REVITALIZATION CONCEPTS FOR SAND MINE PIT IN SOUTHERN POLAND: PRELIMINARY ASSESSMENT OF IMPACT ON AQUATIC ENVIRONMENT

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Abstract
The paper describes briefly the hydrogeological situation of the sand mine “Maczki-Bór”. This mine is located in southern Poland, in the eastern part of Upper Silesian Coal Basin. The mine is divided into 2 fields: “Bór-Zachód” in the West and “Bór-Wschód” in the East. The sand has been used mainly for deep coal mine backfilling. The exploitation started at first in the western field, already before Second World War. The eastern field has been exploited since 1972 until now, whereas the exploitation in the western field stopped in the middle of 1990s. In the area of “Maczki-Bór” sand mine the groundwater flow appears mainly in Quaternary sands and Triassic limestones and dolomites. Carboniferous claystones and mudstones as well as the Lower Triassic clays are the main aquitards of the area. The most important groundwater aquifers of the area are Quaternary and Triassic aquifers. The preliminary assessment of the impact of 3 different revitalization concepts on the aquatic environment is reported in this paper.

Introduction
The sand mine “Maczki-Bór” is located in southern Poland, in the eastern part of Upper Silesian Coal Basin. The mine is divided into 2 fields: “Bór-Zachód” in the West and “Bór-Wschód” in the East. The sand has been used mainly for deep coal mine backfilling. The exploitation started at first in the western field, already before Second World War. The eastern field has been exploited since 1972 until now, whereas the exploitation in the western field stopped in the middle of 1990s.

Before 1972 only 5 m thick layer of sand was exploited, with gravitational dewatering, causing about 2 m of depression in groundwater table, down to the level of +247 m. Then, the exploitation started in the deeper parts of the mine, reaching finally the level of +225 m. This resulted in forming of depression cone in groundwater table and in enforcing the local groundwater flow directions towards the mine pit. However, the shape and the range of the depression cone were unknown until 1994, when first local groundwater monitoring network has been established in this area.

Currently, the western part of the mine is abandoned and filled with the waste, predominantly coming from coal mines. The eastern part of the sand mine is still active with few years’ exploitation perspective. After that, the revitalization of the landscape is envisaged, with turning the mine pit area either to forest or lake. The preliminary assessment of the impact of 3 different revitalization concepts on the aquatic environment is reported in this paper.

Hydrogeological conditions
In the area of “Maczki-Bór” sand mine the groundwater flow appears mainly in Quaternary sands and Triassic limestones and dolomites (Chmura, 1997; Rubin et al., 2006; Frolik et al., 2006). Carboniferous claystones and mudstones as well as the Lower Triassic clays are the main aquitards of the area. The most important groundwater aquifers of the area are Quaternary and Triassic aquifers.

Quaternary aquifers are present in Pleistocene glaci-fluvial sands and gravels filling the paleo-valley of Biała Przemsza River. There are 2 water-bearing horizons in Quaternary, with thin (1-1.5 m) discontinuous clay aquitard in between. Due to exploitation this aquitard currently does not exist in the described mining area. The second aquitard in the bottom of second horizon still exists and it divides the Quaternary aquifer from Carboniferous strata.

The hydrogeological parameters of both Quaternary horizons are similar, so they currently form one 24 m thick aquifer with hydraulic conductivity of general range: $1.5\text{-}3.5 \cdot 10^{-4}$ m/s, which is typical for glaci-fluvial sands and gravels in Upper Silesia. The recharge of this aquifer comes mainly from precipitation; the infiltration from nearby rivers Biała Przemsza and Bobrek is blocked since the river’s bed has been sealed by plastic foil and concrete in the years 1976-84. The drainage of the aquifer is dominated by the system of trenches leading to central pumping station at level +222 m. Due to mine dewatering an irregular depression cone max. 24 m deep, 3 km wide and 6 km long has been formed. Outside the mine’s depression cone the base of drainage is the river Przemsza and its paleo-valley in the West. One top priority groundwater aquifer has been recognized in Quartenary in this area (Fig.1). This is Major Groundwater Aquifer (MGWA) 453 “Biskupi Bór” (Kleczkowski, 1990).

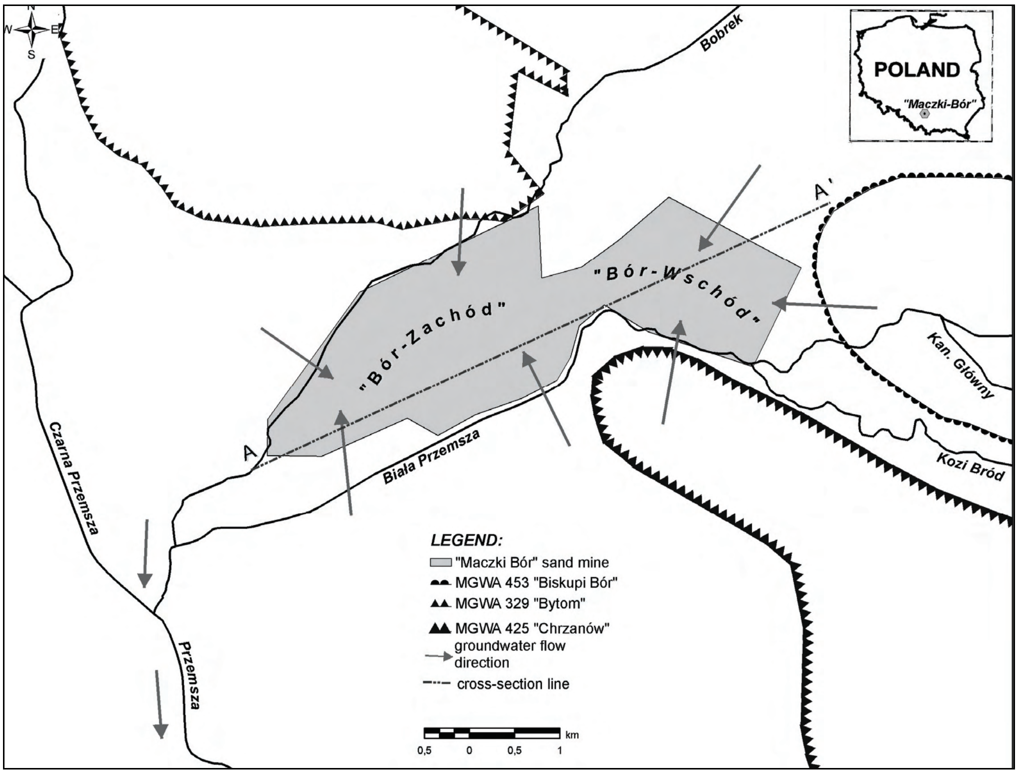

Figure 1. The groundwater flow directions in the vicinity of "Maczki-Bór" sand mine. Current situation.

Triassic sediments are present in the described area in the discontinuous form to NW and SE from the mining area. Although Triassic 4 water-bearing horizons are present in the described area, 2 of them are of major importance: Muschelkalk horizon and Roet horizon. These 2 water-bearing horizons are usually in good hydraulic contact and can be treated as one Triassic aquifer. The recharge of this aquifer takes place mostly through precipitation on Triassic outcrops, in some places also through infiltration from Quaternary. The drainage in described area goes towards the rivers Biała Przemsza and Przemsza. The detailed relations between the Quaternary and Triassic aquifers in the south of "Maczki-Bór" sand mine is unknown. However, it is expected that the mine pit dewatering system is at present a base of drainage for Triassic aquifer as well. There are 2 MGWAs recognized in the described area in Triassic: MGWA 329 "Bytom" in NW and MGWA 425 "Chrzanów" in SE (Kleczkowski, 1990).

There are also water-bearing horizons in Carboniferous sandstones, but they are of minor importance, as regards the area of sand mine "Maczki-Bór". Although Carboniferous is partially dewatered by hard coal mining activity, due to partial hydraulic isolation only minor amounts of water from the overlaying Quaternary sinks to Carboniferous in this area. The rivers and their Quaternary paleo-valleys remain the elements of major importance, as regards groundwater drainage.

Mine revitalization concepts

There are currently 3 concepts of revitalization of the area after the end of sand exploitation in this area (Fig. 2):

- Concept I – building a deep surface water aquifer. In this concept the mine pit in the eastern side of the mine ("Bór-Wschód") would not be filled at all with any wastes, but only with water, forming 25 m deep pit lake, with the volume of about 30 mln m^3. The lake would be futher used for recreation purposes. The groundwater table would rise about to the level of +250 m. However, the Western part of the mine pit ("Bór-Zachód") is already filled with 90 mln tonnes of waste (mainly with hard coal mining waste), up the level of +255 m. After the groundwater table rises, about 67 mln tonnes of waste would be flooded.
- Concept II – building of a shallow surface water aquifer. In this concept the mine pit in the eastern mine field would be filled with about 40 mln tonnes of coal mining waste (up to the level of +240 m) and then in the upper part a 10 m deep pit lake would be built (up to the level of +250 m). After the groundwater table rises, about 107 mln tonnes of waste would be flooded in both mine pits (eastern and western).
- Concept III – filling the entire mine pit with coal mining wastes and further land use for industrial purposes. In this concept the total volume of flooded wastes in both western and eastern pit would amount to 150 mln tonnes.

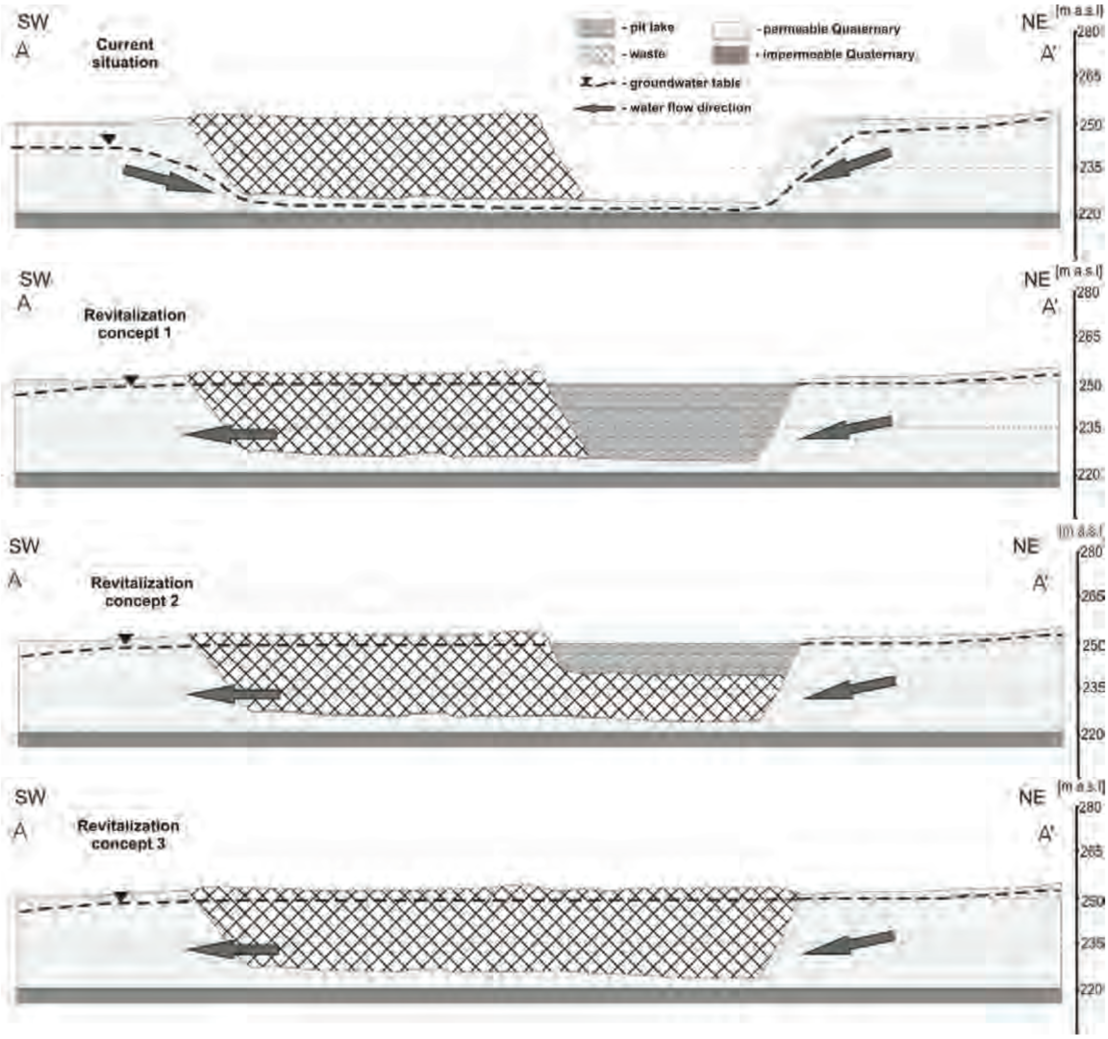

Figure 2. Revitalization concepts for "Maczki-Bór" sand mine.

Preliminary assessment of the impact on aquatic environment

The major contaminants that can be released to aquatic environment from coal mining wastes are similar to those present in water filling old mine voids, so they are: chlorides, sulphates, iron and manganese. The main source for chlorides are the remaining saline pore waters captured in the waste rocks. As regards sulphates, iron and manganese, their content depends strongly on the content of iron sulphides in the coal (Younger, 2000; Younger et al., 2002); manganese is often substituting iron in the sulphides mineral structure. The main mechanism of contaminant release and transport would be then:

1. Changing the redox conditions from reducing into oxidizing (e.g. by dumping the waste in the mine pit in unsaturated zone). This allows for oxidizing insoluble sulphides into soluble sulphates.
2. Flooding the oxidized wastes by rising groundwater table. This allows the dissolution of contaminants.
3. Transport of contaminants along groundwater flow direction.

Table 1. Mean values of chosen contamination parameters in 2005 for the characteristic elements of aquatic environment in the vicinity of "Maczki-Bór" sand mine. All values are in mg/L except pH.

	pH	Cl^-	SO_4^{2-}	Fe	Mn
Inflowing groundwater (background)	6.45	15	36	0.60	0.38
Surface water upstream the mine	8.05	24	190	0.13	0.18
The water pumped from the mine	7.60	111	204	1.79	0.60
Surface water downstream the mine	8.05	30	186	0.17	0.19

Currently the groundwater flow in Quaternary as well as in Triassic aquifer is enforced by mine pit dewatering. Groundwater tends to flow from the MGWAs into the mine pit. This excludes at present the contamination spread from the mining area towards surrounding aquifers. Furthermore, the quality of mine water pumped from "Bór-Wschód" mine pit is only slightly worse than the quality of groundwater and surface water not influenced by sand mining activity and the effect of surface water cannot be seen at the moment (Table 1). This is because due to active dewatering of "Bór-Wschód" pit and high permeability of wastes filling "Bór-Zachód" pit, the whole mine area remains in unsaturated zone. This will change after finishing the dewatering process; regardless of the chosen revitalization concept, the majority of wastes filling the pit are going to be flooded.

The sum of chlorides and sulphates is used most often in Polish mines as the first indicator of contamination, as the mines are paying for the contamination proportionally to the sum of concentrations of these two contaminants. Therefore, in the first draft assessment of impact on aquatic environment, the total mass of chlorides and sulphates to be leached in "first flush" has been estimated. "First flush" is a known phenomenon of rapid increase of contaminant concentration in water just after flooding the old workings of abandoned mine, followed by exponential decrease of the concentration (Younger, 2000; Younger et al., 2002). Authors of current paper believe that the same phenomenon would appear after flooding the coal mine waste filling the sand mine pit. The total mass of chlorides and sulphates to be leached in "first flush" has been estimated using following simple equations:

$$M_{c+s} = M_{fw} \times l_{c+s}$$

where M_{c+s} is the total mass of chlorides and sulphates in "first flush" [T], M_{fw} is the total mass of flooded waste [T], l_{c+s} is the mass of chlorides and sulphates leached per tone of flooded waste during first flush [-]; this can be estimated as:

$$l_{c+s} = V_w \times C_{c+s}$$

where V_w is the volume of the pore water in the tonne of flooded waste [m^3/T], C_{c+s} is the mean concentration of chlorides + sulphates in pore waters after flooding [T/m^3]. Assuming that V_w would be about 0.15 m^3/T and C_{c+s} would be about 2 g/L (so about 0.002 T/m^3), we get $l_{c+s} = 0.0003$. Knowing that M_{fw} is estimated to about 67 million tonnes in concept I, about 107 million tonnes in concept II and about 150 million tonnes in concept III, we get M_{c+s} of about 20 thousand tonnes in concept I, about 32 thousand tonnes in concept II and about 45 thousand tonnes in concept III.

Obviously, the concept I gives the lowest impact on aquatic environment and concept III the highest impact. However, in all concepts the expected mass of flushed chlorides and sulphates (20 – 45 thousand tonnes) is huge. Furthermore, the release of contaminants would proceed with lower concentrations, but over a much longer period than the short "first flush" event. Therefore, it is expected that the total cumulative mass of sulphates and chlorides would be even much higher. This huge mass of contamination would be step by step removed from the wasted and would migrate along the groundwater flow. From the analysis of groundwater table on the edges of depression cone, as well as the water table levels in nearby rivers, it is expected that in all concepts after flooding the mine pit "Bór-Wschód" the groundwater flow directions in Quaternary will in general follow the run of the rivers Biała Przemsza and Bobrek (Fig. 3). Since the beds of these rivers are sealed, the contaminated groundwater would proceed forward to Przemsza River in SW. There, the contaminated groundwater would be partially drained by the river and partially it would migrate along the river's run in Quaternary sediments filling the paleo-valley of Przemsza River.

It is expected that due to estimated future groundwater flow direction none of MGWAs surrounding the sand mine "Maczki-Bór" would be affected by contamination coming from the mine pit. However, to prove this preliminary assessment, it should be supported in future by a regional scale groundwater flow and transport modeling. In any case significant area of Quaternary groundwater aquifer would be contaminated. This area would be much smaller, if the bed of nearby Biala Przemsza River would be unsealed, allowing the river to drain the contaminated groundwater. Since the flow in the river is significant (several m^3/s), there is a chance that the impact on the surface water quality would be much smaller than on groundwater quality in case of leaving the river bed sealed. These issues should be the topic of further study performed with detailed coupled groundwater–surface water model.

Summary

The preliminary assessment of the impact of 3 different revitalization concepts on the aquatic environment is reported in this paper. Concept I assumes building a 25 m deep pit lake, with the volume of about 30 mln m^3. The groundwater table would rise about to the level of +250 m, flooding 67 mln tonnes of waste. Concept II assumes also building a pit lake, but only 10 m deep. In this concept the mine pit in the eastern mine field would be filled with about 40 mln tonnes of coal mining waste (up to the level of +240 m). After the groundwater table rises, about 107 mln tonnes of waste would be flooded in both mine pits (eastern and western). Concept III assumes filling the entire mine pit with coal mining wastes and further land use for industrial purposes. In this

concept the total volume of flooded wastes in both western and eastern pit would amount to 150 mln tonnes.
In the first draft assessment of impact on aquatic environment, the total mass of chlorides and sulphates to be leached in “first flush” has been estimated. Obviously, the concept I gives the lowest impact on aquatic environment and concept III the highest impact. However, in all concepts the expected mass of flushed chlorides and sulphates (20 – 45 thousand tonnes) is huge. Furthermore, the release of contaminants would proceed with lower concentrations, but over a much longer period than the short “first flush” event.
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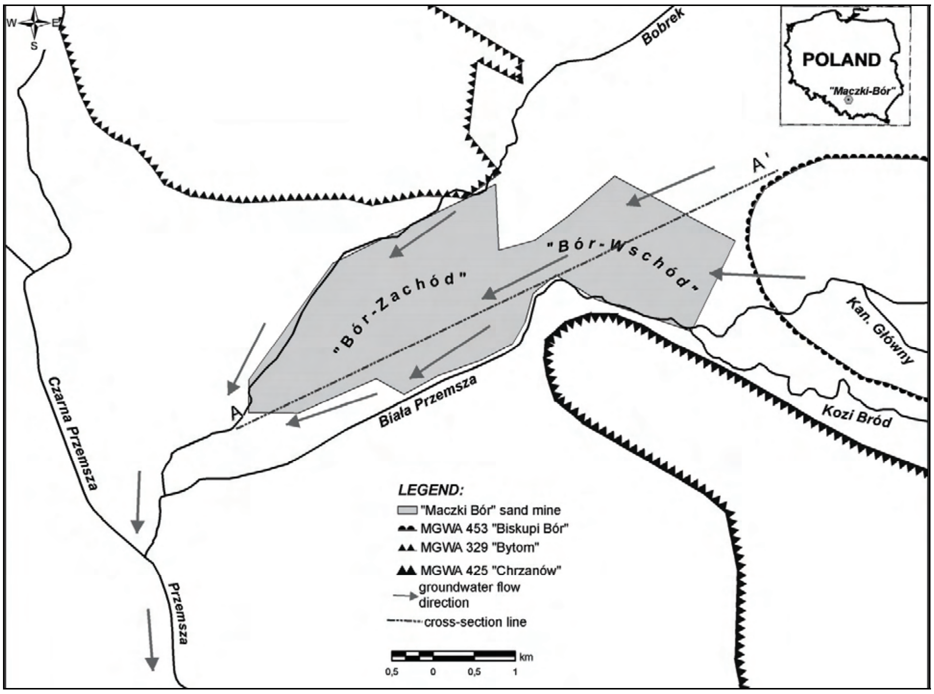

Figure 3. The expected groundwater flow directions in the vicinity of “Maczki-Bór” sand mine after finishing the dewatering.

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