Interactive use of groundwater hydraulic modelling and GIS application for predicting of groundwater level rise impacts

Nada Rapantova[1], Jiri Tylcer[2], David Vojtek[1]

[1]Faculty of Mining and Geology, VSB-Technical University Ostrava, Czech Republic;
E-mail: nada.rapantova@vsb.cz, david.vojtek.hgf@vsb.cz
[2]AQ-test, Ostrava, Czech republic; E-mail: tylcer@aq-test.cz

Abstract: The paper deals with prediction of hydraulic impacts of ceased pumping of groundwater source. Interactive cooperation of the groundwater flow model with the GIS spatial analysis (ArcGIS) proved to be a very effective tool to predict these negative impacts of the exploitation ceasing and to propose appropriate measures to prevent them.

Key words: groundwater, numerical modelling, GIS, spatial analysis.

INTRODUCTION

A large groundwater source for the City of Ostrava started its operation on the outset of the 20th century. At the beginning, it was located on the city outskirts. But with time, the city development has reached its pumping depression area. Today, there are residential areas and industrial enterprises that have been built without respect to the original natural groundwater level. The situation is complicated by terrain subsidence caused by former mining activities. Presently, the operator of the wellfield considers putting it out of operation due to worse economical parameters in comparison with other exploited sources.

There are worries regarding impacts of the groundwater level rise to the original level, which is unknown. It could cause flooding of subsurface sewage and electricity distribution systems, flooding of subsurface building floors and foundations and other related problems. Interactive cooperation of the groundwater flow model with the GIS spatial analysis (ArcGIS) proved to be a very effective tool to predict these negative impacts of the exploitation ceasing and to propose appropriate measures to prevent them. Predictions were done on 3D calibrated and validated transient hydraulic model (MODFLOW).

PROBLEM DEFINITION AND CONCEPTS OF SOLUTION

Groundwater source Ostrava-Nová Ves is situated in the right – bank fluvial plain of the Odra River (Fig. 1). The nearest distance to the Odra River is approximately 1 km. The river plain Quaternary deposits consist of a gravel layer and an overlying fluvial loam layer. The total thickness of the Quaternary cover is generally 5–9 m. It is reposed on Miocene clays. The exception is a deep narrow channel in the tertiary clays below the river plain deposits that is filled with Quaternary sands, gravels and irregular clay interbeds. The depth of the channel is reaching even over 65 m below the terrain; its width is reaching 400 - 500 m (Fig. 2).

With potential capacity of 220 l/s Nová Ves wellfield is the only significant groundwater source available to the city of Ostrava with about 300 000 inhabitants.

At present, groundwater source exploitation is not economically competitive with water

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Figure 1. Situation plan

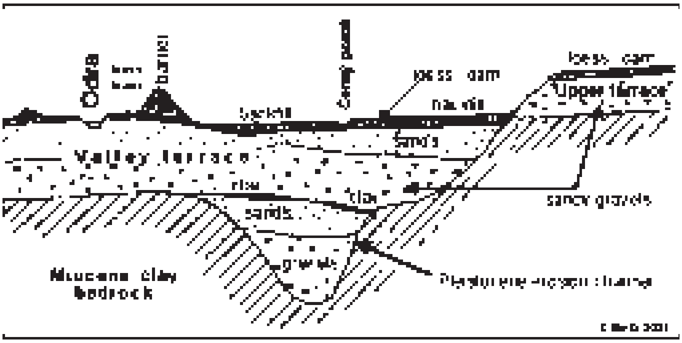

Figure 2. Scheme cross-section

from surface sources. It is the reason that its operator considers the idea of long-term ceasing of its exploitation but with maintaining the possibility to start pumping again in case of necessity. A complex approach taking into consideration all kinds of impacts of ceased pumping, i.e. hydraulic and hydrogeochemical impacts were an absolute necessity. The study was based on exploitation of mathematical modelling and geoinformation technologies with objective to design protective measures to prevent negative impacts of groundwater level rise and changes in hydrodynamic field. The solution could be divided into the following steps:

- data gathering (geological and hydrogeological database, digital terrain model, cadastral and technical maps with engineering networks),
- mathematical modelling of groundwater flow,
  - calibrated present steady state with groundwater source exploitation,
  - calibrated transient groundwater model,
  - simulated scenario of ceased pumping,
- preliminary spatial analysis in GIS,
  - comparison of digital terrain model with predicted groundwater level without groundwater source exploitation,
  - conclusions - proved potential problems of flooding of underground constructions and engineering networks,
- data verification and completing data gaps,
  - field recognition of depths of underground parts of constructions based on cadastral maps information,
  - geodetical measurements of selected points to verify precision of digital terrain model (DTM),
  - drilling of observation wells in threatened areas without hydrogeological information (data gaps) to verify modelling results,

- mathematical simulation of scenario of ceased pumping and spatial analysis of potential flooding of underground constructions (building foundations and engineering networks – water and sewage pipelines, electrical distribution systems) in GIS,
    - position of groundwater piezometric level vs. terrain,
    - position of groundwater piezometric level vs. depths of building foundations and depths of engineering networks,
- uncertainty analysis of predictions,
    - uncertainty analysis of predictions,
    - cumulative error of groundwater modelling, DTM, data gaps from field recognition of underground construction depths,
- design of hydraulic measures to prevent flooding of underground constructions done interactively by mathematical modelling with contemporary spatial analysis of flooding in GIS.

RESULTS AND DISCUSSION

Groundwater modelling was the principal tool for solving the above-defined tasks. Model domain was selected with the aim to cover the whole hydrogeological structure in its natural geological boundaries. Model of geological structure in the form of TIN was based on approximately 150 boreholes reaching impermeable Miocene bottom. Two hydrostratigraphic units were defined in the area:

- fluvial plain sands and gravels (model layer 1),
- sands and gravels of subglacial channel (model layer 2).

Mathematical model was built as three-dimensional steady state based on the numerical method of finite differences by verified code MODFLOW in the GMS 3.1 environment (Groundwater Modelling System – 1998 – Brigham Young University, ECGL).

Model layer 1 (river plain) is limited in the West by Odra River and in the North by Ostravice River. The southern boundary is located in the tributary stream Zábřežka. The rivers were simulated by mixed or Cauchy boundary condition - head dependent flow boundary $q = f(H)$. Eastern boundary between terrace stages was simulated by general head boundary (MODFLOW package) $q = f(H)$.

Model layer 2 (subglacial channel). Boundary conditions were set up on the basis of limited available information. We assume that water flows in and out of the model in the direction of channels. Side borders (in the transversal direction of structure) were simulated as no-flow boundaries $q = 0$. Very good hydraulic connection between layer 1 and 2 is supposed forming continuous water body (in the majority of area). The layer is recharged from the first layer.

The discretization of model domain was done by irregular rectangular block-centered grid with refinement in the area of wellfield. The block size varies from 30 to 80 m. Grid of model domain covers the area of 8 030 x 3 410 m.

Calibration of stationary hydraulic model was finished with mean absolute error (MAE) of 20 cm in the first model layer and 8 cm in the second model layer.

Transient hydraulic model was required for solving the problem of time development of depression cone after the pumping in Nová Ves withdrawal area sis ceased. The results of hydraulic model prove that after the pumping in water withdrawal area is ceased, groundwater in river flood plain in Nová Ves will be recharged from precipitation and outflow from the upper terrace and drained to Odra River. Groundwater will preferentially flow in subglacial channel. To assess the impacts of ceased pumping of groundwater source, the calculations of groundwater piezometric level rise were done; followed by spatial analyses in ArcGIS. According to modeling predictions in wellfield area groundwater level should rise about 5 m. The conclusions were done mainly on the basis of position of piezometric groundwater level vs. terrain and vs. depth of underground constructions and engineering network (Fig. 3). Distribution of the necessary groundwater drawdown to be induced by local hydraulic measures was set up and concrete hydraulic measures (location and discharge of pumping wells) were designed.

Figure 3. Flooding of underground structures

CONCLUSIONS

Combination of methods of numerical modeling (prediction of hydrodynamic system behavior) and spatial analyses in ArcGIS based on digital terrain model, cadastral maps and field recognition brought the very concrete and detailed solutions – design of preventive protection hydraulic measures. The solution is, of course, burdened by uncertainty. Geodetical measurements proved that average error of DTM was 35 cm reaching maximum of 60 cm. Based on the probability distribution of error in numerical model, we concluded that potential error (worst case) of predicted depth of groundwater piezometric level below terrain could be approximately 1m.

REFERENCES

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