Modelling of changes of hydrodynamic conditions in the aquatic environment of the Maczki-Bór sand pit due to the fact of planned closure of mining operations (NE part of Upper Silesian Coal Basin – Poland)

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Abstract Current hydrodynamic conditions in the aquatic environment of the Maczki-Bór sand pit were reconstucted with numerical model of filtration area by using Processing Modflow Pro v.7 software. The methods of the sand pit liquidation by using coalmining wastes and residual sand exploatation in the pit are included in this model. Two methods of liquidation considered: preferred method – in part of the pit, after the remediation, there will be a water reservoir, and rest of the area will be filled up by coalmining wastes (variant 1), and the second method – wastes will be located in the entire pit (variant 2). The results of simulations were a base to estimate main factors which impacted on the amount of intake and drainage.

Key Words hydrogeology, mine drainage, filtration modelling, hydrodynamic conditions, mine closure

Introduction

The Maczki-Bór sand opencast mine is located in southern Poland in silesian county. Its workings are situated on mine areas of four coal mines (three of them are closed). The Maczki-Bór sand pit exploits the sand deposit located between Biała Przemsza river and Bobrek river in Upper Silesian Coal Basin. The surface area of this mine is 5,58 km^2 (558 ha): field Bór-Zachód encompasses 65% of it, field Bór-Wschód 35%. Western part of the field Bór-Zachód was reclaimed by using coalmining wastes and at present (2011 year) it is a development area, whereas in northeastern part of this field municipal wastes are stored. In the field Bór-Wschód Quaternary sands are still exploited.

Gravitational drainage by trenches and channels caused significant changes in the Quaternary groundwater horizon. Elliptic depression cone was come into being and its dimensions are 6,5 km lenght and 2—3 km width (Solik-Heliasz 1994; Kamińska 2008).

Hydrogeological conditions

Aquifers in the Maczki-Bór sand pit area are connected with water permeable Quaternary, Triassic and Carboniferous rocks. They have different conditions of recharge and groundwater flow, and also varied water quality.

Because of advantageous parameters of this rocks Useful Groundwater Aquifers (UGWA) were assigned: one in Quaternary rocks and two in Triassic (Frolik 2006; Aniszczyk 2003).

Quaternary aquifer is connected with Pleistocene alluvium (made of gravels and coarse-, medium- and fine-grained sands with clay intercalation) located in the ice-marginal valley of Biała Przemsza river. In the whole mining area there is only one Quaternary aquifer and its average thickness is 26 metres. In the field Bór-Zachód this aquifer is locally divided by thin clay stratum into two horizons (Frolik 2006). Bottom of the Quaternary aquifer in the whole mining area is filled up with clay.

Filtration coefficient of the Quaternary sands and gravels is between $1{,}85 \cdot 10^{-4}$ m/s in the field Bór-Wschód and $3{,}34 \cdot 10^{-4}$ m/s in the field Bór-Zachód. Quaternary aquifer is recharged directly by infiltration of rainfall.

Because of long-standing exploatation primary hydrogeological conditions were changed. Groundwater flow is stabilised towards bottom of the mine and the sump. Grounwater table of the Quaternary aquifer decreased by 27 metres with regard to natural conditions.

Triassic rocks exist southeast and northwest of the boundary of the sand pit. Triassic aquifer is connected with fissured limestones (Frolik 2006).

Carboniferous aquifer exists within sandstones and conglomerates which thickness varies. This aquifer is marked by differential depth of its occurrence (28 m and 290 m) and mostly confined conditions (Frolik 2006). Carboniferous aquifer is recharged indirectly through Quaternary sands and gravels in places, where impermeable rocks (e.g. clay) don't exist. Drainage takes place by mine workings and deep indented valley of Biała Przemsza river.

General remarks about model

Single-layer model of the hydrodynamic conditions in the area of the Maczki-Bór sand pit were

reconstucted with using Processing Modflow Pro v.7 software (Chiang, Kinzelbach 1998; Kulma, Zdechlik 2009). Surface area of the filtration is 15,3 km^2 and was divided into square cells $\Delta x = \Delta y =$ 100 m (47 rows and 71 columns). Altogether 1534 square cells were used.

Boundaries of the numerical model (exept southeast boundary) were artificially determined. In this way areas which weren't taken into consideration in direct research, could have been projected in the numerical model. Only southeast boundary, which demarcates peripheral contour of model, was determined along valley of Biała Przemsza river.

Watercourses in the Maczki-Bór sand pit area are Interior Boundary Conditions. Lower part of Biała Przemsza river (from the point of drained water discharge), its left-sided tributary Bobrek river and trenches, channels and sump were modeled in this way.

Model calibration and verification were performed by the hand-operated trial-and-error adjustment of groundwater table elevation (Chiang, Kinzelbach 1998; Gurwin 2004) assessed in seven piezometers and in the watercourses, which are in a good hydraulic attachment with groundwater. During the modelling a high accordance to actual groundwater table elevation and water inflow into mine workings were achieved.

Results of the survey

In the numerical model of the filtration area, next to the reconstruction of current hydrodynamic conditions in the aquatic environment (variant 0), simulation of the water conditions after the field Bór-Wschód closure were caried out (table 1). In a variant I a water reservoir of 10 metres of depth with water level at 250,0 metres a.s.l. and the area of about 86,7 ha was assumed. In a variant II a forecast of hydrodynamic condition after complete mine closure and filling up mine workings by coalmining wastes was presented (fig.1).

Entire amount of the Quaternary groundwater included in the water balance of the Maczki-Bór pit area varies between 38 650 m^3/d (variant 0) and 7 650 m^3/d (variant II).

Essential signification in the recharge of the Quaternary aquifer (variant 0) has lateral inflow, which intensity amounts 33 800 m^3/d. It accounts for over 87% of the entire amount of balance water. Main groundwater flow is connected with water infiltration from Biała Przemsza river (22 650 m^3/d) and with inflow from beyond the model boudary (9 800 m^3/d). Left-over 13% (4 850 m^3/d) is connected with infiltration of the rainfall.

Essential signification in the drainage of the Quaternary aquifer have trenches, channels and sump. They drain almost 97% of all water flowed into modeled structure (nearly 37 550 m^3/d). Southwestern part of the filtration area is drained by Bobrek river and Biała Przemsza river.

In the initial state (variant 0) groundwater flow towards bottom of the mine and the sump, which is located in central part of the filtration area. Multiannual exploatation causes the depression cone and 27 metres decrease of groundwater table. Currently, in the filtration area, groundwater table of the Quaternary aquifer varies between 221,5 m

Table 1 *Water balance in the Maczki-Bór sand pit area on the grounds of modelling research.*

Elements of water balance in the Maczki-Bór sand pit area	**Water flow intensity [m^3/d]**					
	Variant 0*		**Variant I****		**Variant II*****	
	recharge	**drainage**	**recharge**	**drainage**	**recharge**	**drainage**
Effective infiltration of raainfall on the whole model, including:	4854	-	4380	-	4601	-
- mining area	2104	-	1781	-	2001	-
Inflow/outflow through the model boundary	9807	-21	3658	-53	2871	-139
Recharge/drainage inside model, including:	23985	-38625	749	-8734	177	-7510
- Bobrek river	1320	-30	-	-1413	-	-1706
- Biała Przemsza river	22665	-1063	749	-4286	177	-5804
- trenches, channels	-	-36802	-	-	-	-
- sump	-	-730	-	-	-	-
- water reservoir	-	-	-	-3035	-	-
Sum of the elements of water balance	**38646**	**-38646**	**8787**	**-8787**	**7649**	**-7649**

* current hydrodynamic conditions in the Maczki-Bór sand pit area
** forecast after mine closure and establishing water reservoir on the field Bór-Wschód
*** forecast after mine closure and filling up mine workings by coalmining wastes

a.s.l. and 256,0 m a.s.l.

According to the results of the numerical modelling, mine closure and water reservoir established on the field Bór-Wschód will cause changes in the groundwater flow dynamics. A slow groundwater table rebound will be occured and it is forecasted to be between 245,0 m a.s.l. and 255,0 m a.s.l. The greater part of the groundwater (3 050 m^3/d) in eastern part of the Maczki-Bór area will be drained by water reservoir. The excesive amount of water which flows into reservoir will be gravitationally drained by channel into Biała Przemsza river.

Groundwater flow intensity, which recharges

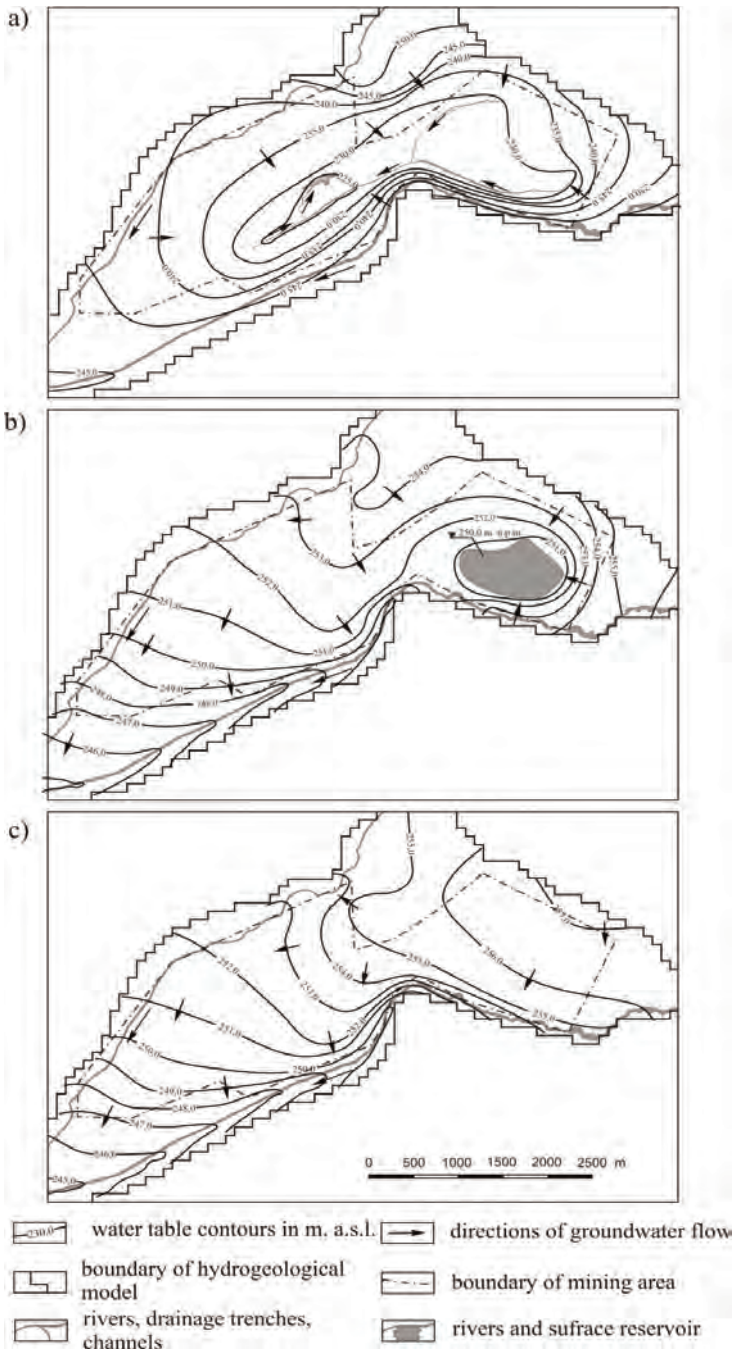

Figure 1 *Water-table map of the Quaternary aquifer in the mining area of the Maczki-Bór sand pit –a) variant 0, b) variant I, c) variant II*

the Quaternary aquifer by lateral inflow, will change. It will decrease more than 7,5 times (relative to variant 0) to 7 780 m^3/d.

Only in the field Bór-Wschód the Quaternary aquifer will be recharged by Biała Przemsza river, and the amount of infiltrated water will be related to the water level in the planned reservoir. By prognostic research means that if the water level in the planned reservoir is at 250,0 m a.s.l., infiltration from Biała Przemsza river will amount to 750 m^3/d. Biała Przemsza river and Bobrek river will be a drainage zones of the Quaternary aquifer in the area of the field Bór-Zachód. They will drain with intensity 5 700 m^3/d.

After mine closure and filling up mine workings by coalmining wastes (variant II) groundwater table contours will vary between 245,0 m a.s.l and 256,0 m a.s.l. Quaternary aquifer will be drained by Biała Przemsza river and Bobrek river with intensity 7 500 m^3/d.

Main source of the Quaternary aquifer recharge will be infiltration of the rainfall with intensity 4 600 m^3/d (over 60% of the sum of the water balance elements). Water resources will be related also to inflow through the model boundary (2 870 m^3/d).

Both rivers will change they character and will drain the Quaternary aquifer at the almost whole filtration area. Only the small fragment of aquifer in eastern part of the model will be recharged (with intensity 180 m^3/d) by Biała Przemsza river.

Regardless of established variant there is no possibility to avoid groundwater pollution caused by coalmining wastes. Concentration of pollution in the groundwater and time of its distribution in definite concentration will be relianted i.a. on the amount and type of wastes and used technology in the remediation.

Conclusions

Results of the numerical model indicate that - according to considerated variant - predictive groundwater inflow into filtration area varies between 38 650 m^3/d and 7 650 m^3/d. In current conditions main flow of groundwater is connected with lateral inflow and accounts for 87% of the sum of the water balance elements.

Mine closure and establishing water reservoir on the field Bór-Wschód (variant I) will cause slow Quaternary groundwater table rebound and changes in the groundwater flow directions. In eastern part of the filtration area groundwater will be drained by reservoir. Groundwater flow in western and northern part will change towards Biała Przemsza river and Bobrek river.

Wastes located in the entire pit (variant II) after mine closure will cause groundwater table rebound to level between 245,0 m a.s.l. and 256,0 m a.s.l. Effective infiltration of the rainfall and the inflow through model boundary will be main factors which will decide about water resources. Quaternary aquifer will be drained by Biała Przemsza river and Bobrek river.

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