Requirements for numerical hydrogeological model implementation for predicting the environmental impact of the mine closure based on the example of the Zn/Pb mines in the Olkusz area

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Abstract Numerical modelling is the only reliable tool to solve such complex problems as mine closure. This paper presents the requirements for the use of numerical modelling for prediction of aquatic environment changes in the area of the liquidates mines based on the example of Zn/Pb ores mines in the Olkusz region (southern Poland). Author's indicate a set of data that should be prepared to create a reliable numerical model which can be easily applied to simulate mine closure and its impact on the aquatic system, especially rebound of the groundwater table and reactivation of the wetland areas.

Key words mine closure, hydrogeological modelling, environmental impact assessment, Olkusz region

Introduction

Mining is often a highly complex long-term industrial operation, with respect to both technological and planning aspects. The mining industry uses several environmental management tools (e.g. life cycle assessment, multi-criteria decision analysis, etc.) during mine development, operation and closure periods (e.g. Duruncan et al. 2006; Reid et al. 2009; Roussat et al. 2009). However, due to uncertainties associated with the liquidation phase it is crucial to adopt solid management practices for environmental impact assessment. It requires a proper preparation to predict all potential hazards related to the whole process of mine closure and reclamation. It is especially significant not only to the mine owners (as the mine closure plan and its environmental impact is usually considered and included within the pre-feasibility, feasibility and design phases) but also to the local community and the mine surrounding area investors, which could directly be impacted by the mine closure process.

Characterisation and prediction of aquatic system changes in relation to mine closure process and requirements associated with that was based on the example of Zn/Pb ore mines in Olkusz region. The mine liquidation process at this area is planned to start at 2020-22 and its regional character and complex structure associated with land development makes the site an interesting example. The site is located in Southern Poland and it's a part of the Biała Przemsza river basin (tributary of the Vistual river). The main constituents of the geological structure are represented by Triassic formations (sediments of the Lower and Middle Buntsandstein, Rot Formation and Muschelkalk). Underlying the Triassic are Permian and Devonian rock, which build an anticline and elevated tectonic block. On the South from Bukowno city occurs Carboniferous sandstones. The Triassic overburden consist of limestone of the Upper Jurassic, as well as Middle Jurassic marl (East part of the site). However, Quaternary material covers the entire area by a layer of varying thickness from a few to a few dozen meters in the Biała Przemsza valley. The Triassic aquifer plays dominating role in the hydrogeological conditions and it is in hydraulic contact with Quaternary aquifer (fig. 1).

The underground mine closure, including Zn/Pb ore mines, is directly related to hydrogeological consequences such as: (i) *rebound of the groundwater table* and (ii) *flooding of the depression cone and underground mine workings*, due to the discontinuation of mine dewatering process. The artificially created hydrogeological conditions due to mine operation will slowly develop to their "natural" state from before mine drainage. Such situation, although from a hydrological conditions point of view is a natural and inevitable occurrence, may also generate a number of adverse phenomena. As a result of even several decades of mine drainage activity, there can changes of the developed state occur and they are associated with observed effects such as:

- *disturbance of water regime* – decrease or disappearance of river flow and slow recovery of natural flow, which can take even decades as the underground mine operation – mine dewatering process and depression cone as it direct consequence has usually a regional scale;
- *reactivation of natural wetlands* – in case of Zn/Pb ore mines there is no mining induced subsidence so restoration of bayous and flooding zones occurs naturally;
- *groundwater quality changes* – in case of Zn/Pb ore mines a contamination of groundwater in sulphates and potentially toxic metals can occur as a result of sulphide minerals oxidation to soluble sulphate;

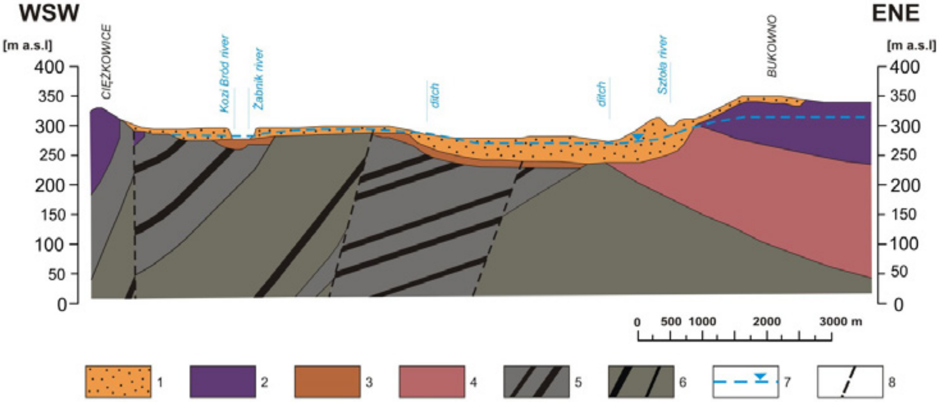

Figure 1 *Schematic hydrogeological cross-section of the studied area (Southern part)*

1,2 – permeable Quaternary (1) and Triassic (2) deposits,; 3,4 – impermeable Quaternary-Carboniferous (3) and Permian (4) deposits; 5,6 – permeable (5) and impermeable (6) Carboniferous deposits; 7 – Triassic-Quaternary groundwater level; 8 – faults

Methodology for predicting changes of aquatic system related to liquidation based on the on the Olkusz region example

To characterise and describe mine closure there could be two methods: analytical and numerical considered. In case of the Zn/Pb ore mines liquidation in Olkusz region due to its complicated nature and regional impact of the mining operation process (its depression cone up to 600km^2) analytical methods are not accurate to properly predict all aquatic system changes and consequences resulted from mine closure process. Numerical methods are more reliable and allows to consider all important parameters and scenarios. However, to apply numerical modelling for mine closure impact on aquatic system and predict its consequences there have to be some special requirements met. The proposed methodology, applied for Zn/Pb ore mines closure in Olkusz region, includes:

- *obtaining a full site description*, assessed through the collection and synthesis of existing data of mining inflow, geological, geo-chemical, hydrogeological characterization of the mine and the surrounding area, including field investigations (rivers and streams flow measurements along with identification of potential water escapes into the rock mass) as well as historical data;
- *data verification and management* using some novel software tools, eg. Hydro GeoAnalyst that integrates a complete suite of analysis; within the HGA data can be quickly analysed, integrated and easily visualised;
- *numerical model development* which requires special emphasis on a structure discretization, which should reflect all important geological layers, both permeable and impermeable (multilayer model). Conceptualization of hydrogeological conditions and proper generalization of the top and bottom of each model layer important for groundwater flow is a key stage of the numerical model development; to predict a restoration of bayous and flooding zones it is a good fit of site topography and geology of Quaternary deposits required to obtain to get reliable results; usually within the numerical model development a site topography is not relevant, as the active cells are located below groundwater table and thus a first model layer is inactive; the model cell size should reflect the scale of the modelled problem – usually between 100–200 m, as the mining operation impact scale typically has regional character;
- *model calibration* – where a requirement is to refer to three types of data: (i) hydraulic head and (ii) surface waters flow measurement and also (iii) to the mine inflow;
- *mine closure scenario simulation* – which requires conducting simulations on transient model as the mine closure process can take dozens of years to reach “natural conditions” and it should be assessed how groundwater table restoration vary in time;

It has to be remembered that mine closure process should be supported not only by numerical modelling and its simulations but also by the wider social, economic, physical and biological contexts within which a mine is located. This will ensure that the broader environment, including its inherent risks and opportunities, influences mine closure, as opposed to merely investigating how the closed mine will impact on the environment and on the surrounding communities. Therefore, it is important for local community and mine’s owners to cooperate, especially with the data availability, as it is a common purpose to predict and assess environmental risk from the mine closure, especially that the whole process can take dozens of years.

Results of numerical modelling of Zn/Pb ore mine closure impact on the aquatic system in the Olkusz area

Applying a developed procedure based on the example of Olkusz region (southern Poland), a numerical multilayer model using a Visual MODFLOW, was developed. The modelled area covering 490 km² was divided into 80 rows and 98 columns (oriented in the N-S direction) with the finite-difference grid size 250×250m and with the active area about 250 km². A model structure consists of 6 layers with varying thickness to fully capture the complexity of the hydrogeological conditions at the site (fig. 2, fig. 3). Top and bottom of each model layer is a result of the geological interpolation of approx. 4000 borehole data using kriging method.

According to the proposed methodology the model calibration was based not only on the size of the mine inflow but also mapped to actual groundwater level contours and measured flow values of the rivers (fig. 4). Obtained results indicate good and accurate fit to real data of mine water inflow to the Zn/Pb ore mines in Olkusz region which equals 250-270 m^3/min. (Motyka et al. 2016) and results obtained on the model are around 255 m^3/min. (4.26m^3/s) (tab. 1).

***Table 1** Modelled area budget for mining operation and mining closure scenarios*

Balance items	mining operation scenario*		mining closure scenario*	
	Input (+)	Output (-)	Input (+)	Output (-)
1. Effective infiltration/Recharge	4.348	0	1.128	0
2. Input/Output (constant-head boundary)	4.611	4.704	2.912	4.038
3. Inflow/outflow to the Zn/Pb ore mines:				
Pomorzany	0.0	3.397	0.0	0.0
Olkusz	0.0	0.764	0.0	0.0
Bolesław	0.005	0.099	0.0	0.0
Total	8.964	8.964	4.041	4.038
Divergence in balance [%]	0.0		0.09	

*units in m^3/s

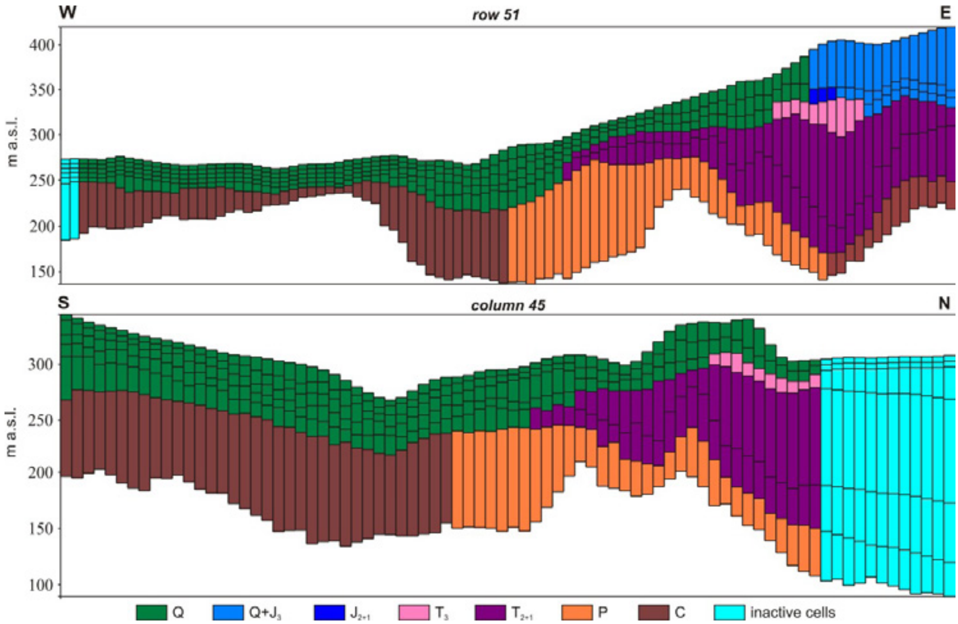

***Figure 2** Numerical model of Olkusz region row/column cross-section*

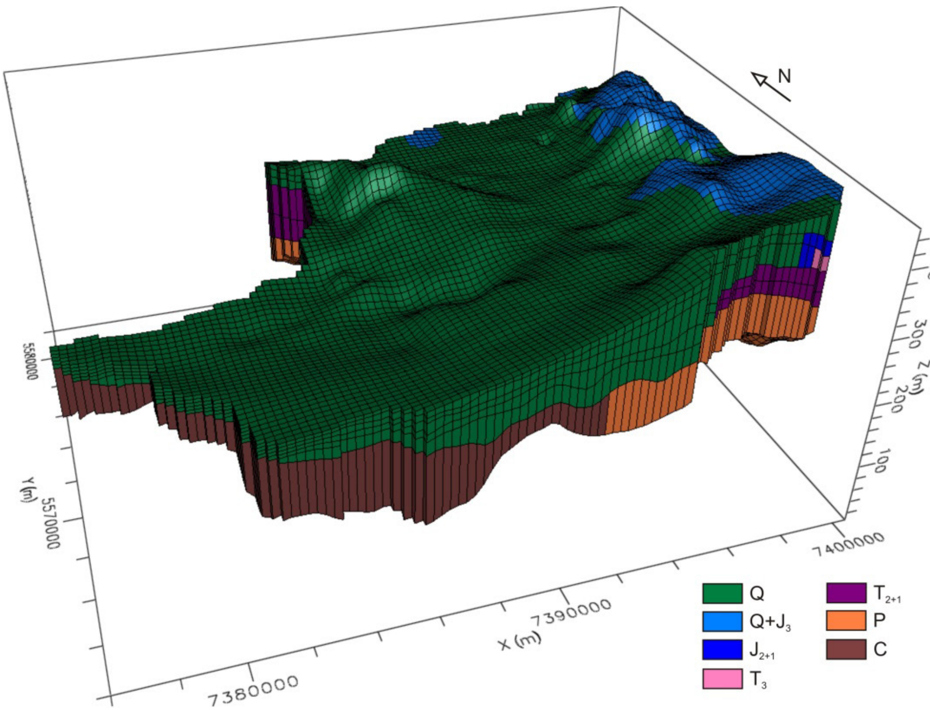

***Figure 3** 3D structure of numerical model of Olkusz region*

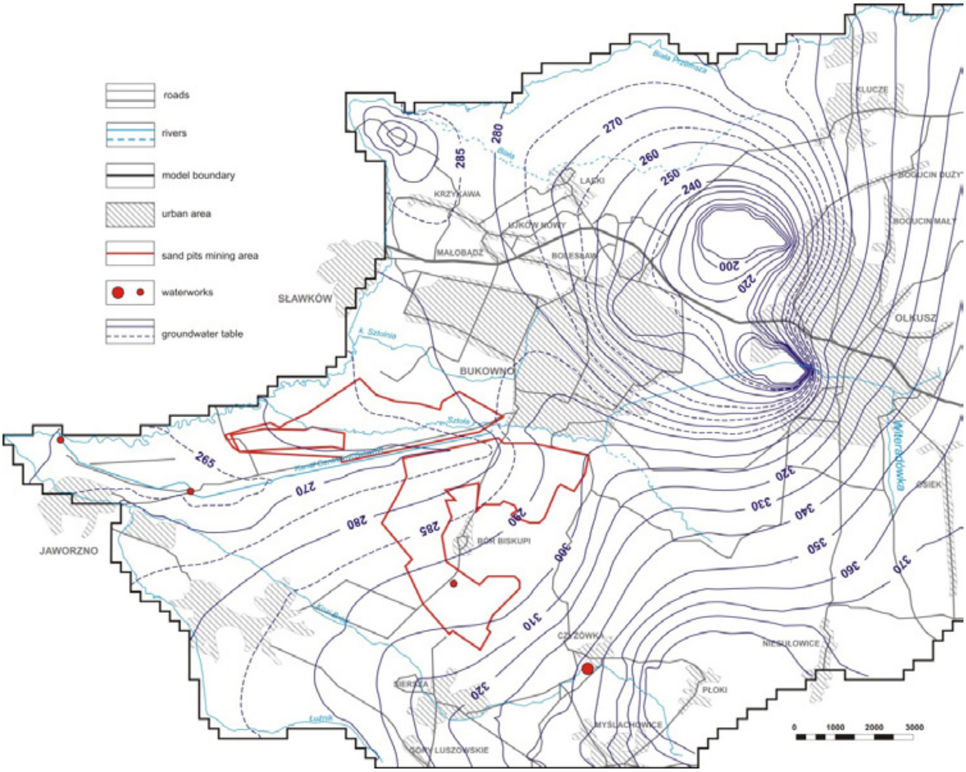

Figure 4 *Map of Quaternary-Triassic multi-aquifer groundwater table obtained on the model – mining operation scenario (as of 06.2016)*

Hydrogeological model allowed for prediction of the Olkusz mine liquidation impact on the aquatic system, especially at the area of surrounding sand pits, Jaworzno and Silesia waterworks' and changes of the surface waters regime including bayous and flooding zones formation. The new groundwater table for mine closure final scenario (after 100 years) is presented on fig. 5. The calculated total time of complete reconstruction of groundwater level to natural conditions is approx. 90–110 years but the first effects of Zn/Pb ore mines closure would be visible after approx. 25 years.

Conclusions

Prognosis of mine closure process is a very difficult task regarding to its considerable complexity and mathematical description. In most cases, this type of activity is based on a computer simulation performed for numerical modelling of hydrogeological conditions. Therefore, there have to be special requirements achieved to create reliable and accurate model of the site for future scenario development. Taking into account all of them (such as data compilation, model discretization: grid size an multilayer character, its regional scale, transient condition of the mine closure process, and a proper calibration) a numerical model of Zn/Pb ore mines liquidation in Olkusz region was developed as an example of area where a numerical modelling is the best tool to predict mine closure foreseen to start at year 2020-22.

Created model allowed for mine closure impact assessment on aquatic system, especially at the area of surrounding sand pits, Jaworzno and Silesia waterworks' and changes of the surface waters regime including bayous and flooding zones formation. The model can be easily implemented for future use related to new waterworks' location or prediction a new Zn/Pb mine impact in the Zawiercie area.

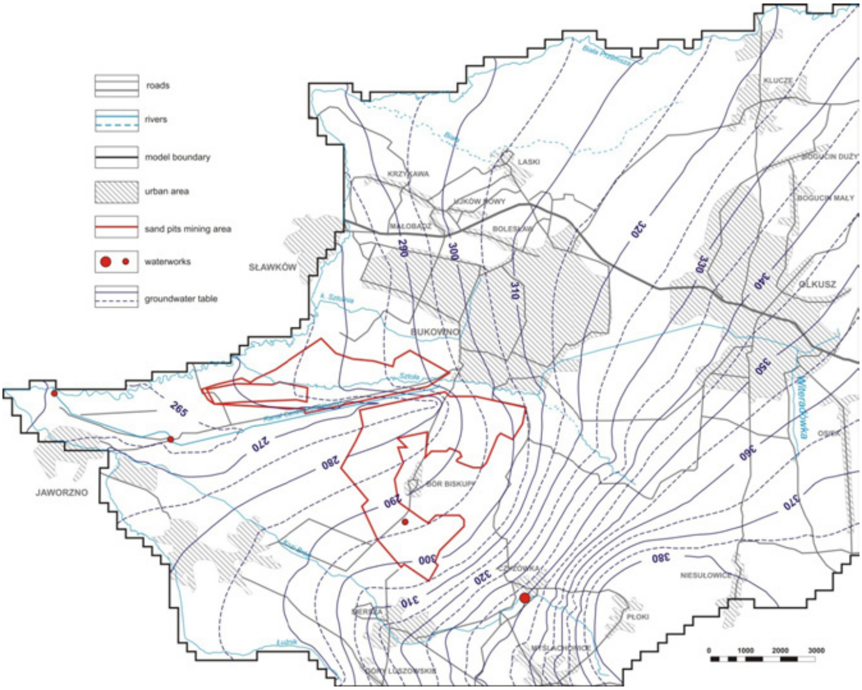

Figure 5 *Map of Quaternary-Triassic multi-aquifer groundwater table obtained on the model – mining closure final stage scenario (after 100 years)*

Acknowledgements

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