Impact of Gravel Pits on Ground water: Case Study of Gravel Pits near the Mohelnice City, Czech Republic

Tomas Kuchovsky [a)], Adam Ricka [a, b)], Jaroslava Cervenkova [c)]

[a)] *Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic, e-mail: tomas@sci.muni.cz*
[b)] *Technical University of Liberec, Faculty of Mechatronics and Interdisciplinary Engineering Studies, Studentska 2/1402, 461 17 Liberec, Czech Republic*
[c)] *Czech Hydrometeorological Institute, Kosetice Observatory, 394 22 Kosetice, Czech Republic*

Abstract
Gravel pits near the Mohelnice city, Czech Republic, are situated in an aquifer that is important for ground water supply. The impact of gravel pits on ground water levels was assessed using numerical computer modeling and different stages of mining were simulated. The maximum rise of the ground water table has reached +1 m, while the decline is -3 m, compared to original levels. The gravel pits become drainage bases of the aquifer as the result of both mining activity and artificial changes in the Morava River channel. As a result of ground water flow into the open gravel pits, there is precipitation of calcite, pyrolusite and amorphous $Fe(OH)_3$, as well as an increase of pH values.

Key words: Gravel pits, Ground water, Computer modelling, Ground water level changes, Mineral precipitation

Introduction

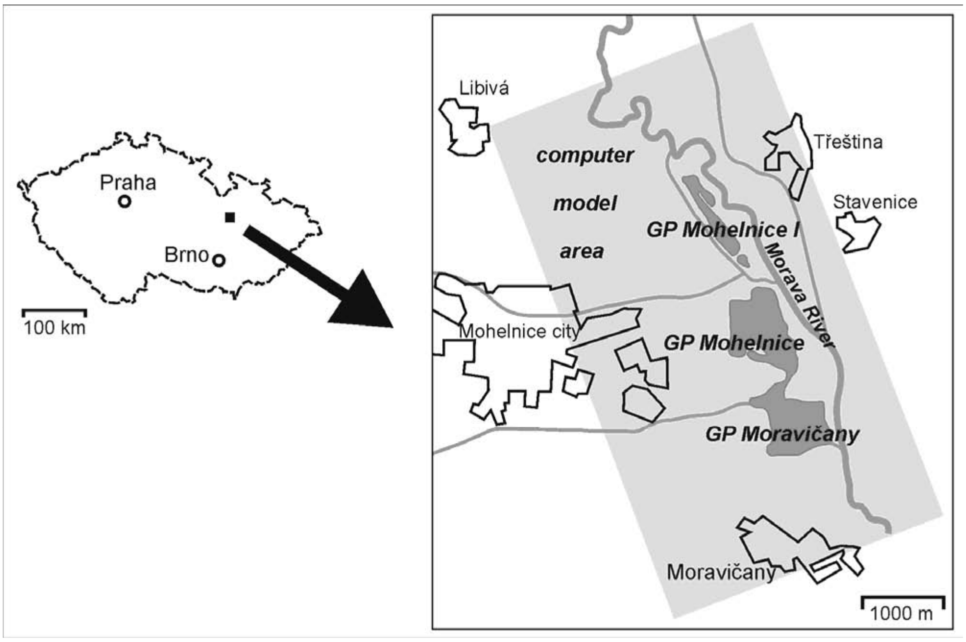
Gravel mining represents one of the most important mining activities in the Czech Republic. Important accumulations of coarse-grained sediments are situated in alluvial plains of large rivers or in sediments accumulated by glacial processes. Favorable hydraulic properties of sediments, as well as the hydraulic connection with rivers, enable formation of aquifers important for ground water supply. During gravel excavation, open pits are formed. The open space is spontaneously filled by ground water from the adjacent aquifers. Changes in ground water levels as a result of hydraulic connection of open pits with the aquifer as well as changes in redox conditions in open pits may cause possible conflict between mining and other activities (such as ground water supply, agricultural activities and urban areas).

The investigation that is the subject of this paper, focused on complex impacts of open gravel pits on ground water, was made in the wider surrounding area of gravel pits near the Mohelnice city, Czech Republic (Fig. 1).

At the present time, three gravel pits are situated in the area — the GP Moravicany, the GP Mohelnice and the GP Mohelnice I. The gravel mining began in 1960s in the southern part of the area and continues to the present time: the north GP Mohelnice I is now being excavated. The gravel pits are located in the alluvial plain of the Morava River, on the right bank , at distances from 100 to 300 m from the river. Since the water table in gravel pits is flat and there is a clear evidence of hydraulic connection of the ground water between pits and the gravel aquifer, important impacts on the ground water levels in the areas surrounding pits were expected. Disturbing the natural hydraulic gradient by the flat ground water table area should result in forming inflow and outflow sides of open pits with respect to ground water flow to/from the pit. The questions of maximum decline and rise of the ground water table, observable distances of ground water level changes from the pits, and changes in hydraulic gradient are aspects of the impacts to the ground water as a consequence of aquifer characteristics. The ground water flow from the aquifer to open pits where the ground water is exposed to the atmosphere should result in changes of redox conditions and possible changes in the chemical composition of the ground water re-entering the aquifer at the outflow sides of pits.

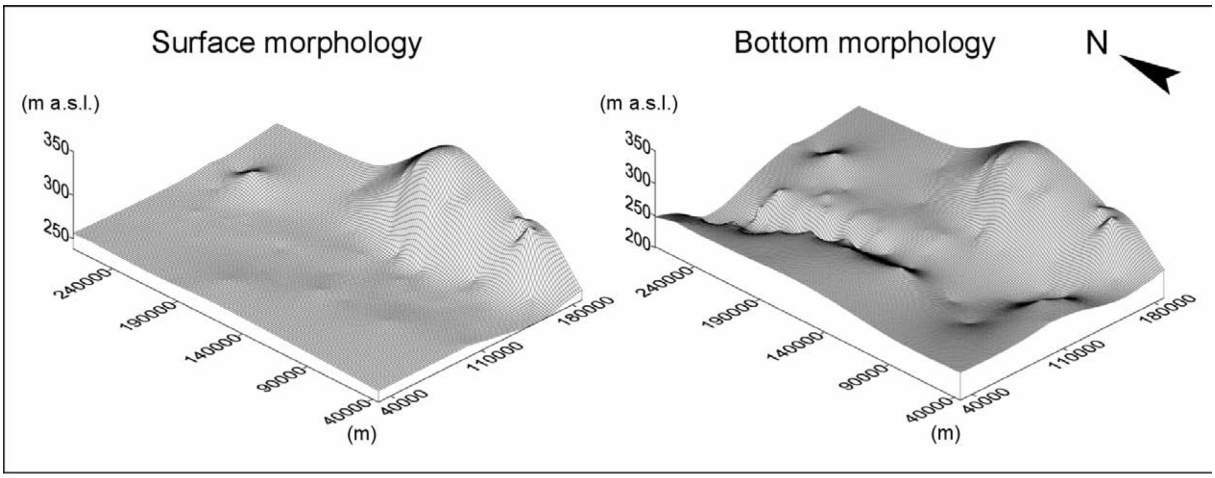
Many investigations aimed at prospecting gravel resources and ground water supply, respectively, were carried out from the 1960s until the 1990´s at the observed site. The detailed geological surveys and hydrogeological measurements in both different stages of mining and prior to mining enable a unique assessment of the impacts of open gravel pits on ground water.

Figure 1 *Locations of observed gravel pits*



Methods
Numerical computer modeling with PMWIN (Chiang and Kinzelbach 2000) was used to determine the changes of the ground water table around the pits. The computer model covers an area of more than 20 km^2. There are 45 600 cells in 3 layers in the numerical model. Basic size of cells is 20x20 m, in the area surrounding the pits but, where increased hydraulic gradients were expected, the cells are refined up to 2x2 m. The geological setting of the wider area was used to set the boundary conditions and the geometry of the layers. The gravel accumulation fills the palaeochannel of the Morava River which follows the regional fault structure with NNW – SSE direction (Fig. 2). The total thickness of the gravel accumulation varies between 5 to 50 m.

Figure 2 *Top of the first t layer and bottom of the third layer in the computer model*

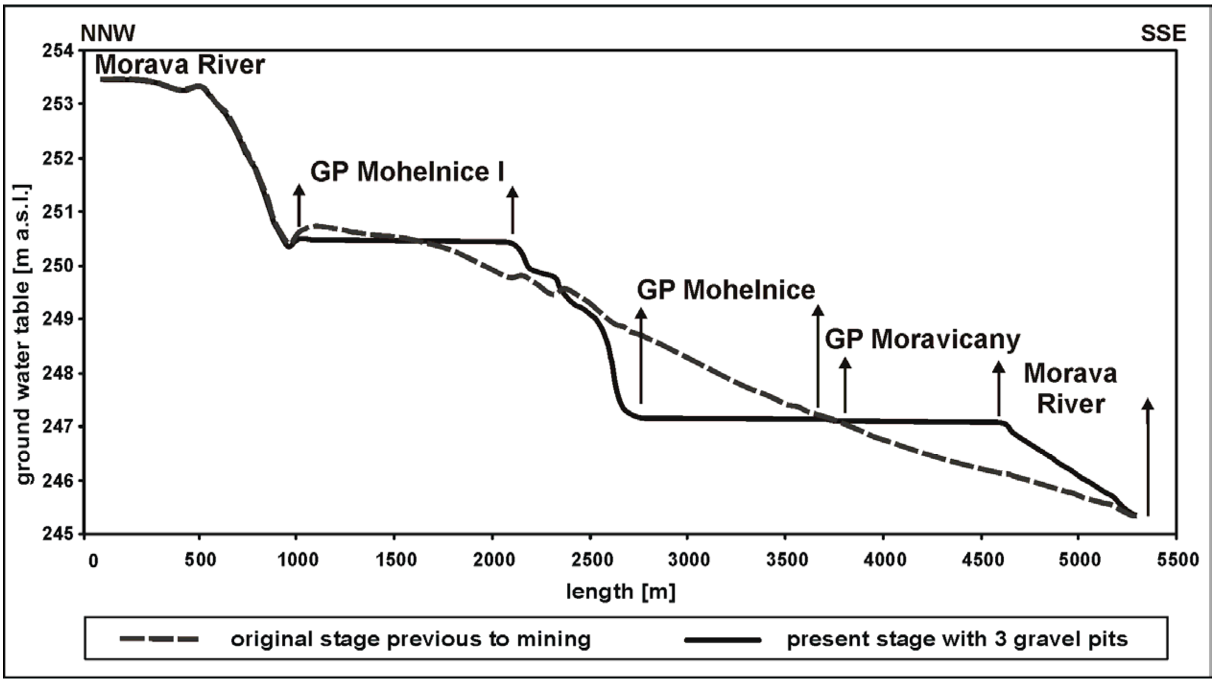


The boundary conditions were carefully chosen to simulate ground water inflow and outflow from the area. Only results of the steady-state simulations for the average ground water stages are discussed in this paper. Ground water levels in three basic stages were simulated. The first one represents the stage previous to mining, when the Morava River was in its natural meandering channel. The second stage is from 1965, when the southern and the middle open pits (the GP Moravicany and the GP Mohelnice) were present and the Morava River was already in the artificial channel. This stage corresponds to the

stage evaluated by Kouril (1970). Ground water table levels from 24 boreholes were used for the verification of the model for this stage. The third modeled stage differs from the second one by the presence of a third open pit, the GP Mohelnice I. Data acquired from the field measurement of ground water and surface water levels at more than 160 boreholes, drainages and selected points in the Morava River were used for the model calibration of this stage.
Geochemical modeling with Geochemist´s Workbench (Bethke 2005) was performed to assess the changes of the ground water chemical composition. Background chemistry of ground water from selected boreholes at inflow sides of open pits was selected as the input chemical composition for modeling. The modeling was focused on the changes of the ground water composition along the flowpath, as the ground water flows from the aquifer to open pit.

Results and discussion
Results of numerical computer modeling confirm a strong impact of open gravel pits on ground water. The typical characteristic of the flow net for the original stage previous to mining are relatively stable values of hydraulic gradients all over the area. The homogenous characteristic of the aquifer is the main reason. Ground water flow directions are in general from NNW to SSE, parallel to the Morava River channel. The Morava River forms the drainage base of the aquifer; the channel is keeping the gaining characteristic all over the observed area. Ground water levels parallel to the principal flow directions are shown in Figure 3.

Figure 3 *Cross-section of ground water table through the gravel pits*



The presence of open pits with a flat ground water table dramatically changes flow net characteristic in observed area. The original homogenous distribution of hydraulic gradient values was significantly disturbed. Since the ground water level is kept by weir at 247 m a.s.l. and pits are connected by channel, the open pits are becoming drainage bases of the adjacent aquifer. Currently, the Morava River loses its gaining characteristic and becomes a losing river over the distance of a few hundred meters. However, changes in drainage characteristic of the Morava River are caused by both mining activities and artificial changes in the Morava River (shortening of the channel and weir construction). The changes of ground water levels are observable over distances of 2 500 metres from the pits. Results confirm the formation of separated inflow and outflow sides at the open pit/aquifer interface. The ground water from the aquifer is drained at the inflow sides into the open pit space. From the open pit space, the ground water returns to the aquifer at the outflow sides of pits. However, part of water entering the pits is lost by weir overflow and evaporation. For the simulated stage, water budget calculations show the total ground water inflow to pits about 60 L/s. The volume of water corresponding to 3 L/s is lost by evaporation, 12 L/s is lost by the weir overflow and 45 L/s re-enters the aquifer. Comparison of the ground water levels for original and present stages in cross section through all gravel pits is shown in Figure 3. The maximum ground water table decline in cross-section is -1.7 m; the maximum ground water table rise is +1.0 m. The ground water table decline is related only to parts of the aquifer adjacent to the inflow sides of pits, while the ground water table rise is related only to the parts of the aquifer adjacent to the outflow sides. However, keeping the ground water level in open pits at a regulated level shortens the distance of impact to the ground water table. It decreases the maximum rise of ground water table in the aquifer adjacent to the outflow sides. The changes of ground water levels are relatively small. This is affected by the short distance of open pits to the boundary condition formed by the Morava River channel. However, in parts of the aquifer westward from the open pits, the decline of ground water levels is much higher and reaches -3.0 m compared to the stage previous to mining.

The inflow of ground water from aquifer to open pit results in changes of the ground water chemical composition. Increase of the O_2 pressure to the atmospheric concentration and the decrease of the CO_2 pressure to the atmospheric concentration and current increase of Eh values are the main processes affecting the change in the ground water chemical composition. The modeling indicates precipitation of a few minerals in open pits. Compared with the background ground water chemistry, there is precipitation of 140 mg of calcite, 3 mg of amorphous $Fe(OH)_3$, 0,2 mg of pyrolusite from 1 litre of water and increase of pH values from 7,1 to 8,2 in the open pit. Currently, Fe and Mn concentrations in ground water decrease from 1,5 to $2{,}5\times10^{-9}$ mg/L and from 0,15 to $4{,}3\times10^{-12}$ mg/L. Ground water chemistry in supply wells close to the outflow side of the GP Moravicany confirms the results of this geochemical modeling.

Conclusions

Numerical computer modeling has confirmed strong impacts of open pits on the ground water table. The open pits affect ground water flow direction and cause a local increase of hydraulic gradient. As the result of a flat ground water table in the open pit, separated inflow and outflow sides (with respect to ground water flows into and out from the pit) are formed at the pit/aquifer interface. The ground water table declines in parts of the aquifer adjacent to inflow sides, while it rises in parts of aquifer adjacent to outflow sides. The values of maximum decline and rise of ground water table, respectively, depend on the length of the pit parallel to principal ground water flow direction and on the position of aquifer boundary conditions. At the observed site, the maximum decline of the ground water table is -3 m, while the rise is +1 m. The changes in ground water levels are observable over a distance of 2 500 m from the pits. Changes of the ground water chemistry inside the open pits simplify the treatment of ground water used for supply in cases with higher Fe and Mn concentrations in aquifer. However, the impact of open gravel pits on ground water should not be marked /taken?as the regional impact.

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