The significance of ground water flow modelling study for simulation of open cast mine dewatering and assessing the environmental impact of drainage

Jacek Szczepiński

"Poltegor-Institute" Institute of Opencast Mining, Wrocław, Poland, jacek.szczepinski@igo.wroc.pl

Abstract

Simulations of open pit dewatering and the environmental impact assessment are performed using a ground water flow modelling. However, numerical models have certain limitations resulting from the existing uncertainties as to the assumed hydrogeological parameters and boundary conditions. They include the shortcomings in the identification of hydrogeological conditions, cyclic changes of precipitation as well as evapotranspiration and evaporation, the impact of local climate changes resulting from land management in the of mining and power generation activity areas as well as changes in schedules of mining and reclamation including post-mining flooding. Even though groundwater models have numerous limitations related to uncertainty of the parameters, they still provide the most comprehensive information concerning the aquifer system as of the time when they are developed.

Key words: open pit, lignite, dewatering, modelling,

Introduction

In mining industry, water-related problems are among the most important aspects which can decide whether a new mine will be feasible or reasonable. For the assessment of costs of mining operations both the rate of mine water inflow and the environmental impact of mine drainage is important. Insofar as in the past one would mainly focus on the aspects of the hazards connected with mine water inflow, at present most of the attention is focused on environmental impact assessment. To estimate the mine water inflow to open pit one typically applies the methods of hydrogeological analogy or hydrogeological balance.

At an early stage of deposit exploration, hydrogeological calculations are usually performed using analytical methods, the most popular of which is the large well method described in numerous textbooks. Further investigations are dominated by numerical methods. They are used throughout the whole mine life-cycle. Numerical methods enable to forecast the process of active mine dewatering as well as the process of flooding the post-mining excavations with greater accuracy, than any other methods. They can assess the impact of dewatering on groundwater, surface water, soil, flora, farmlands and forests, water chemistry, water intakes, land subsidence and others. Particularly, the process of flooding post-mining reservoirs with complex geometry and diversified hydrogeological conditions must rely on numerical models (Schwartz, Crow 1985).

Application of modelling methods throughout an open pit life-cycle

Numerical modelling is used during deposit exploration period and mining activity as well as after its completion. Its purpose is to deliver reliable forecasts of ground water inflow to the mine drainage system and the environmental impact of mine drainage with reference to different scenarios of the deposit opening up, its extraction as well as reclamation of post-mining excavations. In many cases, models are also performed in order to confirm or reject the scope environmental impact of an active mine. They usually pertain to the impact of dewatering on water courses, natural and artificial water reservoirs, ground water conditions, ground water resources, water intakes, soil, flora, farmland and forests, water chemistry or subsidence. The range of impact of mine dewatering is typically assumed to extend to a point where the ground water table was lowered by 1 meter, disregarding the permanent lowering of average multiannual water table.

By 1990's, problems of reclamation of post-mining excavations had not been extensively addressed in research-related publications, since there were no many such a reservoirs (Uberman 1996). Not until the recent dozen or so years these problems have been more extensively addressed all over the world, for the reasons to estimate costs of works related to flooding the future post-mining excavations as well as assessment of their environmental impact. The most crucial elements in these studies were: the rate of flooding, restoration of ground water table, the impact of reservoir on ground water and changes in the water quality in reservoir and aquifer.

Specificity of application of modelling methods for purposes of surface mining

The procedure for developing a ground water flow model in mining conditions generally complies with the overall modelling methodology. However, it must account for the specificity of operation and drainage of mines. The ground water flow model developed for open pit mine should be a full three-dimensional (3D), with the hydraulic head specified for each model layer. It is particularly important in the areas adjacent to the open pit, especially near the slopes of the pit. For the assessment of the range of the cone of depression, one can apply a quasi-3D model which only represents the vertical flow in semi permeable layers (Szczepiński 2013).

In order to develop reliable forecasts, it is necessary to recognize hydrological conditions of the deposit as well as to identify all environmental, mining and technological factors which can affect the mine water inflow. The most important factors influencing mine water inflow and environmental impact of drainage of surface mines are: hydrogeological parameters of deposit and the neighborhood aquifers, aquifers recharge from precipitation, aquifers recharge from surface water, dewatering technology and management of post-mining excavations. All these data are required to developed a reliable conceptual model. Conceptual model requires not only detailed identification of hydrogeological conditions, but also right representation of the mine drainage system. It should be developed taking into account information on the location of deposit opening out, the mining face advancement, location and advancement of internal dump as well as the parameters of final excavation.

Simulation of mine drainage and its influence on the water environment is associated with a huge amount of data, more than for models created for other reasons. The water courses, lakes and reservoirs on the model area should be simulated taking into consideration the drying as well as the re-watering in the case of groundwater rebound. Recharge and evaporation boundary conditions should ensure appropriate representation of effective infiltration changes during water table fluctuation, whenever such changes take place.

As the mine drainage is the process variable in time and space, the models used in mining hydrogeology are solved in transient simulation. However, at the first stage - for natural hydrodynamic conditions prior to the deposit dewatering – the model should be solved in a steady-state conditions. Calibration performed under steady-state conditions enables preliminary determination of recharge and the horizontal and vertical hydraulic conductivity of aquifers. Model verification should be proceed in transient conditions taking into account preliminary well pumping before the drainage system is put into service. This enable to improve parameters determined in steady-state conditions and estimate the specific yield and specific storage coefficients of the aquifer. At the stage of predictive simulations, one is required to change certain input parameters and boundary conditions of the model used for calibration and verification of the model (horizontal and vertical hydraulic conductivity as well as specific yield and storage capacity). Outside the mining area, it is necessary to update boundary conditions related to decommissioning or construction of new water intakes, ditches or reservoirs, industrial and municipal waste dumps as well as to simulate relocation of rivers and other water courses. The new parameters should represent the advance of the deposit extraction, the overburden dump area and the post-mining excavations. Besides modification of boundaries conditions representing the dewatering system, updating the spatial conditions of the model layers and filtration parameters are required.

Documenting the results of modelling study in mining hydrogeology is more extensive compared to models used for groundwater resources assessment. However, it must account for all boundary conditions and parameters of aquifers subject to changes in time. While applying a model, one should envisage both natural conditions, the dewatering period, the post-mining excavations management as well as conditions after completion of reclamation period. The results thus obtained, including the hydraulic head in each modelled layer, the range of the cones of depression for all layers, the groundwater balance, the rate of mine water inflow as well as the hydrogeological conditions after reclamation completion, should be presented in both descriptive and graphical form for all the periods assumed.

Limitations of modelling methods

Numeric models have certain limitations and uncertainties related to the assumed hydrogeological parameters and boundary conditions. They include shortcomings in the identification of hydrogeological conditions, changes in groundwater recharge and modifications of mining schedules. Proper identification of hydraulic parameters, the nature of faults and fissure as well as karstic formation phenomena, is decisive for reliability of modelling studies. For example natural hydraulic barriers, such as faults filled with semi-permeable material or rock formations with low hydraulic conductivity compared to adjacent rock layers, can decrease the mine water inflow as well as to diminish the negative environmental impact of dewatering. Under natural conditions, i.e. those existing before the drainage commencement, the most efficient method to identify hydrogeological structures and parameters of rock layers is a trial pumping. While the deposit is being dewatered, the model should be subject to verification based on new information related to the actual response of the aquifer to the mine water drainage. It may lead to the necessity of adjusting hydraulic parameters of aquifers and semi-permeable layers in the model.

Despite the fundamental importance of recharge in the water balance, it is an element with the highest uncertainty, since its volume primarily depends on the accuracy assumed when calculating other elements of the balance equation (Healy 2010) Changes in the recharge may be consequences of many factors which were not accurately estimated or identified. These may include: unidentified leakage of surface waters into aquifers, water losses from the water supply and sewage disposal system, technological waters recharging the rock mass during drilling, changes of recharge caused by land management.

Assuming the amount of recharge based on average multiannual precipitations does not account for the cyclic deviations and trends resulting from climate variability. For instance, small precipitation may lead to increase of ground water table below a level referred to as the evapotranspiration extinction depth, which causes an increase in effective infiltration. On the other hand, the change of water deficit, i.e. the difference between potential evaporation form reservoir and the precipitation, affects the rate at which post-mining reservoirs are filled with water. It particularly applies to long-term forecasts which sometimes have more than 100 years.

Mining and power generation activity, including formation of large open pits and overburden dumping areas as well as the existence of powerful heat and steam emitters at nearby power plants, may lead to changes of hydraulic parameters of layers as well as local climate variations, influencing recharge form precipitation.

Post-audit analyses imply that ground water flow models can fail to forecast the future due to the wrong input parameters or different boundary conditions which are not compatible to the actual conditions. Due to changes in schedules of mining activities or reclamation of post-mining excavations, the input data used in the model should be verified and updated with reference to the most recent recommendations and assumptions. Continual improvement of the conceptual mod3el by collection of new field data wil imrove the numerical model (Anderson, Woessner 1992).

Conclusions

Even though ground water flow models used in mining hydrogeology have numerous limitations related to uncertainty of the parameters, they still provide the most comprehensive information concerning the aquifer system and the dewatering system as of the time when they are developed. However, they will always require verification based on new information emerging in relation to an actual response of the aquifer system to the drainage being conducted. They should also be subject to periodical verification with reference to recent information about the actual climate conditions, the response of the aquifers system to the dewatering as well as up-to-date schedules of deposit extraction and mine closure. The numerical modelling used in scientific studies as well as in applied hydrogeology is a combination of practical and scientific knowledge. Standardisation of modelling methods does not exclude the need for a subjective approach applied in solving every single problem during the entire modelling process.

References

Anderson MP, Woessner WW (1992) Applied Groundwater Modeling, Groundwater Flow and Advective Transport, Academic Press Inc., San Diego–New York–Boston, pp. 381.

Healy R (2010) Estimating Groundwater Recharge, Cambridge University Press, pp. 256.

Schwartz FW, Crowe AS (1985) Simulation of changes in ground-water levels associated with strip mining. Geological Society of America Bulletin, 96: 253—262

Szczepiński J (2013) Modelowanie numeryczne w badaniach hydrogeologicznych dla oceny wpływu kopalń odkrywkowych na środowisko wodne, Wydz. Geoinż., Górn.i Geol. PWr (in polish), pp. 200.

Uberman R (1996) Niektóre czynniki warunkujące wybór sposobu zagospodarowania wyrobisk poeksploatacyjnych w górnictwie węgla brunatnego. In II Intern. Mining Congress „Górnictwo Węgla Brunatnego", Prace Nauk. Inst. Górnictwa PWr. 79: 435—442 (in polish)