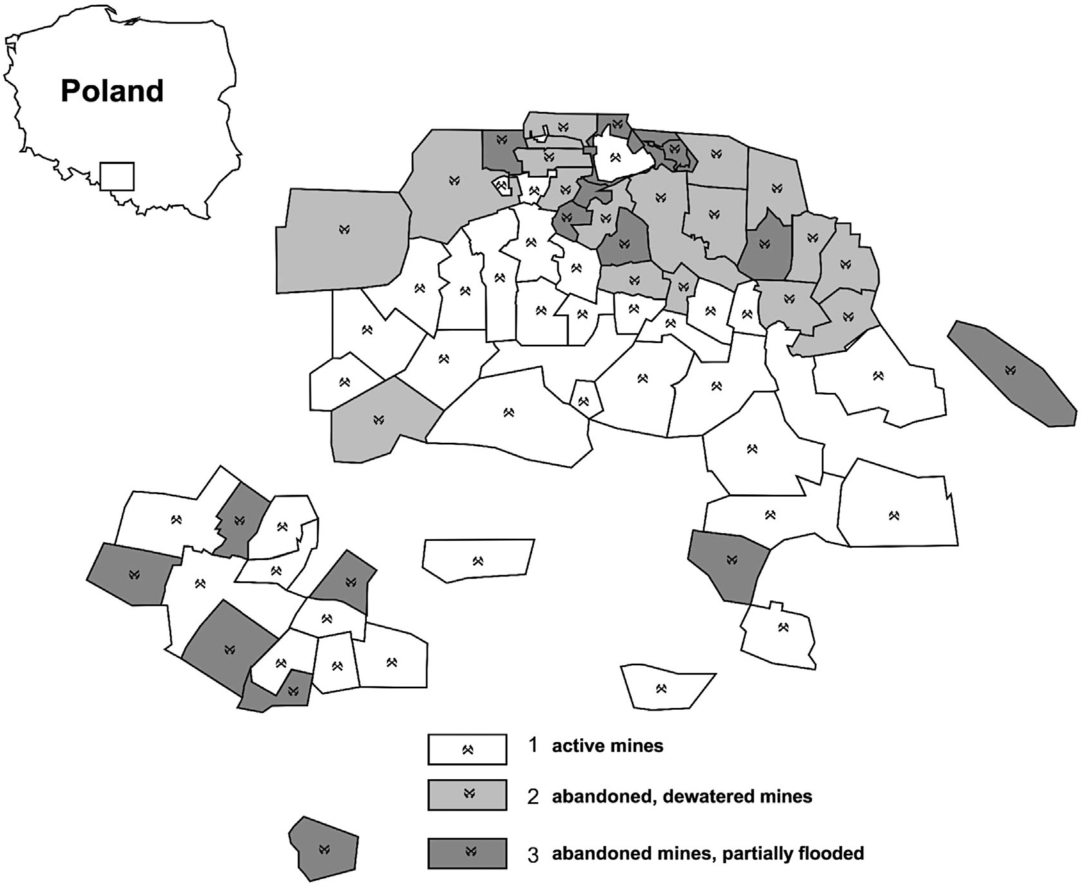

FIG. 17.1 Location of the Upper Silesian Coal Basin with minefields and their current status

Intensive exploitation goes along with the intensive drainage and discharge of water by the mining industry. Mine water discharges play an important role for surface water quality and quantity in the USCB. The mining region is situated in the spring area of many small rivers and creeks, being the tributaries of two main Polish rivers: Wisła and Odra in the upper part of their catchments, called Upper Odra and Little Wisła.

The impact of mining activities on groundwater and surface water bodies in the USCB results mainly from the rock drainage due to mine dewatering and discharge of saline water into surface watercourses. However, in the area of the USCB all the possible influences of coal mining on the aquatic environment are present. Mining transforms natural water conditions both qualitatively and quantitatively. These transformations are caused by: rock drainage as a mine dewatering effect, discharge of mine water to surface water receivers, land subsidence caused by mining exploitation, leading to changes in water conditions on the surface as well as storage of large quantities of waste extracted from the mine which affects soil quality.

17.2 GEOLOGY OF UPPER SILESIAN COAL BASIN

The tectonic unit forming the Precambrian basement of the USCB is known as the Upper Silesian Block, being a part of a larger tectonic unit known as Brunovistulicum, which also includes the Brno Block located in Moravia, the Czech Republic (Buła and Żaba, 2008).

Within the Precambrian basement of USCB three following complexes are known, listed here from the southwest towards the northeast (Buła et al., 2015):

1. complex of Neoproterozoic (660–556 Ma) crystalline (metamorphic and igneous) rocks found in the Cieszyn-Żywiec-Bielsko-Biała-Andrychów-Kęty area (Fig. 17.2). The rocks continue to the southwest as far as the Brno region in the Czech Republic;

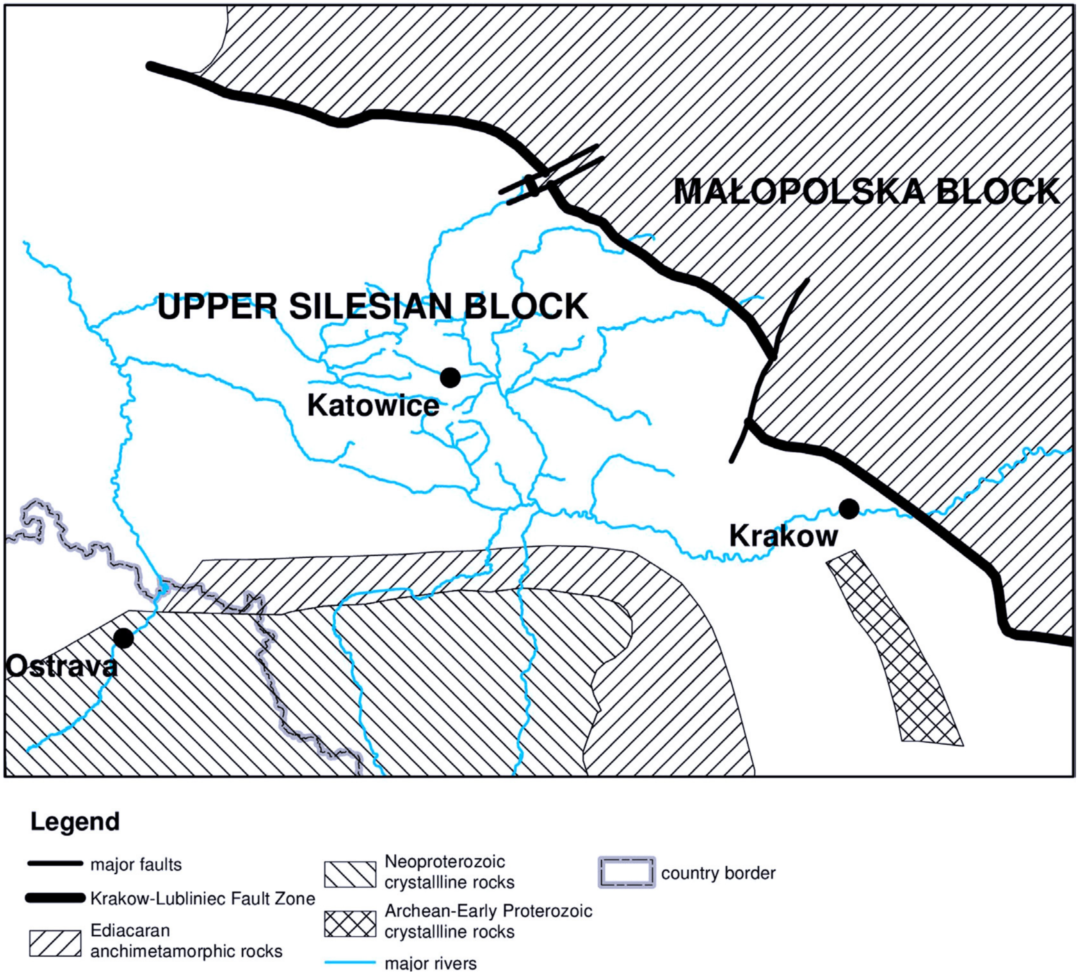

FIG. 17.2 Geological map without formations younger than the Ediacaran. *Based on Buła, Z., Habryn, R., Jachowicz-Zdanowska, M., Żaba, J., 2015. The Precambrian and Lower Paleozoic of the Brunovistulicum (eastern part of the Upper Silesian Block, southern Poland)—the state of the art. Geol. Quart. 59 (1), 123–134, simplified.*

2. complex of Ediacaran anchimetamorphic flysch-type siliciclastics, strongly tectonically deformed and locally phyllitized. This rock complex has been examined in a narrow belt stretching from Goczałkowice through Piotrowice-Wysoka-Potrójna to the Lachowice area. On the south and west, it adjoins the previously mentioned complex of Neoproterozoic crystalline rocks;
3. complex of Paleoproterozoic (2.0 Ga) crystalline (metamorphic) rocks with inherited Archean elements of 2.7 Ga age. These rocks have been examined in the Rzeszotary-Wiśniowa region (south of Kraków) within a subsouthern structural element—the Rzeszotary Horst.

The Lower Paleozoic sedimentary cover in the eastern part of the Upper Silesian Block is represented by nonmetamorphosed Cambrian siliciclastic and Ordovician siliciclastic-carbonate rocks. The top surface of these deposits is characterized by very high relief variations from 170 m a.s.l. to 6000 m b.s.l. (Buła et al., 2015).

The molasse coal-bearing sediments of the USCB form an 8000-m thick succession which has been divided into two parts (Gmur and Kwiecińska, 2002; Fig. 17.3). The lower part is

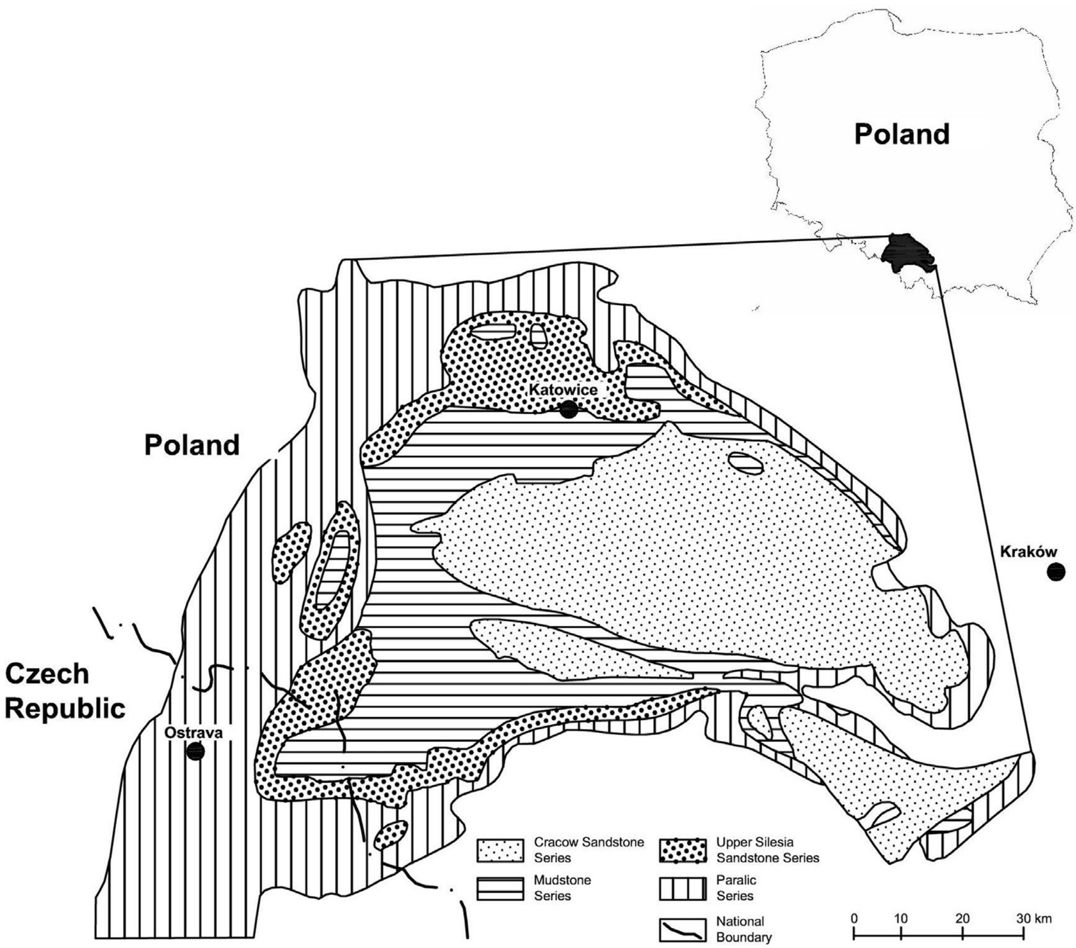

FIG. 17.3 Geological sketch—map of the Upper Silesian Coal Basin.

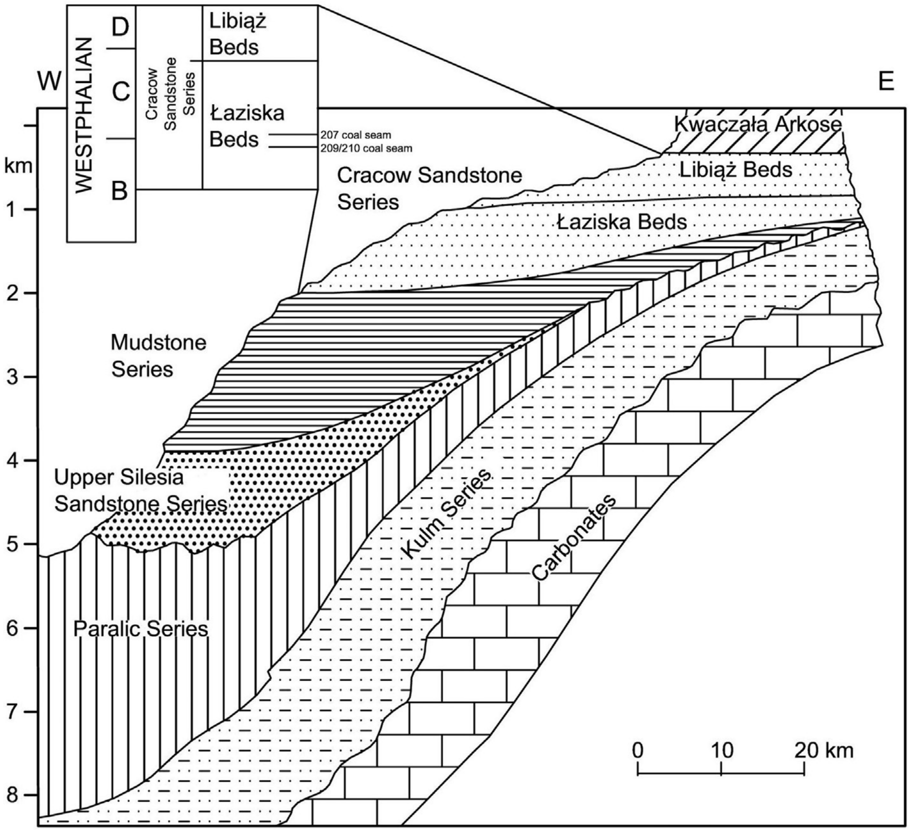

FIG. 17.4 Stratigraphic cross-section through the Upper Silesian Coal Basin infill, showing the reconstructed distribution and thickness of the main lithostratigraphic units. *After Gmur, D., Kwiecińska, B.K., 2002. Facies analysis of coal seams from the Cracow Sandstone Series of the Upper Silesia Coal Basin, Poland. Int. J. Coal Geol. 52 (1–4).*

represented by paralic coal-bearing sediments (Paralic Series) which overlay, with sedimentary continuity, the siliciclastic marine sediments of Kulm facies (Fig. 17.4). The upper part of the succession contains continental rocks and is separated from the underlying marine deposits by a stratigraphic gap. The upper part consists of three units: the Upper Silesian Sandstone Series, Mudstones Series, and Cracow Sandstone Series (Fig. 17.4).

17.3 HYDROGEOLOGY OF USCB

Three water-bearing formations have been identified in the hydrogeological section of the USCB: Quaternary, Mesozoic and Carboniferous (Różkowski et al., 1993) while clay Tertiary sediments form the most important aquiclude formation. The Upper Carboniferous formation is represented by a clay-silt-sandstone complex with coal seams. Two sandstone series as well as two siltstone-claystone series can be distinguished in the vertical section of those deposits. There are: Cracow Sandstone Series (Westphalian

B-D), Upper Silesian Sandstone Series (Namurian B-C), Siltstone Series (Westphalian A, lower Westphalian B) and Paralic Series (Namurian A). Carboniferous aquifers represented by sandstones, partly siltstones, have a thickness ranging from 0.5 to more than several dozen meters. They are isolated from each other by intercalations of impermeable claystones except for areas of mining, fault zones and natural hydrogeological windows where hydraulic connections are traced. The effective porosity of the sandstones varies from 0.5% to 31% while their specific yield ranges from 0.1% to about 23%. The permeability of Carboniferous sandstones tested in the laboratory varies in a very wide range from 0.005 to 1400 m/d. Hydraulic conductivity tested in the boreholes varies from 4.0E−11 to 5.0E−4 m/s. Hydraulic properties of Carboniferous rocks vary significantly with depth. Sandstones below the depth of 900–1000 m are practically impermeable, while the higher they are, the more permeable they are, due to increased porosity and fracturing under lower pressure conditions.

Taking into account the recharge conditions of the Carboniferous aquifers two hydrogeological regions (I, II) may be distinguished in the USCB. A boundary between these two subregions follows the extent of the continuous cap of clayey Miocene deposits (Różkowski et al., 2015; Fig. 17.5)

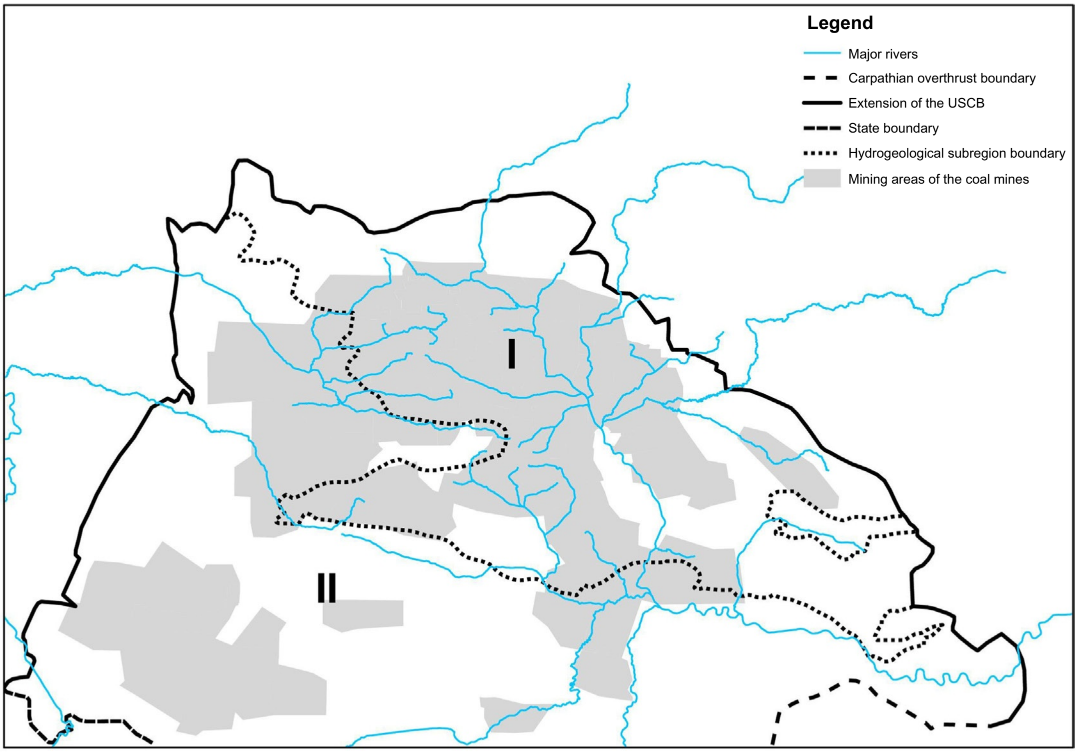

FIG. 17.5 Hydrogeological regions (I, II) of the USCB. *Based on Różkowski, K., Różkowski, A., Sołtysiak, M., 2015. Participation of quaternary aquifers in groundwater inflow to mines in the Upper Silesian Coal Basin (USCB). Arch. Min. Sci. 60 (1), 419–437.*

In subregion I there are two hydrogeological systems. The first one covers the area of the main saddle structures, the NE fold-block structures within the young Paleozoic platform, and the northern part of the Fore-Carpathian depression. The Quaternary sediments within this system lay directly on a productive Carboniferous roof. The second system consists of two syncline forms of Chrzanów and Bytom which occur within the Mesozoic platform. Triassic sediments, locally covered by Jurassic deposits, lay directly on the roof of Carboniferous rocks. The aquifers present in the Muschelkalk and Quaternary are rarely in hydraulic connection. Such a situation occurs only in their outcrop areas. They are isolated from each other by clay sediments of Upper Triassic in the other parts of this complex.

In the subregion II within the Carpathian Foredeep, the roof of the Carboniferous is isolated from the surface and from the Quaternary by Miocene deposits. Hydraulic connections between the aquifers present in the Carboniferous and in the Quaternary are possible only in erosional hydrogeological windows. Thickness of the Quaternary aquifers varies from less than 1 to about 80 m. They can occur in sandy-gravel deposits of Pleistocene and Holocene age.

The quality of groundwater within the USCB varies over a very wide range. Fresh waters occur in the Quaternary, Jurassic and Triassic aquifers as well as in the outcrop areas of the Carboniferous formation. Groundwater in the Tertiary formation is characterized by TDS ranging from 0.5 to 220 g/L. The low mineralized waters (TDS below 1.0 g/L), occurring in the Jurassic and Triassic deposits, are mostly of the HCO_3-Ca and HCO_3-Ca-Mg types. In the coal-bearing Carboniferous formation the TDS of water ranges from 0.5 to 372 g/L. Low mineralized waters of the chemical types HCO_3-SO_4-Ca-Mg, HCO_3-Na and CI-Na predominate in the zone of exchange and mix with infiltraton waters. Highly mineralized waters of isolated and poorly permeable structures represent brines of the CI-Na and CI-Na-Ca types. Methane from degasification of coal seams predominates in the gaseous composition of those brines. Increased radioactivity of the brines due to the presence of radionuclides is also recorded.

17.4 HISTORY AND PRESENT-DAY MINING IN USCB

The first references to mining of coal in Upper Silesia date back to around 1540 in the area of the subsequent Wawel mine, near Ruda Śląska. However, it has not been proven whether the exploitation there had indeed started. The first discrete mine, Murcki, was established in 1657, at Rudne Kotliska, very close to Katowice-Kostuchna, where the coal outcropped. The first shaft was sunk in 1755, marking the commencement of underground mining at the oldest mine in Upper Silesia (Włodarska, 1957).

The production of coal increased from 0.5 million tonnes (Mt) in 1840 to 9.5 Mt in 1865. By 1913 the production increased even more and reached 110 Mt. The First World War significantly restricted production (40% less than the 1913 levels). The Second World War led to increased production from Polish mines under German occupation. In the postwar state-controlled economy, mining was centrally administered and production targets were specified at a political level (Jaros, 1975). As a result, by the end of the 1980s, Polish coal production was at an all-time high, reaching some 180 Mt. Following the political upheaval of 1989, culminating in the collapse of the Warsaw Pact, 34 of the 65 hard coal mines in Upper Silesia were abandoned and the remaining collieries have been forced to adopt a free-market approach. Coal production steadily decreased; by 2005 it was down to 98.5 Mt and at the end of

2013 it reached the level of 76.5 Mt (Malec et al., 2014). Currently, the restructuring process of the Polish mining industry has reached its second phase and five hard coal mines are going to be closed down due to economic and technical problems (depletion of coal deposits, etc). The action of closing down the mines will change the current situation and structure of exploitation and the necessity of dewatering systems in the whole region.

17.5 DEWATERING SCHEMES OPERATING IN ACTIVE AND ABANDONED MINES

Underground coal mining inevitably requires dewatering of excavations, the coal seam itself, and underground aquifers. Mining operations disrupt the local groundwater balance both during and after mining. The galleries excavated during mining often require dewatering and this affects the groundwater flow. Then, once mining and dewatering have ceased, the mines flood and the groundwater attempts to attain a new chemical and dynamic equilibrium (Collon et al., 2006). During exploitation, the hydrogeological and hydrogeochemical regimes are infringed due to constant pumping of water from the mining area. Dewatering systems in Polish coal mines in the USCB are generally designed with a relation to total inflow to the mine with respective safety factors (Rogoż, 2004).

In the USCB most of the mines are interconnected directly or indirectly by drifts, boreholes, goaf, roadways or intact coal barriers of limited thickness. In most mines water enters: (i) as infiltration from the surface, (ii) as groundwater from adjacent aquifers, overlying or underlying, (iii) from adjacent older mine workings, or (iv) as process water (Hall et al., 2011). The restructuring process of the coal mining industry in Poland has resulted in the necessity of closing down mines connected with those still operating. Fifteen abandoned mines are constantly dewatered to protect active mines against water hazards or for environmental protection purposes (guarding against pollution or mine gas issues; Younger et al., 2002). Fig. 17.6 presents examples of connections between mines.

The Central Department of Mine Dewatering (Polish abbreviation CZOK) was formed in 2001 and charged with the responsibility for management of mine water and dewatering operations in abandoned mines in the USCB. CZOK is also engaged in the monitoring of mine water levels, the management of discharge water chemistry, and the rationalization of mine dewatering systems. Two main systems are used for dewatering of abandoned mines (Fig. 17.7):

(1) The so-called "stationary pumping system" comprises pumps located in an underground plant room in the partially dewatered mine. Such a system requires continued ventilation, staffing, and mechanical infrastructure in the shaft and mine.
(2) Submersible pumping systems have been installed in flooded shafts. The system is controlled from the surface and in the case of failure the pumps and motors can be removed by mobile cranes for inspection and repair. The water level is automatically measured by transducers and recorded by data-loggers (Janson et al., 2009).

Mixed pumping systems are employed in mines where partially flooded workings are dewatered by submersible pumps, but infrastructure on higher levels is not completely transformed for technical reasons.

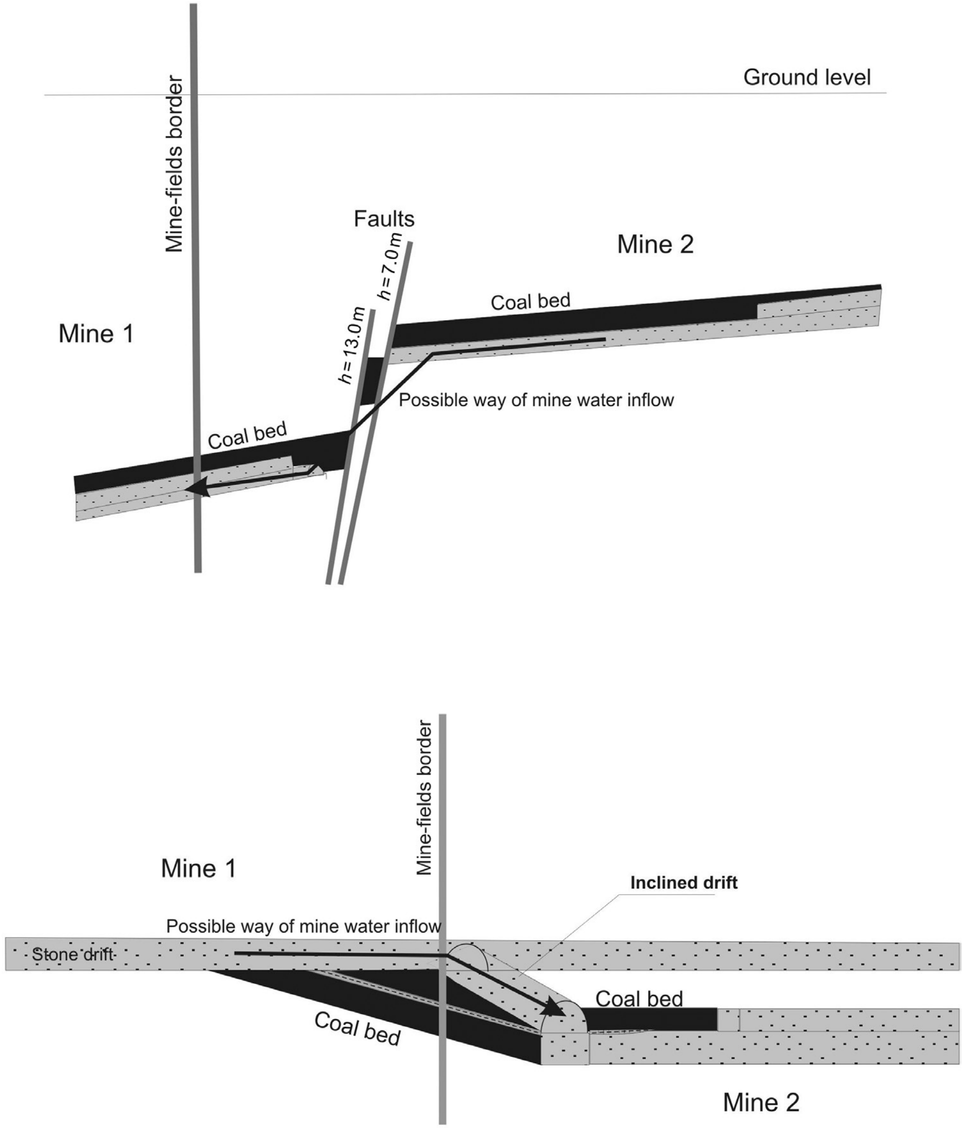

FIG. 17.6 Examples of hydraulic interconnections between mines. *Modified after Kropka, J., Janson, E., Czapnik, A., 2005. Changes of hydrogeological conditions in the area of liquidated coal mines in the north-eastern part of Upper Silesia Coal Basin (southern Poland). In: Loredo, J., Pendás, F., (Eds.), Proc. 9th International Mine Water Congress, Oviedo, Spain, pp. 209–215 and Janson, E., Gzyl, G., Banks, D., 2009. The occurrence and quality of mine water in the Upper Silesian Coal Basin, Poland. Mine Water and the Environment 28 (3), 232–244.*

In a few other abandoned coal mines, water is deliberately drained by gravity via dedicated drifts or boreholes towards adjacent working coal mines, from which it is then discharged (Kropka et al., 2005). Fig. 17.7 illustrates the main systems of dewatering abandoned mines in the USCB.

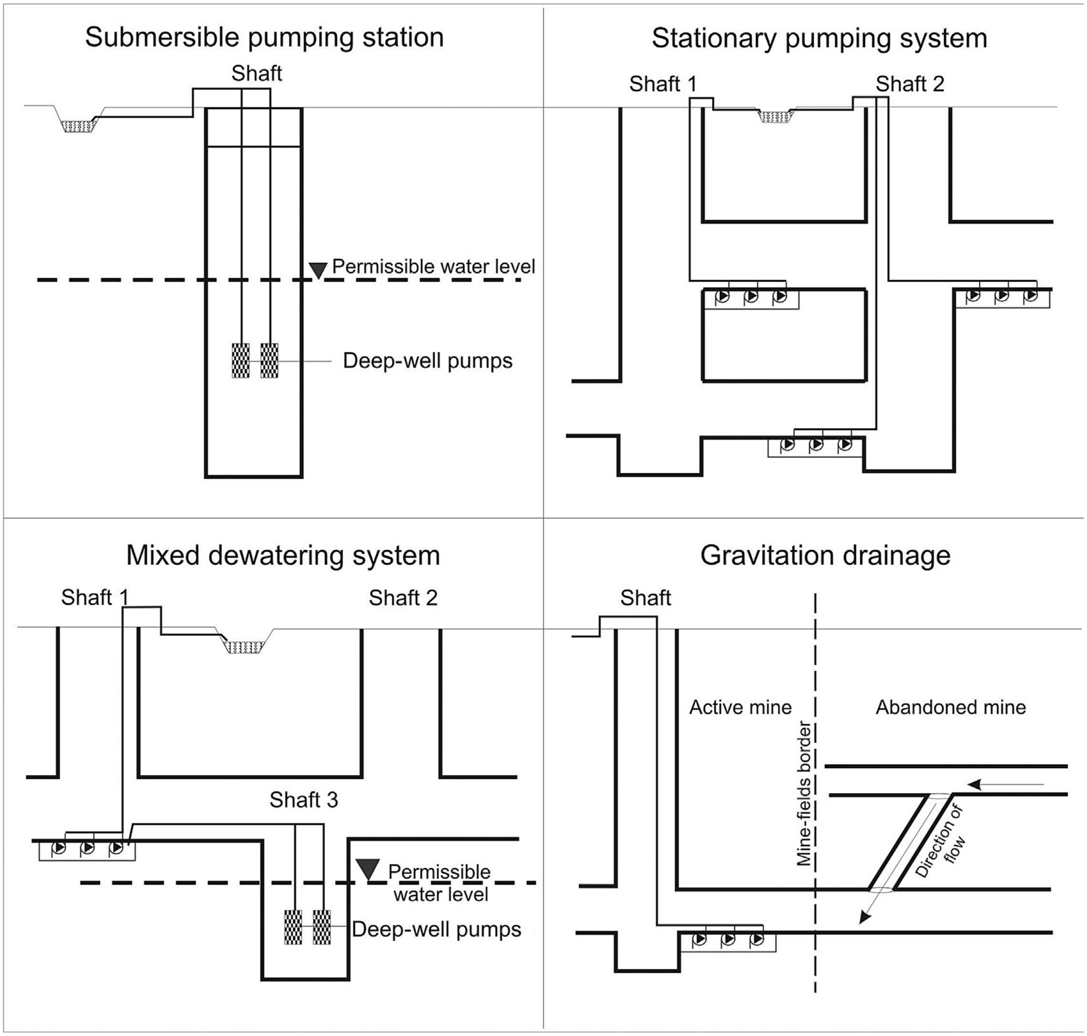

FIG. 17.7 Main systems of dewatering abandoned coal mines in the USCB. *Modified after Kropka, J., Janson, E., Czapnik, A., 2005. Changes of hydrogeological conditions in the area of liquidated coal mines in the north-eastern part of Upper Silesia Coal Basin (southern Poland). In: Loredo, J., Pendás, F., (Eds.), Proc. 9th International Mine Water Congress, Oviedo, Spain, pp. 209–215 and Janson, E., Gzyl, G., Banks, D., 2009. The occurrence and quality of mine water in the Upper Silesian Coal Basin, Poland. Mine Water and the Environment 28 (3), 232–244.*

17.6 MINE WATER IMPACT ON SOIL, SURFACE WATER AND GROUNDWATER BODIES

The process of dewatering and discharging of mine water into surface waters is influencing the water environment and its related elements (solis, groundwater layers and flow regime). Furthermore, interaction of neighboring mines is observed (overlapping cones of depression in groundwater table, increased salinity of surface waters as a result of multiple discharges of mine water into the same watercourse). Mine waters are characterized by diverse mineralization, which determines their possible use. Most of these waters, however, are discharged directly or after only mechanical treatment, to the surface watercourses, where flow rate increases and salinity causes severe pollution (in particular due to high contents of chlorides and sulfates).

17.6.1 Rock Drainage

Dewatering of mines causes rock drainage and leads to drawdown of the water table in groundwater aquifers as well as disruption of the water balance in the affected catchment. The possible effects are decreasing of natural runoff as well as changing of the river regime (draining, infiltrating). Changes in pressure gradient, groundwater flow velocity, and reduction of groundwater resources come primarily from mine dewatering systems. The total area of decreased piezometric pressure as a result of mine drainage in the USCB covered about 2000 km^2 over 20 years ago (Różkowski et al., 1993). The exact extent of this zone has been studied by Różkowski (2004) (Fig. 17.8)

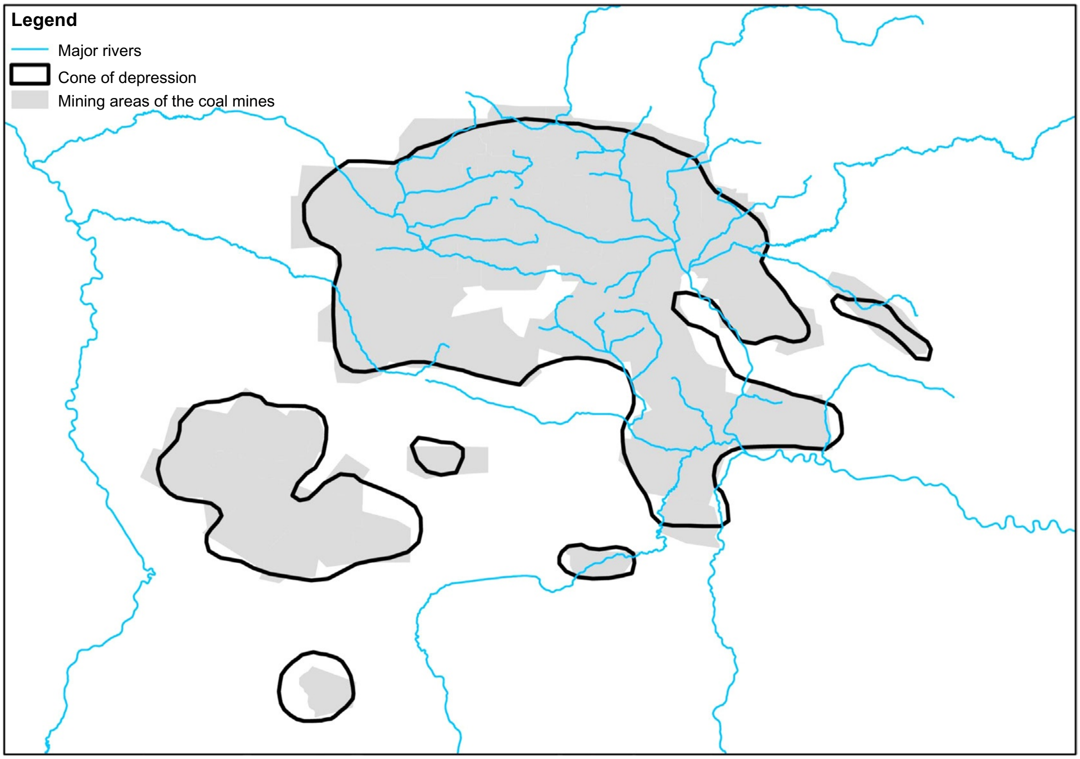

FIG. 17.8 The area of decreased piezometric pressure as a result of mine drainage in the USCB according to Różkowski (2004).

Flooding of mine workings in abandoned mines is a long-term process. After flooding of excavated workings, pyrite oxidation products are dissolved and hydrolyzed from rock mass. The dewatering process of a flooded mine causes a change in the chemistry regime in mine waters. This phenomenon was already documented as early as the mid-20th century, but it was Younger (1997) who subsequently termed it the mine water "first flush" phenomenon. Gzyl and Banks (2007) as well as Banks et al. (2010) have studied the example of this phenomenon in a mine at the eastern part of the USCB. The regional model for simulation of the flooding process in the major part of the USCB is presented in Klinger et al. (2012).

17.6.2 Storage of Mine Waste

Waste rocks extracted from the mines are deposited on the surface in the form of mine waste heaps. Sediments collected in tanks and settling tanks associated with the process of alteration and enrichment of mined material are also treated as a mine waste. Deposited material consists of two-thirds of waste coarse sandstone-mudstone and claystones with granulation of 30–500 mm (Szczepańska, 1987). Placement of the waste on the surface starts the process of leaching of soluble minerals, mainly chlorides, sulfates, complexes of heavy metals and compounds of aluminum, iron and manganese, as well as the products of weathering of the waste by precipitation waters infiltrating the waste heaps. Infiltration of leachates into the groundwater aquifers underneath the heap and into the surface water causes changes in their mineralization and chemical composition. These processes result in the degradation of groundwater and surface water, which is difficult to control (Sracek et al., 2010). Moreover, storage of mining waste causes distortion in surface runoff and the formation of flooded areas and wetlands in surrounding areas. These processes also result in soil degradation. In the area of the USCB, the impact of mining on the soil also resulted in pollution of watercourses, for which there are no direct discharges of mine water. In these watercourses increased concentrations of chlorides and sulfates are observed. There are two general types of impact of mine waste on surface water. The first is generated by mining waste dumps, which are drained by trenches. Leachate from the mining waste dumps are discharged into rivers, causing their pollution: for example, the river Jamna in the Odra River basin. The second type of impact consists of areas where mining waste rocks were used for land reclamation. Rainwater rinsing such areas causes contamination of soil and nearby water courses. An example of such a situation is Potok Szczygłowicki in the Odra River basin.

Coal mining in the USCB also poses another type of impact on soils: for example, the areas of old shallow workings and around old shafts tend to collapse, which may destroy the soil layer (Kotyrba and Kortas, 2016). In most of the coal mine dumps, self-heating processes are ongoing, which produce as a result a variety of gaseous, liquid and solid contaminants in oxygen-depleted conditions, such as bitumen with chemical features similar to those of coal tars (Misz-Kennan, 2010; Misz-Kennan and Fabiańska, 2010; Misz-Kennan et al., 2013; Fabiańska et al., 2016). As a result, "hot spots" with elevated surface temperatures are being formed above self-heating zones, which are characterized by high moisture, strong bitumen odor, crusts of mineral blooms and absence of vegetation (Fabiańska et al., 2013; Ciesielczuk et al., 2014). Another impact of mining on soils in the USCB is the increase of radon content in soil gas. Wysocka (1999) supposed that changes of radon concentrations in the ground are related to smaller seismic events induced by the mining industry and she planned continuous measurements with the aim of finding out the possible correlation between changes of radon concentrations and seismic shocks induced by mining. The analysis performed by Wysocka and Chalupnik (2003) in the vicinity of mining areas has revealed the important correlation between mining activity and radon content.

17.6.3 Mine Water Discharges

Mine water discharges have an important influence on surface water quality and quantity in the USCB. The discharge points are commonly located in the spring areas of small rivers and creeks, where intensive water losses into the underlying underground mines occur. Mine water discharges affect surface water in both a quantitative and qualitative way, especially in small streams, where significant changes in their hydrological regime are caused by large loads of contaminants in a high quantity of mine discharges. The consequences are transformation of the natural aquatic environment, and in extreme cases, eliminating of flora and fauna of the river. The salinity of surface water limits the possibility of using water from rivers for municipal purposes, agriculture and industry.

Urbanization of the catchment area in combination with small physical size and low natural flow of the streams causes environmental conditions in the river to be extremely variable. Changes in the natural hydrological regime are noted: reduction of the medium and minimum flows and increase of the maximum flows. Among the mine water chemistry parameters, the main concern in the USCB is salinity. The prominent role of salinity, as the factor most influencing the surface water quality, has been reported in the studies on regional surface water quality (Absalon and Matysik, 2007; Bujok, 2008; Olkowska et al., 2014). In such cases, most of the mines are not forced to report on a regular basis the full list of water quality parameters, but all of them are forced to control and report on a regular basis the concentrations of chlorides and sulfates as well as the flow of discharged water. These parameters are the main concern, as the environmental fees paid by the mines for discharging mine waters are proportional to the load of salts, calculated from concentration of chlorides, sulfates and the flow of discharged mine waters. Most mining companies discharge mine waters with a high content of chlorides and sulfates, and the level of salinity makes it impossible to achieve the environmental objectives (in the meaning of the Water Framework Directive) of the surface water bodies without the establishment of an appropriate derogation. In fact, the level of chloride and sulfate concentrations itself is less harmful to the aquatic environment than the abrupt changes in the concentrations. This is due to the gradual adaptation phenomena of bacteria, algae, invertebrates and fish, and whole mixed communities of organisms, to elevated salinity. Another important factor is the pH of discharged mine water, as a water environment sensitive to salinity increases with the acidity of waters. In the case of the USCB mine water, a strongly acidic pH does not occur, which should be considered as a very favorable circumstance.

In this study we report the key parameters of mine water quality and quantity from 53 mines (working and abandoned with continuous dewatering) in the USCB from a period of 11 consecutive years. The statistics for the discharges are presented in Tables 17.1–17.3.

TABLE 17.1 Statistics for Chloride Load (Mg/Year) in 53 Mine Water Discharges in USCB

	Percentiles				
Years	**5th**	**25th**	**50th (Median)**	**75th**	**95th**
2002	0.0	739	5321	17,830	222,241
2003	1.1	593	5106	17,120	251,113
2004	0.3	976	4531	18,957	221,872
2005	2.4	809	7196	15,892	221,816
2006	14.4	799	6351	19,232	210,386
2007	41.5	957	6017	16,830	222,518
2008	7.5	725	6829	16,987	158,973
2009	10.3	615	6391	18,726	141,153
2010	3.1	843	7210	19,395	179,675
2011	3.7	815	7515	19,473	111,491
2012	2.2	973	7426	19,485	149,270
2002–2012	**3.8**	**813**	**6362**	**18,335**	**134,786**

TABLE 17.2 Statistics for Sulfates Load (Mg/Year) in 53 Mine Water Discharges in USCB

	Percentiles				
Years	**5th**	**25th**	**50th (Median)**	**75th**	**95th**
2002	0.0	118	1054	3113	13,634
2003	0.3	105	1329	3779	14,585
2004	0.1	121	1040	3672	13,167
2005	20.1	185	966	3603	14,055
2006	23.0	266	951	3292	13,284
2007	29.9	265	974	3096	14,368
2008	27.1	255	710	2867	13,378
2009	25.8	252	840	3071	12,823
2010	12.4	292	1036	3829	15,404
2011	27.1	298	924	4061	11,841
2012	22.6	314	996	2938	13,866
2002–2012	**28.4**	**247**	**986**	**3290**	**11,470**

TABLE 17.3 Statistics for Summarized Chloride and Sulfate Load (Mg/Year) in 53 Mine Water Discharges in USCB

	Percentiles				
Years	**5th**	**25th**	**50th (Median)**	**75th**	**95th**
2002	0.0	2061	7708	20,614	233,448
2003	1.4	2509	7847	21,739	262,389
2004	0.4	2307	8088	21,154	232,672
2005	36.2	2182	8333	18,049	233,419
2006	45.4	2446	8406	19,785	222,326
2007	100.5	2035	8337	17,040	234,218
2008	39.0	2263	9309	18,555	165,682
2009	31.9	1996	11,011	21,684	146,691
2010	16.8	2478	8936	21,055	187,975
2011	37.6	3081	10,055	20,625	118,936
2012	28.4	2253	9281	21,720	158,361
2002–2012	**39.8**	**2403**	**8936**	**19,864**	**139,814**

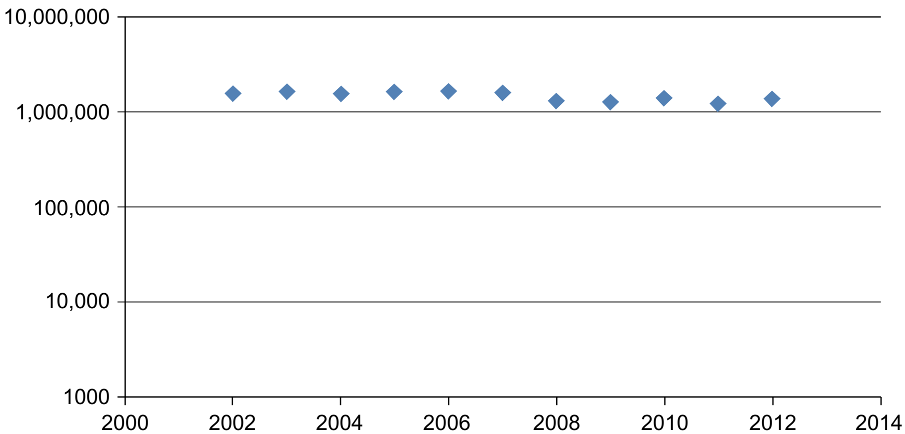

FIG. 17.9 Temporal variation of total chloride and sulfate load (Mg/year) in 53 mine water discharges in USCB.

The temporal variation of load of chlorides and sulfates are visualized on graphs in Figs. 17.9 and 17.10.

While thinking about expected changes in the load of chlorides and sulfates discharged into surface waters, one should consider two general phenomena: the number of active mines is being reduced with time, while particular active mines are becoming

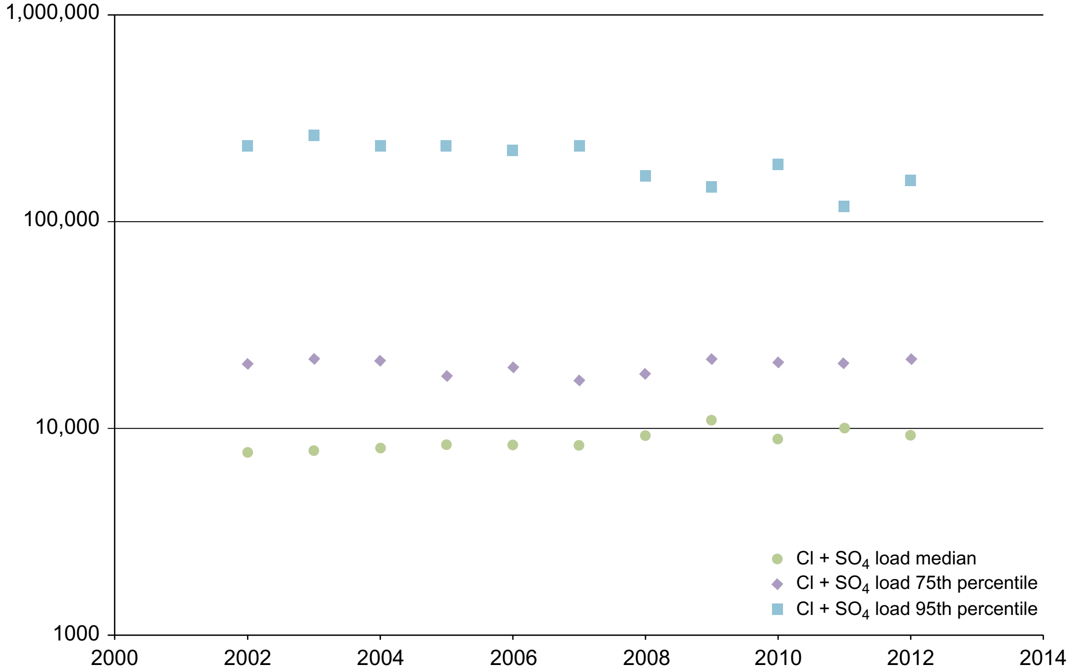

FIG. 17.10 Temporal variation of statistical measures for chloride and sulfate load in USCB (Mg/year) based on data from 53 mine water discharges.

deeper with exploitation. The first results in decreasing the load of all contaminants, while the second causes increases, especially in chloride content. However, the overall load shows quite stable values throughout the investigated period. Therefore, the total load of salts present in mine water discharged into surface waters in the whole USCB could be treated as a relatively constant value, in spite of local variations that should be treated case by case in a local context. However, unlike the temporal ones, the spatial variations are very significant. As already mentioned, two hydrogeological regions may be distinguished in the USCB and the boundary between these two subregions follows the extent of the continuous cap of clayey Miocene deposits (Różkowski et al., 2015; Fig 17.8). In the northeastern part of the USCB, where the isolating Miocene clays are absent, the infiltration from precipitation is significant. As a result, the mines are very wet, but the salinity of mine water is low, as the carboniferous rocks have been already well "washed" by permanently circulating waters, even prior to mining activity. Therefore the load of salts in mine water is relatively low. In the southeastern part, where the Miocene clays form a thick impermeable cover, the original salinity of waters from carboniferous aquifers remained.

In 2014 a detailed assessment of the impact of discharges of saline water to surface water bodies in the water regions of Little Wisła and Upper Odra was carried out. A total number

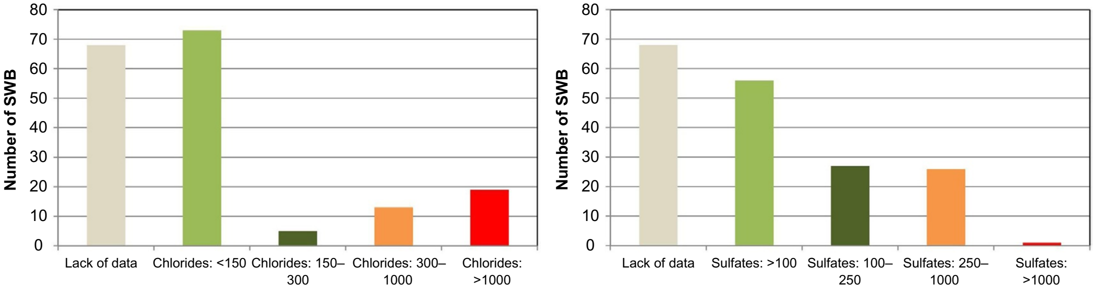

FIG. 17.11 Concentration of sulfates and chlorides in USCB surface water bodies.

of 177 surface water bodies was analyzed. Assessment of the impact of mining activity on the physical and chemical state of surface water bodies was based on data from the State Environmental Monitoring for the years 2010–12. Concentrations of chlorides and sulfates for each surface water body (SWB) were referenced to the parameters described as in good condition: 300 mg/L for chlorides and 250 mg/L for sulfates. It is important to have in mind the lack of monitoring data in 25 SWB in the Little Wisła water region and 42 SWB in the Upper Odra water region, which is 37.8% of analyzed SWBs. As Fig. 17.11 shows, most of the analyzed SWBs with available data has a concentration of chlorides better than needed for a good condition (78 of 110). The same situation concerns sulfates: a concentration better than needed for good condition was noted in 83 of 110 rated SWBs. Concentrations of both chlorides and sulfates below that needed for a good condition were identified in 76 of 110 rated SWBs.

As the analysis shows, the impact of mining companies on the physical and chemical parameters of SWBs was identified in 22 out of 85 SWBs in the Little Wisla water region and 15 of 92 SWBs in the Upper Odra water region. At the same time, the limits for the good state/potential concentrations of chlorides or sulfates were exceeded in 19 SWBs in the Little Wisla water region and 15 SWBs in the Upper Odra water region. Exceeding of chloride and sulfate concentrations together with the impact of mining have been identified in 13 SWBs in the Little Wisla water region and 12 SWBs in the Upper Odra water region. This means that 15% of surface water bodies in Little Wisla and Upper Odra water regions have a bad status due to mine water discharges. The identified impact of mine water on surface waters in the USCB is shown on the map in Fig. 17.12.

The red color indicates the area of SWB under the influence of mining. The rivers which are exceeding the physicochemical parameters in terms of chlorides or sulfates are marked in black.

Generally, it is expected that in the future the total amount of water pumped from the mines is going to decrease, but the concentration of chlorides and sulfates will increase. This is due to the increase in the average depth of the mine workings. Past experience suggests that while the depth increases, the salinity increases, but the flow rates of inflow of mine water to the deeper levels are much lower. Both tendencies make a stable trend of salinity load the most probable forecast for the future.

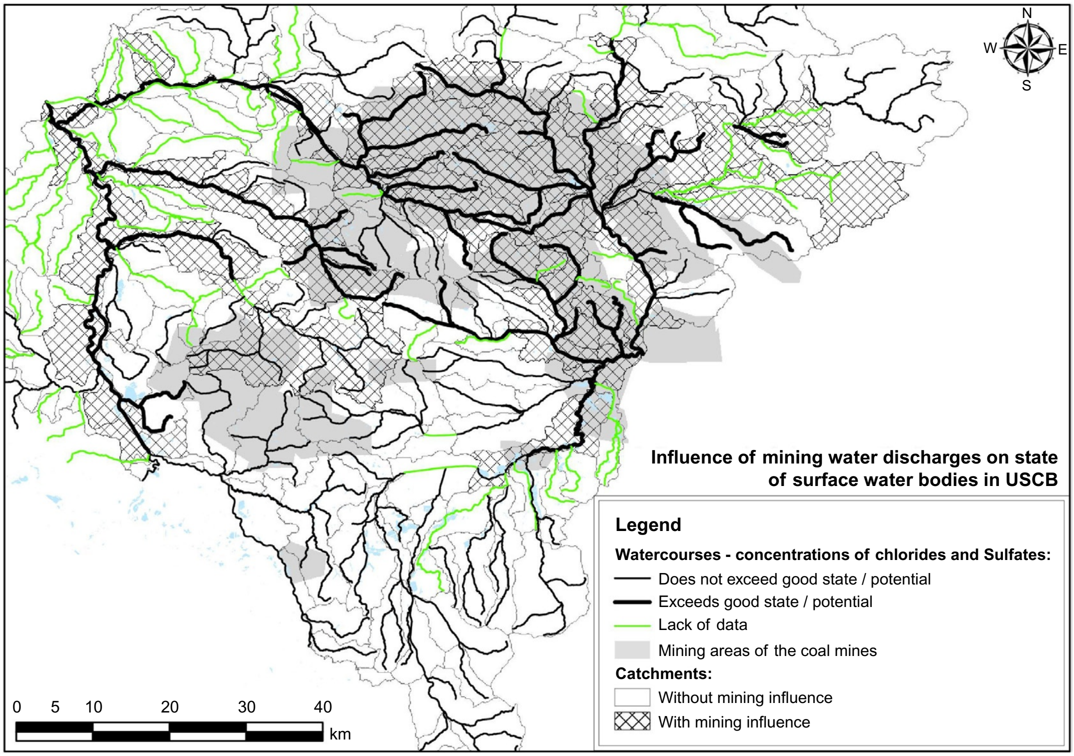

FIG. 17.12 The impact of mine water discharges on surface waters in the USCB.

17.7 REGULATIONS AND REQUIREMENTS IN POLISH ENVIRONMENTAL LAW IN RELATION TO MINE WATER DISCHARGES

In Poland, as in other European Union countries, requirements of the Water Framework Directive that have been transposed into national legislation are in force. In accordance with these requirements sewage discharged to surface waters must not cause a deterioration of their condition or potential. Limits of the concentration of pollutants in the rivers in relation to the chlorides are 300 mg/L and sulfates 250 mg/L. According to Polish regulations it is possible to discharge sewage waters that contain more than the standard content of chlorides in some cases, if a concentration of 1 g/L chlorides and sulfates downstream of the discharge after full mixing is achieved. In order to identify river stretches in which a concentration of 1 g/L chlorides and sulfates downstream of the saline water discharges have been exceeded, analyses have been carried out using available data concerning discharges and flows in receivers. Results of these analyses have been shown on the map in Fig. 17.13.

In the case of water permits, data from the sum of the concentrations of chlorides and sulfates in the receiver exceeded 1 g/L in 28 cases. In seven cases the impact of discharges was also identified on the river stretches even downstream of the confluence point. Only in four

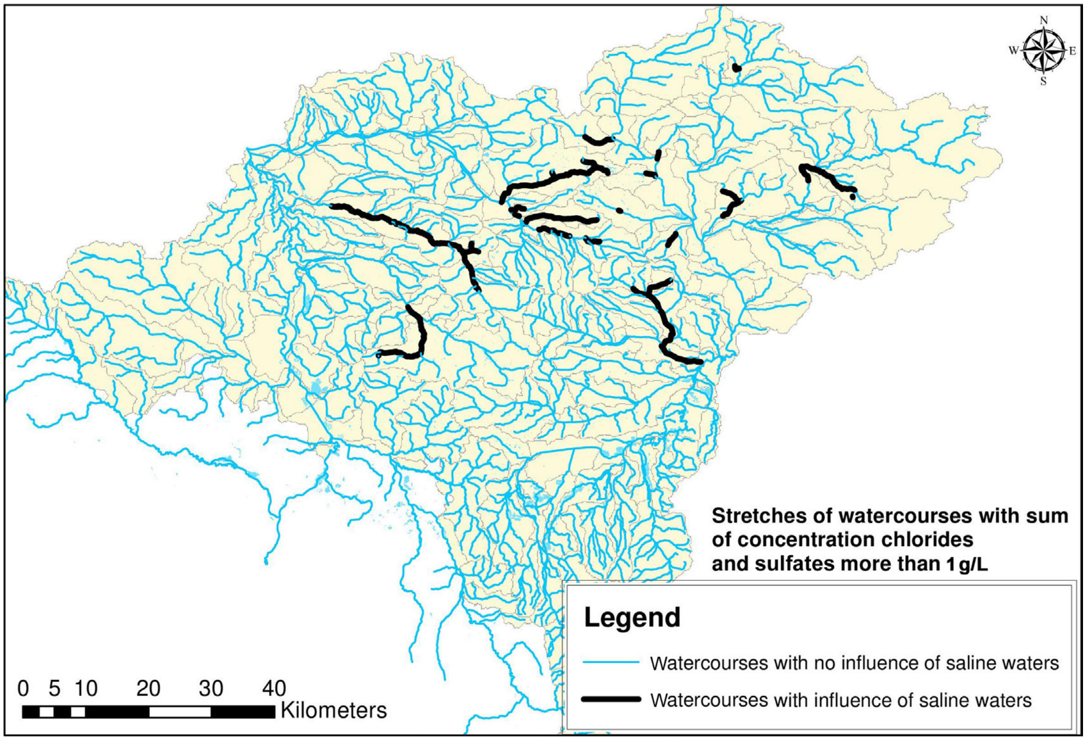

FIG. 17.13 The impact of mine water discharges on surface waters in the USCB.

cases did the river stretches with concentrations above the limit of 1 g/L not exceed 10% of the total length of the particular river. It can be concluded that in almost all cases of concentrations exceeding 1 g/L in the stream, it was maintained over more than could be considered "short." In 21 cases, the concentration in the receiver does not exceed 1 g/L.

For data based on the actual discharges, concentration of 1 g/L was exceeded only downstream of 16 discharges, while in four cases exceedance was identified also on downstream receivers. In six cases the river stretches, with the concentration above the limit of 1 g/L, do not exceed 10% of the total length of the particular river. This means that, as in the case of the data for water permits, the exceeding of 1 g/L occurs for clearly longer than a "short" stretch of the watercourse. In 29 cases, the concentration in the receiver does not exceed 1 g/L.

Lack of a "short" stretch definition in the Polish regulation enables mining companies to obtain water permits for mine water discharges that significantly affect water courses. This effect is clearly visible in dry years when the sum of rainfall is smaller than in average years and river flows are respectively smaller too. On the other hand, there are no cheap and effective methods of decreasing chloride and sulfate concentrations in mine waters. This means that, as long as coal mining continues, a high load of chlorides and sulfates will be discharged to surface water bodies and the most reasonable option is the proper management of this process.

17.8 MANAGEMENT OF SALINE MINE WATER DISCHARGES

Management of saline mine water in the USCB is a difficult issue. As described previously, the overall load of salinity generated by mining is significant on one hand and quite stable on the other hand in a regional context. In the local context, the magnitude of problems with saline mine water discharge results from the relations between the flow in the receiving river and the rate, as well as the concentrations in the discharged mine water. In general the management possibilities can be divided into those that reduce the load of salinity in the discharged waters and those that modify the discharge pattern. The reduction of salinity load can be obtained by implementation of desalination methods, known for many decades (Sidorenko et al., 1981; Zapol'skii et al., 1982) and still being in use. However, the impact on the aquatic environment can be minimized also without treatment, through implementation of retention and dozing systems allowing for adjustment of discharge to natural flow rate variations in the receiving rivers. Another possibility for management of saline water is to shift the discharge point from small tributaries to major rivers with much higher flows to use the dissolution effect. Such a system is known from the southwestern part of the Upper Silesian Coal Basin, where a pipeline called "Kolektor OLZA" transports saline water from several mines directly to the Odra River, avoiding the discharges to its smaller tributaries. Another idea has been designed for the Ruhr Coal Basin in Germany. Mine water is supposed to be pumped only from the mines close to the River Rhine, which has much higher flows than its tributaries, such as Emscher or Ruhr (Goerke-Mallet and Drobniewski, 2013; RAG Aktiengesellschaft, 2014). It is expected that hydraulic connections among the mines would allow for pumping only from the mines that are close to the Rhine with the desired dewatering effect for the whole Ruhr Coal Basin.

The most environmentally friendly idea for saline mine water management seems to be to transport it via pipeline directly into the sea. The marine environment is obviously more tolerant of high salinity than is the freshwater environment. Moreover, dilution potential in the sea is enormous compared to surface water systems. However, this option is quite limited by the distance to the sea. Younger (2008) lists the examples of such management of mine water from abandoned and active coal mines in Europe. The examples mentioned therein are:

- East Fife Coalfield, Scotland (Michael Shaft and Frances Shaft);
- Bates Colliery, Northumberland, England;
- Durham Coalfield, County Durham, England;
- Gardanne Coal Basin, Provence, France.

The salinity coming from mine water into the surface water systems is an emerging issue also in Australia (Sarver and Cox, 2013). An interesting example of a management concept implemented there is the catchment of Wellington Dam at Collie River, SW Australia (Tingey and Sparks, 2006; Bills, 2006). The management concept uses both the exploited mine voids for retention and the nearby sea as a discharge target after the retention. Using this management concept, the salinity increase is avoided in the Wellington Dam, which is an important drinking water reservoir.

The location of the Upper Silesian Coal Basin in Poland is much worse for this saline mine water management option. The nearest sea is the Baltic Sea in the North, over 500 km away. Such a distance limits the possibilities of implementation of this concept. However, mine water management installations are currently operating in the USCB, but have been implemented on a small scale in relation to collieries located in the southern part of the region. The implemented method of surface water protection against high salinity is a hydrotechnical system of discharging and storage of mine water in relation to hydrological conditions in river catchment. This hydrotechnical method is based on using impoundment of surface and underground reservoirs in a controlled process of discharging waters during periods of high flows in the rivers (recipients of high saline mine waters). A hydrotechnical system for management of saline discharges is operating in four coal mines in Little Wisła river basin. The basic requirement is to maintain total concentration of chlorides and sulfates below 1 g/L in river water (measured in a control point). Dosage of mine waters depends on total river flow in the river catchment; therefore during long-lasting dry periods there are problems with discharging of mine waters while continuous dewatering of the coal seam is necessary.

Taking into consideration the operating salinity management schemes both from the USCB and from the rest of the world, in current study future salinity management possibilities are discussed. The basis for the management is the assumption that the total salinity load discharged by the mining sector in the USCB is not going to be significantly reduced in the future. It is expected that the number of active mines is likely to be reduced over time, which may cause a decrease of a number of mine water discharges as well as the total flow rate of mine water in the whole USCB may be decreased in the future. However, particular active mines are expected to become deeper and deeper with exploitation, which is going to cause an increase in salinity of discharged waters. New mines with deep exploitation under saline water conditions are also likely to be opened. On the other hand, no new cost-effective desalination technologies are emerging. Therefore, the total load of salts present in mine water discharged into surface waters in the whole USCB could be treated as a relatively constant value. In large coalfields with many interconnected mines, the management of the quantity and quality of discharged mine water is particularly complicated. Besides the obvious problems, the interconnected mine systems offer possibilities for using their complicated interconnections for creating alternative regional strategies of mine water pumping and discharge. However, hydraulic connections in mines are limited in lifespan and efficiency, e.g., by scaling and collapse. There are numerous options for water management in interconnected hard coal mining areas. This applies to a lesser extent when mining is active and different mining companies are in charge. However, during closedown and the transfer of water management to a regional institution (which is a common practice in most of the European mining areas), options are available to regulate mine water discharge with respect to the overall impact. This impact includes both environmental and economic aspects. In such situations, the most reasonable way to reduce the pressure on surface water bodies is to shift the load of salinity from small tributaries into main rivers. In practice, it would require the building of a pipeline system for mine water gravitational transport along the rivers and streams. The pipelines would end low enough to allow mine water to mix with much larger flow in order to obtain lower concentrations with the same load. A similar system already works in part of the USCB and was described previously.

17.9 CONCLUSIONS

The Upper Silesian urban-industrial agglomeration is one of the most industrialized areas in Europe. The mining, its scope and depth, duration of mining works, extraction systems being used and the total volume of the drainage fundamentally affect the conditions of soil, groundwater and surface water in the studied area. Underground coal mining inevitably requires dewatering of excavations, the coal seam itself, and underground aquifers. Mining operations disrupt the local groundwater balance both during and after mining.

Following the political upheaval of 1989, culminating in the collapse of the Warsaw Pact, 35 of the 65 hard coal mines in Upper Silesia were abandoned until 2014. In the near future a further five hard coal mines are going to be closed down due to economic and technical problems (depletion of coal deposits, etc.). However, due to identified existing hydraulic connections between active and abandoned mines, it is necessary to protect the active mines from the water hazard coming from their abandoned neighbors. Therefore, not only the still-active mines, but also a majority of the ones that are abandoned have to be continuously dewatered, which is a fact that is derived straightforwardly from continuous coal exploitation in the USCB.

The influence of mine water on surface waters within the area of the USCB depends on the features of the mine water receivers. Since the area of mining activity is concentrated in the watershed area between the water region of Upper Odra and Little Wisła, and the area is mostly urbanized, receivers of mine waters are mostly small urban rivers. The main concern among the mine water quality parameters in the USCB is given to salinity. The prominent role of salinity as the factor most influencing the surface water quality has been reported in the studies on regional surface water quality. Most mining companies discharge mine waters with high content of chlorides and sulfates, and the level of salinity makes it impossible to achieve the environmental objectives.

In this study the salinity load from 53 mines in the USCB during a period of 11 consecutive years has been analyzed. Generally, it is expected that in the future the amount of water pumped by the mines is going to decrease, but the concentration of chlorides and sulfates would increase. Both tendencies make the stable trend of salinity load the most probable forecast for the future. On the other hand, the treatment of mine water from chlorides and sulfates is a very expensive process. Therefore, most of all the management options for decreasing the impact of saline mine water disposal into surface waters have to be considered, as discussed in the present study.

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