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 m^3 water, per produced oil shale tonnage was necessary to remove 15.2 m^3 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.

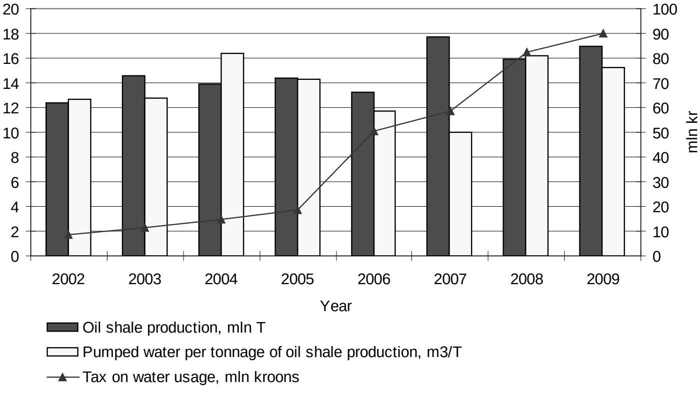


Figure 1 *Taxes on water usage are increasing; mine dewatering rate is high per produced oil shale tonnage*

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 etc, 2006). Middle of the area crosses karst zone. At western area the new mining permissions are applied, Ojamaa started to dewater at 2008 and Uus-Kiviõli environmental impact assessment is going on. Analysed time period is from January 2008 until December 2009 considering Ahtme underground mine closure at 2002 where the groundwater table has increased and stabilised to the pre-mining level.

The concept of the hydrogeological conditions was completed at previous research (Reinsalu etc, 2006) and during collection of the available information, review of previous analyses (Savitski, Savva 2001, 2009). Model area includes 1650 km^2 of oil shale deposit at north east of Estonia within 330 km^2 of mined out land. Model has 4 layers – upper quaternary layer has average thickness 4.7 m; second limestone layer thickness varies at ranges 0…95 m increasing to the south. Third oil shale layer has average thickness 2.7 m and bottom clayey layer is defined as no flow or impermeable layer to reduce convergence problems instead of using very low conductivity.

There are 28 observation wells used as calibration points (Figure 2) with the Keila-Kukruse aquifer ground water table elevation. The data of observation wells is gathered into MS Access database linked with geographical information by MapInfo professional software (Lind, H etc 2008). Database is used for the overview of the observation well (aquifer, depth, coordinates, average water table per year etc), record continuously observed water table head values and extract the needed information for groundwater model. Created database allows extracting output at structured format and change the start time of the observed head values for different groundwater models as the calendar time is necessary to convert into time steps starting from zero.

The model includes 35 pumping stations of active mine sites, average pumping capacity for Estonia mine is 260·10^3 m^3, Viru mine 70·10^3 m^3 and Aidu open cast removes 190·10^3 m^3 groundwater per day.

Hydraulic properties – conductivity and storage values for each model layer are defined in the four model zones described at Table 1. Conductivity values are applied from the previous analyses and literature (Savitski, Savva 2001 and 2009; Reinsalu etc 2006; Perens, 1997). Specific yield (Sy) parameters are based on literature by Weight, Sonderegger (2000) and specific storage (Ss) was calculated by using ratio of specific yield (equal to effective porosity) to layer average thickness (Fitts, 2002; Waterloo Hydrogeologic, Inc 2005). Karst occurs in the middle of area, divides the area into northern and southern part and is defined into model with higher conductivity at vertical 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

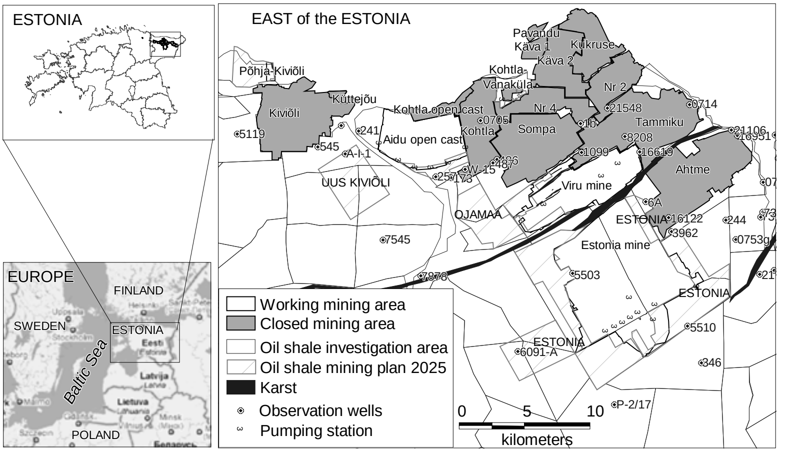


Figure 2 *Location of the analysed area*

***Table 1** Used ranges of hydraulic properties at the model*

Model zone	Geological unit	Model layer	K (m/d)	Sy (-)	Ss (m^{-1})
North	Quaternary	L1	0.1...3.6	0.32	0.068
	Limestone	L2	3...50	0.4	0.1...0.012
	Oil shale	L4	2...10	0.09	0.035
South	Quaternary	L1	0.1...3.6	0.32	0.068
	Limestone	L2	2...9	0.1	0.1
	Oil shale	L4	2...10	0.05	0.019
Mined out area	Quaternary	L1	30...70	0.4	0.053
	Limestone	L2	15	0.4	0.004
	Oil shale	L4	999	1	0
Karst	Quaternary	L1	0.1...3.6	0.32	0.1...0.068
	Limestone	L2	Kx, Ky= 50, Kz=500	0.36	0.022
	Oil shale	L4			

was activated a cell rewetting option to allow to wet initially dry grid cells. Hydraulic properties were adjusted during process of calibration.

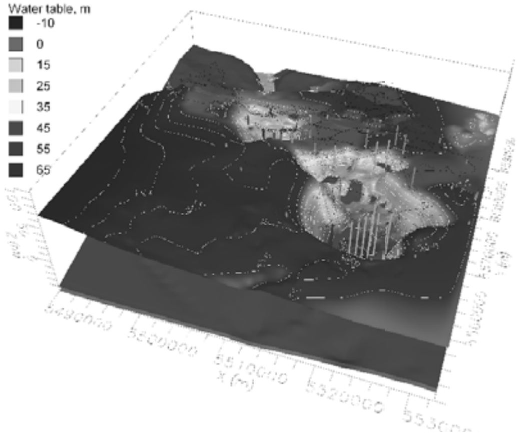
A boundary condition of recharge is added into model zones as percentage of monthly precipitation rate: Aidu and Vanaküla opencast with 63%, Kohtla, Mine No 2 and Sompa underground with 41%, Ahtme 40%, Tammiku 44% and Viru 42%.

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 $6.48 \cdot 10^6$ m^3 annually ($17 \cdot 10^3$ m^3/day; Reinsalu etc, 2006). With groundwater modeling the calculations received higher rate than previously, $27 \cdot 10^3 ... 42.8 \cdot 10^3$ m^3/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 m^3/day. Following research should test a variable rate of recharge.

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



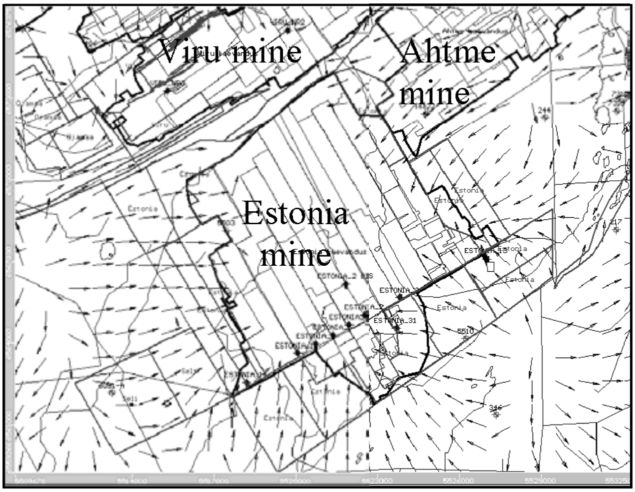


Figure 4 *Example of water inflow into working Oil shale underground mine Estonia at December 2009*

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 analyse. 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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References

Wolkersdorfer, C. 2008. Water Management at Abandoned Flooded Underground Mines. Springer Berlin Heidelberg. 129—140 p

Adams, R., Younger, P L. 2001. A strategy for modelling ground water rebound in abandoned deep mine systems. Ground Water 39(2): 249–261

Reinsalu E., Valgma I., Lind H., Sokman K (2006). Technogenic water in closed oil shale mines. Oil Shale Vol. 23. Estonian Academy Publishers, 46—48 p

Savitski, L., Savva,V. (2009) Predictions of hydrogeological changes due to opening of Uus-Kiviõli underground mine and closure of Aidu open cast. Estonian Geology Fund. [in estonian]

Savitski, L., Savva,V. 2001. Predictions of hydrogeological changes at Estonian oil shale mining area. Phase I-III: Closure of Kohtla, Aidu open cast and Ahtme underground mines Estonian Geology Fund. [in estonian]

Lind, H., Robam, K., Valgma, I., Sokman, K. (2008). Developing computational groundwater monitoring and management system for Estonian oil shale deposit. Geoenvironment & Geotechnics (Geoenv08). Heliotopos Conferences. 137 – 140 p.

Perens, R., Vallner, L. 1997. Geology and mineral resources of Estonia. Estonian Academy Publishers. P. 137–145.

Weight, D., Sonderegger, J.L. (2000). Manual of applied field of hydrogeology. New York: McGraw-Hill.

Fitts, C.R. (2002) Groundwater science. Academic Press. Elsevier Science Ltd. P.

Waterloo Hydrogeologic, Inc (2005). Visual ModFlow version 4.1 user's manual.