Groundwater flow model of the Estonian oil shale mining area towards to innovative system

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Abstract In the following decade in Estonian oil shale deposit there are expected changes in groundwater regime while the new mine sites are planned to open and where the oil shale reserves are ending as the areas will be flooded. Here described research is developing dynamic groundwater flow model using Visual ModFlow 4.2 software. A structured MS Access database of observation wells was created. Hereby is presented a three dimensional groundwater elevation map of the Estonian oil shale mining area, a preliminary estimations of water inflow into working underground mine from closed and water filled mine side was extracted.

Key Words oil shale, mine water, modelling

Introduction For the mining activity at Estonian oil shale deposit the groundwater level of Keila-Kukruse aquifer is decreased below the oil shale layer down to 30...80 meters. That creates cone of depression 2...5 kilometres. Beside the influence on to environment through changing groundwater elevation, mine dewatering is expensive for the mining companies. At previous year 2009 Eesti Energia Mining Company removed ca 260 million m³ water, per produced oil shale tonnage was necessary to remove 15.2 m³ water. Taxes on used ground- and drinking water has increasing trend and at previous year approximately 90 mln Estonian kroons was paid (Figure 1).

Groundwater flow models at mining area are nowadays frequently used to estimate the situation and find solutions for the problems described. However, modeling is a challenging task at geologically disturbed area where hydraulic properties are changed from the initial condition, water flow at voids are turbulent and therefore mine water models are comparatively complicated (Wolkersdorfer, c. 2008). A strategy for modelling groundwater rebound and its difficulties using standard techniques of modeling in abandoned mine systems are described by Adams and Younger (2001). Here discussed research is developing a dynamic groundwater flow model of mining area at the Estonian oil shale deposit. The scope is to obtain the groundwater flow capacities and main inflow locations into working mines. Further scope would be the possible solutions of new mine site dewatering, choosing location and capacity of pumping stations and water inflow reduction possibilities. The approach visualising groundwater increase and mine floods at oil shale mine that will be closed down, has not given good results for today.

Figure 1 Taxes on water usage are increasing; mine dewatering rate is high per produced oil shale tonnage

Wolkersdorfer & Freund (Editors) 47
Methodology

Model includes the mining area of oil shale deposit at north east of Estonia (Figure 2). There are nine closed underground mines, five active mine sites – Viru and Estonia underground mines, Aidu with two smaller open casts Vanaküla and Põhja-Kiviõli. Closed mine sites are mostly water filled and is source of water inflow into working mine sites (Reinsalu et al., 2006). Middle of the area crosses karst zone. At western area the new mining permissions are applied, Ojamaa started to filled and is source of water inflow into working mine sites (Reinsalu et al., 2006). Middle of the area is defined into model with higher conductivity at very-tilt scale. It was difficult to define the void spaces that underground mining creates while the dry model cells act as impermeable wall. Here was used a high conductivity value 999 m/d and specific yield value equal to one while all the water could be yielded from the defined area. There

Figure 2 Location of the analysed area
was activated a cell rewetting option to allow to wet initially dry grid cells. Hydraulic properties were adjusted during process of calibration.

A boundary condition of recharge is added into model zones as percentage of monthly precipitation rate: Aidu and Vanaküla opencast with 63%, Kohtla, Mine no 2 and Sompa underground with 41%, Ahtme 40%, Tammiku 44% and Viru 42%.

Results

Model run was done at the dynamic regime using Geometric Multi Grid Solver of ModFlow 2000 engine as advised for complex and large system that the mined out area is. Steady state regime had problems with convergence of the model calculations. During several test runs the model was calibrated with correlation coefficient 0.97 and maximum residual of calculated and observed water level elevation of -1.57 m of all the calibration points. The calibration procedure was a difficult task to achieve the model behaviour on to realistic groundwater flow, the variation at input parameters can be varied by different parameters and at large ranges. After the model calibration some preliminary results are extracted. A three dimensional view of a water table is presented on Figure 3. There can be seen the disturbances at mined out area whereas the groundwater table is decreased.

To see the water flow directions, a velocity map is provided at Figure 4 describing the water inflow into Estonia underground mine. There were extracted water flow capacities from the side of closed Ahtme underground mine. At previous analyses the water inflow was calculated 6.48-10⁶ m³ annually (17·10³ m³/day; Reinsalu et al., 2006). With groundwater modeling the calculations received higher rate than previously, 27·10³…42.8·10³ m³/day. There was tested variations of storage values and conductivities at separate model runs, but the difference between the described case was insignificant – 20…80 m³/day. Following research should test a variable rate of recharge.

Table 1 Used ranges of hydraulic properties at the model

<table>
<thead>
<tr>
<th>Model zone</th>
<th>Geological unit</th>
<th>Model layer</th>
<th>K (m/d)</th>
<th>Sy (-)</th>
<th>Ss (m³/ )</th>
</tr>
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<tbody>
<tr>
<td>North</td>
<td>Quaternary</td>
<td>L1</td>
<td>0.1…3.6</td>
<td>0.32</td>
<td>0.068</td>
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<tr>
<td></td>
<td>L2</td>
<td>3…50</td>
<td>0.4</td>
<td>0.1…0.012</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>L4</td>
<td>2…10</td>
<td>0.09</td>
<td></td>
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<td>South</td>
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<td>L1</td>
<td>0.1…3.6</td>
<td>0.32</td>
<td>0.068</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>2…9</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L4</td>
<td>2…10</td>
<td>0.05</td>
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<td>0.019</td>
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<tr>
<td>Mined out area</td>
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<tr>
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<td>0.004</td>
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<td>999</td>
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<td>0</td>
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<tr>
<td>Karst</td>
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<td>0.1…3.6</td>
<td>0.32</td>
<td>0.1…0.068</td>
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<tr>
<td></td>
<td>L2</td>
<td>Xₖ, Xₜ= 50, Kₚ≥500</td>
<td>0.36</td>
<td></td>
<td>0.022</td>
</tr>
</tbody>
</table>

Figure 3 Groundwater table of Keila-Kukruse aquifer at time step 730 days (December 2009)
Conclusions

Groundwater issues concerned with mining remain before the new mine site will be opened, during the mine operating and after the closure as the initial situation is disturbed. Here described groundwater flow model was calibrated and three dimensional visualisation materials were created; preliminary water flow capacities were extracted and found higher water inflow from the closed underground side than previous analysis. However, during modeling the difficulties concerned with defining mine void hydraulic properties was faced. The further research and model development at predictive state while new mine sites are opened and old areas are closed and flooded will be a challenging task for the innovative system approach.

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