Hydrogeological problems concerning open digging of filling sands in the area of Upper Silesian Coal Basin (southern Poland)

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Abstract: Within the nearest few years over 100-year-old open digging of filling sands in the area of Upper Silesian Coal Basin (USCB) is possible to be finished which is due to falling demand for sands for filling mine workings in Polish coal mines. Four deposits of Quaternary sands that are being mined at present are characterised by rather simple hydrogeological conditions. Total water inflow from Quaternary aquifers drainage and infiltration of river water is ca. 140 m³/min., with maximal depression 30 m and total range of mine drainage ca. 135 km². Preliminary forecast aims mainly at forestation and aquifer reclamation of mine workings.

1 INTRODUCTION

Hydraulic filling in Polish mining in USCB area has been already used on an industrial scale for 110 years. During the first 40-50 years filling sands were mainly extracted out of small (from several up to a few dozen hectares) sand pits situated next to coal mines. Mine waters which flew into shallow mine workings in the amount of several m³/min., were then gravitationally piped away to the nearest superficial streams. After the Second World War, in the 1950s and 1960s, open digging of filling sands started to develop intensely. It was connected, among other things, with obtaining huge amounts of coal from protective pillars created for built-up areas and other important protected objects on the surface. The pillars exploited in coal mines had to be filled with material with low compressibility and high water permeability. In the 1960s and 1970s, the years with the highest demand for sand, their total average annual extraction exceeded 30 million m³. In the second half of the 1980s coal mining started to prefer caving exploitation and demand for filling sands decreased. At present, extraction of filling sands is ca. 8 million m³ per year.

2 GENERAL CHARACTERISTICS OF DEPOSITS

Form, structure, thickness and water inflow into the filling sand deposits as well as the quality of extracted filling sand were determined by Quaternary relief, morphogenetic processes and accumulative actions of glacial and river water. The basic role was played by eopleistocen relief development, which, in southern

Poland, created buried valleys with steep slopes and basinlike lowerings of valley type, cut into post-Quaternary ground at the depth ranging from a few dozen up to over 100 metres. In several stages, throughout eo-, mezo- and neo-Quaternary, proglacial, extraglacial and river water (connected with glacialisation of The Odra and The Warta rivers) and river waters connected with glacialisation of the Vistula, were storing clastical material, mostly sand- and sand-gravel, in the mentioned morphological lowerings. (Lewandowski, 1993, Lewandowski & Zieliński, 1988).

Deposits of filling sand, documented at present, are exploited by four open cast mines (Figure 1). The Kotlarnia (K) mine is localised in the western edge of USCB. The mine exploits upper level of sands and gravel with thickness from several up to 20 metres. The deposits are situated on the glacial level consisting of clay, stagnant silt and loam with differentiated thickness.

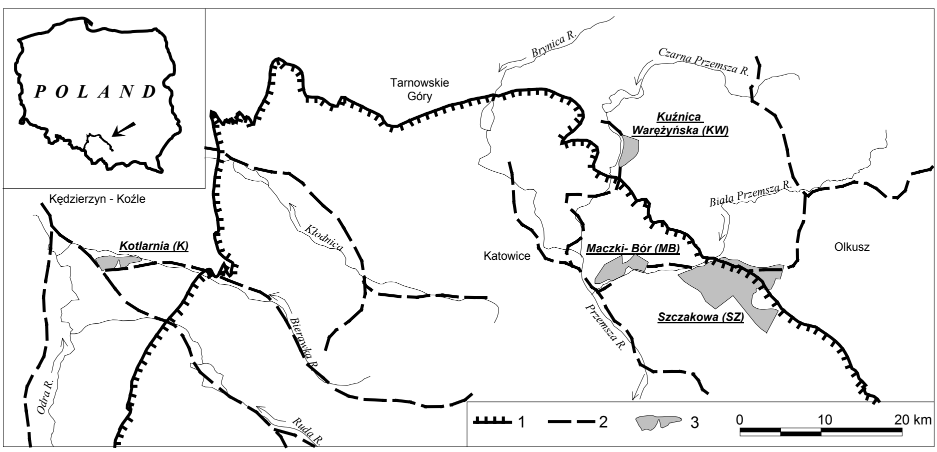


Figure 1 Location of the filling sand open pits
1- border of the Upper Silesian Coal Basin (USCB), 2- buried valleys, 3- filling sand open pits

Three remaining mines, Kuźnica Warężyńska (KW), Maczki-Bór (MB) and Szczakowa (SZ), are situated on the highly diversified morphologically and geologically Silesian Upland, in the area of buried valleys and lowerings of valley type. Quaternary deposits have a slightly diversified lithology with a very distinct dominance of sand- and sand-gravel deposits. Maximal thickness of these deposits was 40-60 m. At the base of exploited deposits there are clay-silt-sandstone deposits of Upper Carboniferous (Namurian A - Westphalian B), Permian (Rotliegendes) as well as Lower and Middle Red Sandstone with diversified permeability (Jureczka et al., 1995).

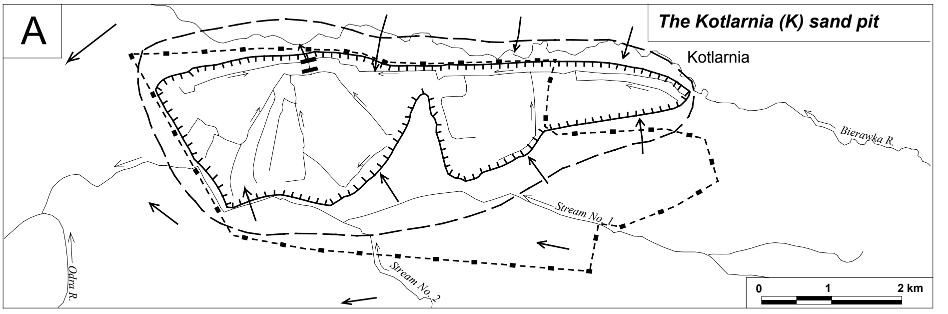
The common feature of the discussed sand deposits was the presence, in natural environment, of one Quaternary aquifer, consisting of sand, mainly medium-grained, fine-grained or different-grained, sand-gravel mix and gravel. Its thickness ranged from several centimetres up to 16 metres in the area of K mine working and 50-60 m in the area of SZ mine. The calculated values of hydraulic conductivity amounts to $1.6\text{-}4.1 \times 10^{-4}$ m/s, and transmissivity to 50-1500 m^2/day. Groundwater table in the analysed areas was generally unconfined. Originally it became stable at the depth from a few dozen centimetres (KW) to 14.4 m below surface (SZ), and average at 3.0-3.5 m. Quaternary aquifers were not isolated from the surface. They were supplied through direct infiltration of precipitation water. Contemporary valleys of the nearby rivers had discharging character in natural environment and constituted the basis for drainage of local water inflow systems in Quaternary deposits.

3 INFLUENCE OF MINE DEWATERING ON WATER ENVIRONMENT

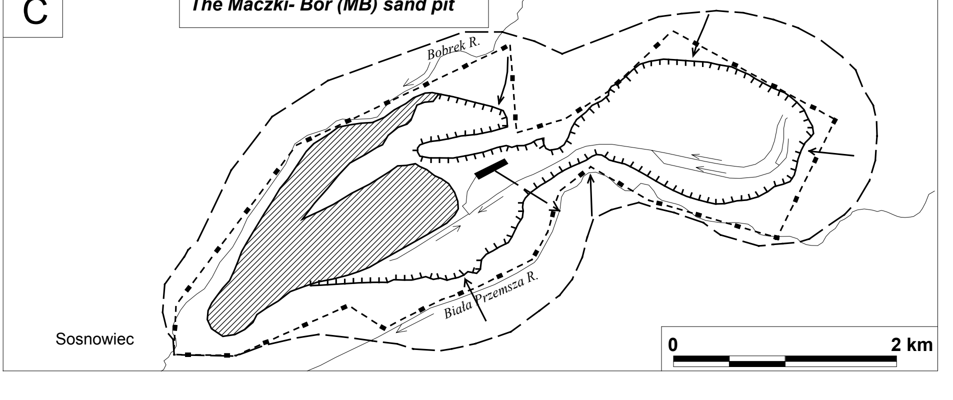
Mining that was performed for several years in the area of Quaternary aquifers within the discussed mines caused changes in original hydrogeological conditions.

In the area influenced by mine dewatering groundwater flows into mine workings. The basis for Quaternary aquifer drainage in the area of sand mine consists of the net of collector trenches localised near the slopes as well as the system of collective and main ditches and canals situated below the ordinates of exploitation level. Ditches and canals form gravitational dewatering system with average inclination of 0.7-3.0 $^{o}/_{oo}$. Mine water in the workings of K, KW and MB mines flow into retention reservoirs (sump), localised in the lowest places in a sand mine. These reservoirs, apart from temporary mining water retention, serve as preliminary depositors, in which mineral suspension precipitates and is deposited. Reservoirs are supported by pumping stations that occasionally pump out collected water and then, usually through an additional sand depositor, throw them into the nearby rivers (Figure 2). Two retention reservoirs belong to the dewatering system of K mine, into which accordingly the so-called clean and dirty waters flow (Figure 2A). Dewatering system of SZ mine (Figure 2D) is slightly different, in this case water from drainage of Quaternary aquifer flows into the central canal, and then is gravitationally taken by depositors into a big water supply system.

The area of sand mine dewatering was determined basing on comparing actual (according to measures done in the second half of 1999) and natural (dating from the period of gathering deposits documentation in the 1950s and 1960s) situation of groundwater table. Current condition of hydrodynamic field is known thanks to measuring groundwater table in a total net of 120 observation points (piezometres, shallow dug wells) and knowing the ordinates of


A
The Kotlarnia (K) sand pit
Kotlarnia
Bierawka R.
Stream No. 1
Stream No. 2
Odra R.
0
1
2 km


B
The Kuźnica Warężyńska (KW) sand pit
Czarna Przemsza R.
Trzebyczka R.
0
1
2 km


C
The Maczki- Bór (MB) sand pit
Bobrek R.
Biała Przemsza R.
Sosnowiec
0
2 km

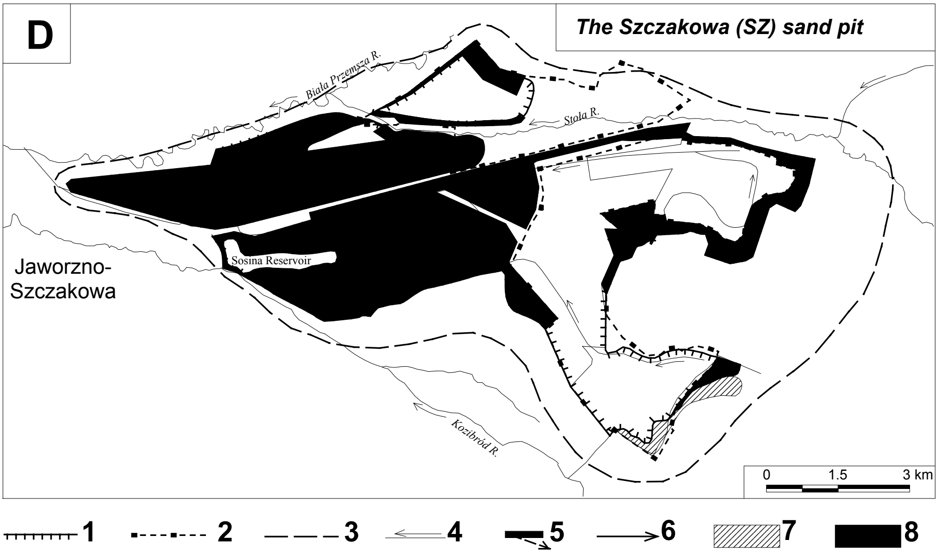


Figure 2 Hydrogeological sketches of the filling sand open pits: A- Kotlarnia (K), B- Kuźnica Warężyńska (KW), C- Maczki-Bór (MB), D- Szczakowa (SZ)
1- border of mine workings, 2- border of mine area, 3- the range of mine depression cone, 4- ditches and canals dewatering system, 5- retention reservoirs (sump) with pumping station,, 6- groundwater flow directions, 7- coal mining waste heaps, 8- reclamated former exploitatiom pits

groundwater table in collector trenches and canals. Dewatering of sandpits decreased groundwater table by 8.0-30.0 m. Depression isoline s = 1.0 m (Wilk, Adamczyk, Nałęcki, ed., 1990) is accepted as the range of mine depression cone. It was verified by calculation working on empirical formula by Sichardt's [R=f (s, K)], Kusakin's [R=f (s, K, H)] and Kerkis'es [R=f (Q, w)], taking into account substitute radius of dewatered area (r_o in m) for workings having rectangular shape. In order to define the estimated borders of depression cone range Sztelak's formulas were also employed [R=f (s, Q, w)] as well as Surow's and Kazeński's [R=f (K, w, H, h)] (Turek, ed., 1971). The latter gave overstated results and were not employed in practical calculation. Dewatering action of sand mine led to forming not very wide, from 100 to 1350 metres from the edge of workings, most often irregular depression cones (Figure 2). Area of mine drainage calculated on such a basis, ranges from 13.6 to 88.9 km² in the area of MB and SZ mines accordingly. Total area of mine drainage in four existing filling sand mines is ca. 133.1 km².

There is a complicated hydrogeological situation at the point of contact between mine dewatering action and river valleys with riverbeds. The results of a few dozen hydrometric measures done mainly in the 1980s and 1990s have shown differentiated, generally low infiltration of water from surface currents in the area of mining influence. The Bierawka and The Sztoła rivers (Figure 2A and

2D) are characterised by the highest infiltration (14.4 and 27.7 1/s/1km accordingly).

The reason for very low water infiltration from The Biała Przemsza river, or even its lack, along the workings of SZ and MB mines, is the colmatage of riverbed deposits. Hydraulic conductivity value of colmatage zone in riverbed deposits of this river is 0.02 m/day (Kropka, 1988).

Water inflow into sand mines is connected first of all with direct recharge of mine workings with precipitation and side inflow of underground waters into the workings. Because of dewatering degree these deposits belong mainly to partly watered and watered (Staniek, 1989). Average amount of water flowing into mine workings is variable and depends mostly on the level of precipitation (after intense precipitation it increases by ca. 30%). This inflow ranges between 16.5 (MB) up to 85.0 m^3/min (SZ), at maximum depression 24.0-30.0 metres accordingly. Drainage caused by mining actions in the depression-influenced areas is illustrated by means of effective underground infiltration coefficient. Underground runoff stays between 12.3 (SZ) up to 19.9 1/s/km^2 (KW) (Table 1). Mines drain 140.4-144.5 m^3/min water on average, out of which only 30.0-80.0 m^3/min is taken directly by water supply system. Described deposits have favourable hydrogeological conditions, which is the reason for lack of water danger such as significant artesian flows or water forcing from surface currents. Suffosion is not observed either.

Water flowing into mine dewatering systems is generally usable, with mineralization (total dissolved solids) from 0.15 to 0.90 g/dm^3 and is of hydrochemical type HCO_3-SO_4-Ca-Mg, SO_4-HCO_3-Ca-Mg and SO_4-Ca-Mg with locally increased concentration of sulphates, iron, manganese and nitrates. Overwhelming part of water flowing into the K mine from the north is characterised with mineralization from 1.10 up to 1.80 g/dm^3. This water is of Cl-Na type, its high concentration of chlorides (up to 1.0 g/dm^3), sodium (up to 0.65 g/dm^3) and sulphates (up to 0.27 g/dm^3) is connected with infiltration of polluted water from The Bierawka river (Figure 2A).

Lowering of groundwater level in the neighbourhood of mine workings influences not only the depth of water table (draining) and actual capacity of shallow dug wells and captures taking in water from draining Quaternary aquifer. It also influences arable and forested lands and the amount of water and changes hydraulic connection from draining to infiltrating in surface currents. Documented influence of mine dewatering on the condition of shallow groundwater caused the necessity of building water supply system in total of 23 places situated in the direct neighbourhood of mines. Also 5 drilled wells, capturing water from Quaternary aquifers for the needs of country water supply system and for mine plants (K, SZ), stay under actual influence of mine drainage. These wells were bored after the sand mines had started operating. Documented decreased admissible volume of extracted groundwater in the wells that are localised in the area influenced by drainage does not threaten the needs of their users.

Table 1 Sand pits Kotlarnia (K), Kuźnica Warężyńska (KW), Maczki-Bór (MB) and Szczakowa (SZ). Hydrogeological-deposition issues

Name of a mine / Beginning of mining / Mine area [km^2]	Characteristics of deposits	Method of exploitation	Dewatering system in the workings	Inflow $Q_{av.}$ [m^3/min] / Depression S [m] / Underground runoff Q_u [$1/s/km^2$]	Expected end of exploitation / Type of reclamation
K / 1966 / 14.187	fine- and medium-grained sands with local interlocations of coarse-grained sand, gravel and boulder (mainly in the lower part)	open digging, wall-exploitation system, average length of slopes 1500-2000 m, height 3-13 m, exploitation at 1-4 levels (I-IV strata), up to the bottom (K, KW, MB) or possibility of gravitational dewatering of deposit (SZ)	surface dewatering, gravitational, with slope ditches, and then with dewatering ditches (trenches) and canals system (slope 0.7-3.0$^o/_{oo}$) to slump with pumping station (K, KW, MB) or to the central canal (SZ)	23.7 / 1.0-16.0; average 8.5 / 16.2	end of 2024 / water
KW / 1967 / 12.713				19,1 / average 18.0; max.30.5 / 19.2	2004 ? / water
MB / mid-war period / 6.563				16.5 / max. 24.0 / 16.5	2006? / industrial- water
SZ / 1954 / 20.040				81.1 – 85.2 / several – 30.0 / 12.3	2003 ? / forestation or forest-water

The second and very important issue is the influence of mine drainage on changes in natural arrangement of hydrographic relations. Several replacements and sealings of riverbed conducted until 1999 caused significant restriction or elimination of river water infiltration (e.g. The Czarna Przemsza river, The Kozi Bród river). After their replacement partial mine exploitation of the deposits was possible (e.g. Trzebyczka stream and Jaworznik stream in deposits belonging to KW and SZ accordingly). The greatest changes took place in the area of SZ mine drainage, where one can observe shortening the length of riverbed by 4.16 km and decreasing the area of The Sztoła basin by ca. 37 km^2, as well as radical changing bed course and decreasing the area of Jaworznik stream basin. On the other hand, thanks to sand exploitation in SZ mine central canal was created with basin of ca. 66.0 km^2.

Mining damages in arable and forested lands are very difficult for clear estimation. Out of sand deposits, built mainly of quartz, poor in basic components, podzol soil has been formed. They are highly acidified, mainly with pH 3.0-5.0 with little or very little sorption capacity and little buffering capacity (Dobrzański, Zawadzki, ed., 1995). Prevailing soil on the discussed area has a low bonitation class R-V, R-VI, characterised by low level of groundwater and typical, precipitation-retention type of water management. Lowering the level of soil moisture, so typical for areas with lowered groundwater table and for after-drought periods, causes excessive decomposition of organic matter and increases the content of humus compounds in accumulative level. As a result, sorption capacities of soil that are already low decrease in comparison to food compounds of plants and store capacities of precipitation water.

4 EXPECTED FINISHING OF MINING EXPLOITATION. LAND RECLAMATION OF MINE WORKINGS

A very rapid increase in demand for sand to fill mine workings in coal mines in USCB area caused significant decrease in their mining rate. Forecasts concerning the actual finishing of mining works are very unreliable. It is supposed that mines KW, MB and SZ as the first will finish mining in the years 2003-2006. In spite of the soon end of mining there are no unanimous concepts of land reclamation in the mentioned area. Still in the 1980s forecasts on land reclamation involved extension of already existing or building new industrial waste heaps (from mines, power stations and steelworks) in the workings of K, KW and MB. Only water from central canal basin in the SZ mine was from the very beginning destined for usable purposes i.e. water supplying system. At present even the preliminary analyses and pre-designing assumptions resign from industrial development of mining workings and all of them tend to water reclamation (K, KW), forestation or mixed water-forest reclamation (SZ) and industrial-water reclamation (MB).

Open digging of filling sand in Poland fulfils two basic reclamation streams in its former sand-exploitation pits: forestation and water reclamation. The basis for forestation on the discussed area is proper shaping the bottom of workings, especially proper regulation of water relations that can be reached by suitable depth of groundwater. Equally important is type of soil and its location in superficial strata of the working (Krzaklewski, 1990). Forestation involves both bottom and slopes (mainly 1:1.5 or 1:2) of the working. SZ mine has undoubtedly the most advantageous conditions for developing soil-creating processes, especially on the surface of the bottom consisting of loose sands, where groundwater reaches the level of 41-100 cm. A very intensive and successful forestation performed in the western and central part of the sand workings caused that in the 1990s SZ mine handed over ca. 2000 ha of forested lands to the public management (Figure 2D). As a very positive result, mainly deciduous trees are cultivated, since they are more resistant to the influence of heavy industry in Silesia, where emission to the atmosphere of harmful gases and dust is very high. The situation is far less advantageous in the western part of MB mine, where waste has been dumped within the confines of the central coal mining waste heap since the mid 1970s (Figure 2C). Exploitation of this heap is additionally complicated by problems with fire prevention, forest reclamation and groundwater monitoring.

Water reclamation of the sand workings requires rational management of sand deposits and highly advanced mechanisation, which creates the necessity of mining the deposits up to the bottom, using artificial dewatering. It requires earlier forming of slopes and dishes of a basin, building hydrotechnical buildings, allowing for optimal height of damming up-water and providing, if possible, water inflow to the reservoir and biological reclamation of coastal area (Czuber, 1988). Preliminary assumptions and pre-designing studies estimate that direction of water reclamation will involve total area of sand workings in K and KW mines. Reclamation of the eastern sand workings in the MB mine is supposed to be conducted by creating water reservoir with the volume of ca. 10 million m^3 and area ca. 1 km^2 and having both recreation and anti-flood function (Table 1). Recent years have shown the tendency towards restricting space development of SZ mine, with simultaneous advisable mining up to the bottom in the eastern part of the deposits and dewatering the working by means of a sump. Such mining would then enable creating two reservoirs with total volume of 10-13 million m^3. As results from still quite unreliable forecasts, five reservoirs are going to appear in the discussed area of 4 mines with total volume of ca. 100 million m^3 after mining has been finished.

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Problemy hydrogeologiczne odkrywkowej eksploatacji piasków podsadzkowych w rejonie Górnośląskiego Zagłębia Węglowego (południowa Polska)

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Streszczenie: W najbliższych kilkunastu latach możliwe jest zakończenie ponad 100. letniej, odkrywkowej eksploatacji złóż piasków podsadzkowych w rejonie Górnośląskiego Zagłębia Węglowego. Jest to spowodowane spadającym zapotrzebowaniem na piaski do podsadzania wyrobisk górniczych w polskich kopalniach węgla kamiennego. Aktualnie eksploatowane 4 złoża czwartorzędowych piasków charakteryzują się dość prostymi warunkami hydrogeologicznymi. Sumaryczny dopływ wód z drenażu czwartorzędowych poziomów wodonośnych i infiltracji wód rzecznych wynosi ok. 140 m^3/min, przy maksymalnej depresji 30 m oraz łącznym zasięgu drenażu górniczego ok. 135 km^2. Wstępne programy zmierzają głównie w kierunku leśnej i wodnej rekultywacji wyrobisk pogórniczych.