EVALUATION OF CONTAMINATION BY USING HYDROGEOLOGICAL MODEL FOR THE INCUKALNS AREA, LATVIA

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ABSTRACT

In the Incukalns area (Latvia), the Devonian sandstone aquifer is heavily polluted by emissions of sulphur sludge pools. In 1998, a hydrogeological model (HM) for the place has been created and rough prognoses of contaminant migration in groundwater have been obtained. In 2004-2005, this model has been considerably improved in order to find the best methods of stopping pollution plumes and of lessening their impact on the local environment. Improved HM is described and the new results obtained are presented.

INTRODUCTION

From 1956 to 1981, the Oil Processing Factory of Riga created annually about 16,000 tonnes of highly toxic waste. This sludge consisted of tar, asphalthens, H_2SO_4, surface active components (SAC) and other hazardous substances. The waste was discarded into two abandoned sand – pits located at the Incukalns village. The pits become waste pools, each covering about 1.3 ha. The pools were informatively named the Northern and Southern ones, which were formed during 1956 – 1965 and 1964 – 1981, accordingly (Aleksans et al., 1993). In 2005, the pools still acted as old hazardous sources and their pollution plumes were expanding.

The waste from the pools leaked downward from the sandy Quaternary aquifer *Q* into the Devonian sandstone aquifer *D3gj2*. There dissolved waste was migrating downgradient towards the Gauja river. Fortunately, for both pools, contaminated areas of the *Q* aquifer now are limited and practically motionless. In centres of the still expanding plumes of the *D3gj2* aquifer, concentrations of the anion SO_4 and SAC reach 4,500 mg/l and 100 mg/l, respectively (Figure 1 for the SO_4 plumes).

In Latvia, the maximal allowed concentrations (MAC) for SO_4 and SAC are 150mg/l and 0.02mg/l, accordingly. Therefore, the observed maximal concentrations for SO_4 and SAC exceed MAC, correspondingly, 30 and 5000 times. These two pollutants are the most important, because the amount of SO_4 in groundwater is the largest one and the SAC concentration exceeds MAC very much.

In 1998, rough prognoses of the SO_4 and SAC migration have been obtained by applying HM (Spalvins et al., 1999). In 2004 – 2005, this model has been considerably improved, in order to obtain information needed to remediate the contaminated place (Report, 2005a). In the paper, reasons for improving of HM are described and the results of modelling are presented.

DESCRIPTION OF HYDROGEOLOGICAL MODEL

The model of 1998 covered the 8 km × 12 km area. The model accounted for four aquifers (*Q*, *D3am*, *D3gj2*, *D3gj1*) and for two boundary condition surfaces (the maps of landscape elevations ψ_{rel} and the fixed head distribution ψ_{D2ar} of the *D2ar* aquifer) on the HM top and bottom, respectively. Formally, the maps ψ_{rel} and ψ_{D2ar} also represented aquifers. These six aquifers were separated by five aquitards (*aer*, *gQ*, *D3gj2z*, *D3gj1z*, *D2br*) where the *aer* aquitard was a formal substitute of the unsaturated aeration zone of the Q aquifer. On the four vertical sides of HM, the piezometric boundary conditions were specified.

The REMO system (Spalvins et al., 1996) was used for creating and calibrating of HM. The final results provided Groundwater Vistas (GV) system (Environmental Simulations, 1997) where the MODFLOW model supported HM. Contamination migration prognoses were obtained by the MT3D'96 code as part of the GV system.

Although, the first HM version provided valuable results (Spalvins et al., 1999), the following drawbacks, regarding contaminant migration modelling, were discovered:

- it was impossible to account for three dimensional (3D) nature of contaminant migration in the *Q* and *D3gj2* aquifers, because they were represented by one grid plane each; in the *Q* aquifer, the real depth of the Northern waste pool, as the pollution source, was not accounted for;
- when applying the MT3D'96 system, the quasi – 3D approximation scheme was used; for this reason, the

system was not able to provide quite correct results of the contamination transport;

- the MT3D'96 version included a lot of errors and it also was not able to provide correct results for longer time periods.

Improved HM was built by using main parameters (area, approximation step, geometry of strata) of basic HM. The following necessary changes were made:

- the *Q* and *D3gj2* aquifers were divided in the three subaquifers Q_1, Q_2, Q_3 and *D3gj21*, *D3gj22*, *D3gj23*, correspondingly (Figure 2); the subaquifers Q_2 , Q_3 and *D3gj21*, *D3gj22* had equal thicknesses, thin Q_1 subaquifer existed only in the vicinity of the pools; the thickness of the *D3gj23* subaquifer was 10 metres;
- the *D3am* and *D2ar* aquifers were excluded from HM, because the *D3am* aquifer was nonexistent in areas of the waste pools and the *D2ar* aquifer had small impact on contaminant migration processes; therefore, the bottom surface of the D3gj1 aquifer was set impermeable;
- accuracy of permeability maps of geological strata was improved and boundary conditions of the HM edges were adjusted, in order to obtain concurrence of migration trends for the modelled and observed pollution plumes (Report, 2005b);
- for the enhanced GV system (Environmental Simulations, 2003), the 3D scheme was used and the next MT3D'99 version (Zheng, 1998) was applied.

Calibration of HM was accomplished by using the REMO and GV systems, because the hydraulic and transport parameters were interdependent. It was rather difficult to match observed and simulated paths and velocities of migration. For example, the youngest Southern pool plume had covered almost the same distance, as the oldest Northern one. However, the hydraulic gradient at the Southern pool area was considerably smaller than for the Northern one. To obtain the observed velocity of the Southern pool plume, it was necessary to enlarge the permeability of the *D3gj2* aquifer for the pool area.

It was important to obtain the variable infiltration flow for the HM area, because the flow had considerably influence on the groundwater table of the *Q* aquifer. The flow differs considerably for the areas of the pools (~100 mm/year and ~400 mm/year for the Northern and Southern pool, accordingly) and this fact results in diverse waste dissolution for the pools. Due the original method of simulating of the infiltration flow (Spalvins et al., 1996, Spalvins et al., 2004) it was possible to obtain the complex flow by applying the ψ_{rel} map, as the boundary condition. Then the infiltration was computed by HM.

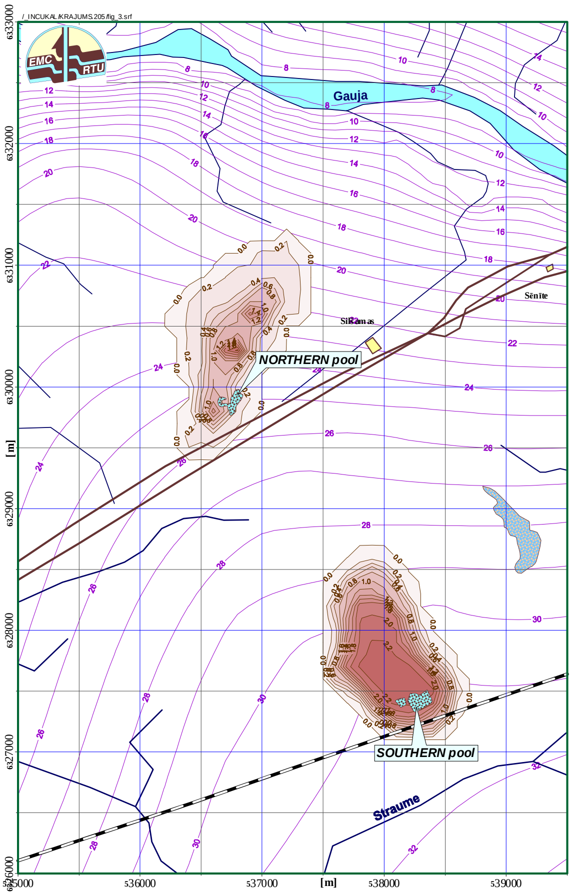

Figure 1: A fragment of the model. Distribution of the head [m asl] for the *D3gj22* subaquifer. The SO_4 concentrations [g/l] are shown, the year 2005

Main tasks to be solved by HM were, as follows:

- to evaluate current parameters for the SO_4 and SAC plumes of the *D3gj2* aquifer;
- to obtain prognoses for the no sanitation case; to test effectiveness of various sanitation methods.

CURRENT PARAMETERS OF CONTAMINATION PLUMES

Current parameters (year 2005) were obtained by using observed concentration distributions of SO_4 and SAC as initial data. For SO_4, its stratification under impact of gravity was accounted for by specifying initial concentrations in the subaquifers *D3gj21*, *D3gj22*, *D3gj23* at the ratios 0.7:1.0:2.0, accordingly. For SAC, the concentrations at these subaquifers were set equal. In Figure 1, the observed SO_4 concentrations are shown for the *D3gj22* aquifer (Report, 2005b). It was assumed that contours of the SO_4 and SAC plumes coincided. The value 0.27 of porosity was applied. No sorption of SO_4 and SAC and no destruction of SO_4 were accounted for. For SAC, the half life time value $t_{0.5} = 15$ years was used to simulate destruction of this substance.

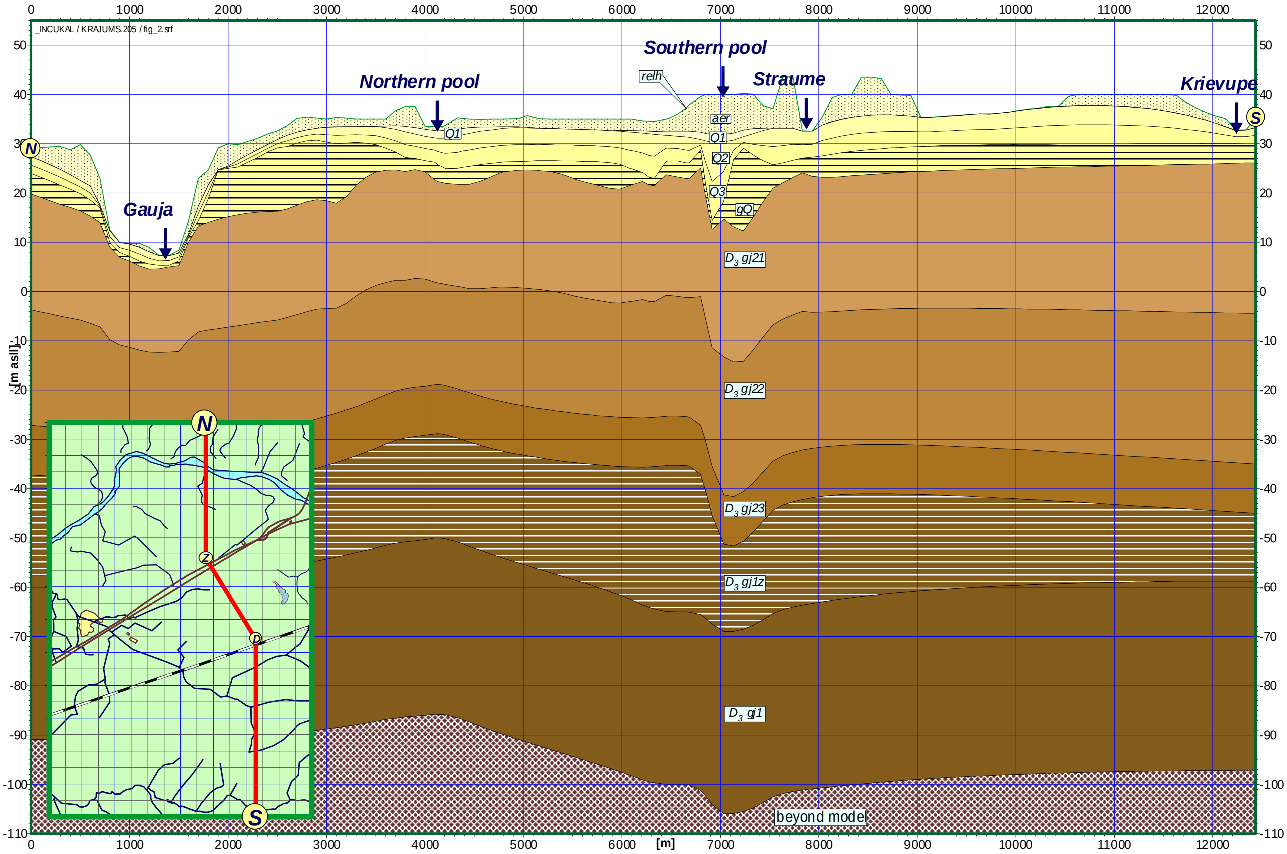

Figure 2: The geological cross section N_Z_D_S drawn through the Northern and Southern pools

Table 1: Current parameters (year 2005) for the SO_4 and SAC plumes in the *D3gj2* aquifer

Nr.	Parameters	Northern pool	Southern pool
1.	existence time of pool [years]	50	40
2.	after what time will contamination reach Gauja river [years]	25	65
3.	mean migration speed till 2005 [m/year]	28	44
4.	mean migration speed a from 2005 till 2030 [m/year]	50	46
5.	contaminated area [ha]	148	139
6.	volume of contaminated groundwater [$10^6 m^3$]	17.65	18.73
7	mass of SO_4 [10^6kg]	9.1	24.8
8.	mean concentration of SO_4 [mg/l]	515	1320
9.	mean outflow of SO_4 from pool [kg/day]]	500	1700
10.	mass of SAC [10^6kg]]	0.106	0.131
11.	mean concentration of SAC [mg/l]	6	7
12.	mean outflow of SAC from pool [kg/day]]	18	20

The main tracks of the simulated contaminant migration versus time were obtained by the MODPATH system (part of GV). Areas and volumes of the plumes were computed by using the SURFER system (Golden Software, 1997). The mean concentration c_m of a the pollutant carried by a plume was computed as c_m =mass/volume of the pollutant.

In Table 1, the current parameters for the SO_4 and SAC plumes are summarized. The following conclusions can be drawn from considering these data:

- the plumes of the Northern and Southern pools will reach the Gauja river after 25 and 65 years, accordingly; since 2005, the Northern pool plume will move faster, due to the larger hydraulic gradient of the groundwater flow in vicinity of the river (Figure 1);

- the geometrical parameters of the both plumes are almost equal: the area ~ 150 ha, the volume ~ $18 \cdot 10^6$ m^3;
- the mass of SO_4 for the Southern pool plume is larger than for the Northern one ($24.8 \cdot 10^6$ kg > $9.1 \cdot 10^6$ kg) because the mean outflow of SO_4 for the Southern pool is larger (1700 kg/day > 500 kg/day);
- the mean concentration of SO_4 (500 – 1300) mg/l exceeds MAC (3.3 – 8.7) times;
- the mean concentration of SAC (6 – 7) mg/l is much larger (325 times) than MAC.

It follows from the above data that the Northern pool SAC plume presents the main danger for the Gauja river that runs nearby the well fields Remergi and Baltezers providing drinking water for the Riga city. Both contaminant plumes are causing serious problems also for inhabitants of the Incukalns area. For this reason, cleaning of the Northen plume is planned in the near future and sanitation methods of the polluted place are to be simulated to find the best ones.

INVESTIGATION OF SANITATION METHODS

Three main sanitation methods were considered:

- withdrawal from the *D3gj2* aquifer of polluted groundwater, its cleaning and reinfiltration into the aquifer;
- blocking of the infiltration flow for the pool areas, in order to reduce the waste dissolution rate;
- excavation of the waste pools.

Firstly, the worst case (no sanitation) was considered, when the Northern and Southern pool plumes would reach the Gauja river approximately after 25 and 65 years, respectively. Each plume will enter the river into ~ 500 m wide zone where the groundwater flow is ~1000 m^3/day. For these zones, the computed mean SO_4 and SAC concentrations are, correspondingly, 400 mg/l; 2 mg/l and 300 mg/l; 0.15 mg/l, for the Northern and Southern pool plumes (Table 2). These values are lower than the initial ones (year 2005) due to dilution of pollutants and destruction of SAC. However, the quality of groundwater there is far from the one obligatory for drinking water, especially, for the Northern plume SAC fraction (2 mg/l » 0.02 mg/l).

The effect of dilution on the practically steady SO_4 concentration distribution (year 2045), for the subaquifers *D3gj21*, *D3gj22*, *D3gj23*, was shown in (Report, 2005). For the two upper subaquifers, especially, for the *D3gj21* one, the concentrations have strongly descreased, in comparison with the initial ones (year 2005). Such a considerable change is due to the flow of water entering the *D3gj2* aquifer through the *gQ* aquitard. Therefore, the improved model has provided the 3D image of the SO_4 concentrations accounting for the dilution processes of the pollutants. This result also confirms the observed fact that the SO_4 concentration is the highest one in the *D3gj23* subaquifer (Aleksans et al., 1993).

To stop migration of contaminants, polluted groundwater should be pumped out from the *D3gj2* aquifer to be cleaned by a overground equipment and reinfiltrated back into the aquifer. For the current stage of investigation, only rough parameters of this approach were sought and the following results were obtained:

- at least, two discharge wells should be used with the total pumping rate ~ 3000 m^3/day = 1500 m^3/day × 2; the wells should be situated in these front area locations of the plumes where contaminant concentrations are high enough;
- no less than three wells for reinfiltration of cleaned water (~ 3000 m^3/day) should be located before the river; the distance between the discharge and recharge lines should be 500 - 700 m.

Table 2: Parameters accounting for sanitation of the Incukalns place

Nr.	Parameters	Northern pool	Southern pool
1.	mean SO_4 concentration for first inflow into river (no sanitation) [mg/l]	400	300
2.	mean SAC concentration for first inflow into river (no sanitation) [mg/l]	2.0	0.15
3.	pumping – infiltration rate stopping contaminant migration [m^3/day]	3000	3000
4.	mean SO_4 recovery rate during first three years [kg/day]	1700	5200
5.	mean SAC recovery rate during first three years [kg/day]	40	30
6.	reduction of contaminant outflow from pool if its infiltration flow is blocked [times]	1.3	1000

For the both pools, such a system stops and remediates their contaminant plumes. To make modelling simpler, it was assumed that cleaned water contains no contaminants

In Figure 3, the disposition of discharge and recharge wells is shown for the Northern pool plume. In the area of the plume, the mean hydraulic gradient has increased 1.5 times and this factor accelerates remediation of the plume.

During the first three years, the following mean SO_4 and SAC recovery rates are expected, accordingly, 1700 kg/day; 40 kg/day and 5200 kg/day; 30 kg/day, for the Northern and Southern pool plumes (Table 2).

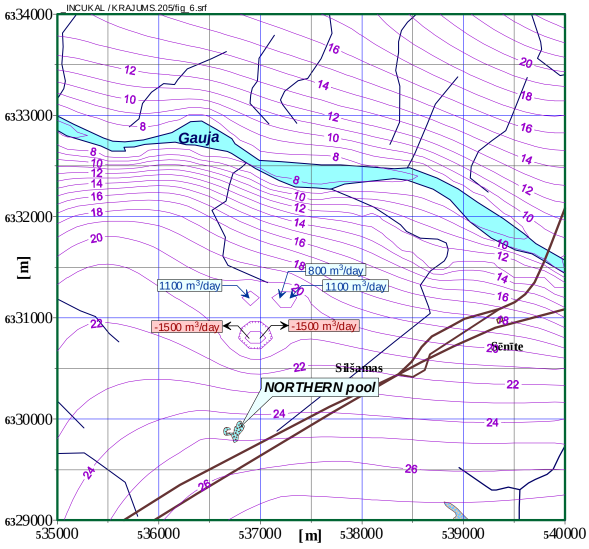

Figure 3: The scheme used for sanitation of the Northern plume. The changed distribution of piezometric levels [m asl] for the *D3gj2* aquifer is shown

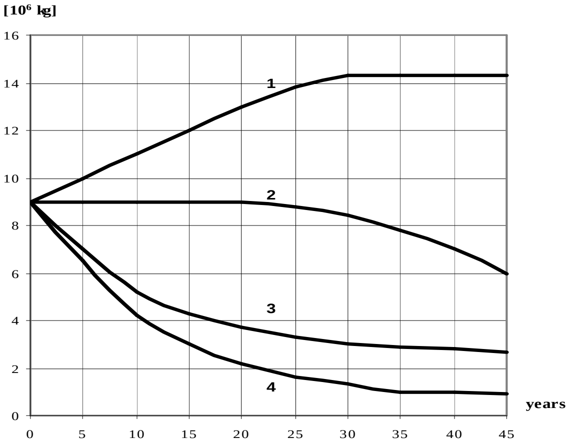

Figure 4: The SO_4 mass [kg] versus time in the D3gj2 aquifer for the Northern pool plume. No sanitation (graph 1); excavation only (graph 2); no excavation, cleaning of plume (graph 3); excavation and cleaning (graph 4)

If the disposition and pumping rates of the remediation system remain fixed then recovery for contaminants should decrease versus time. To restore the rates, the system of wells should be moved upgradient to areas with higher contaminant concentrations.

The factor of reducing the contaminant outflow from the pools by blocking their infiltration flows is 1.3 and 1000 times for the Northern and Southern pools correspondingly. The lower part of the Northern pool is located into the Q_1 subaquifer, and for this reason, blocking of infiltration (~ 100 mm/year) has such a small effect on the waste dissolution there. The Southern pool lays into the aeration zone, and only the infiltration flow (~ 400 mm/year) dissolute the waste of the pool.

However, it is not easy to block the infiltration there because the pool is still a open pit filled with the highly toxic sludge.

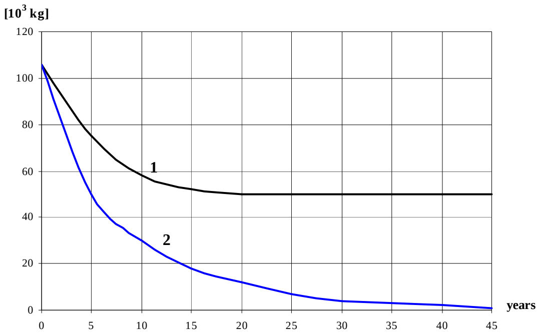

Figure 5: The SAC mass [kg] versus time in the D3gj2 aquifer for the Northern pool plume being under sanitation. The Northern pool is not (graph 1) and is (graph 2) excavated in 2005

It is not difficult to stop infiltration for the Northern pool, because it has been filled with a sand. To reduce the waste dissolution of the pool, the groundwater table here should be lowered, in order to increase the thickness of the *aer* zone, to such an extent that the pool losses contact with the Q_1 subaquifer.

Excavation of the waste pools may give only long term benefits if no remediation of their plumes is done. Then the total SO_4 mass of plumes will remain constant until they reach the Gauja river. For the Northern pool, plume it will happen after ~25 years (Figure 4, graph 2).

If the discharge and recharge wells are used for remediation then excavation of pools may considerably improve the sanitation process (Figure 4, graph 4 for SO_4; Figure 5, graph 2 for SAC).

In Figure 4, the SO_4 mass changes versus time for the Northern pool plume are shown. The graphs 1 and 2 correspond to the no-sanitation and the pool excavation cases. It follows from the graph 1 that after the pollutant enters the river, increase of the total mass of the plume stops. However, no decrease of the SO_4 mass can be expected. The graphs 3 and 4 demonstrate effectiveness of cleaning the plume if the Northern pool is not and is excavated.

For the SAC fraction, the positive effect of excavation is even more impressive. In Figure 5, the graphs of the mass change versus time for the Northern pool plume being remediated are given if the pool is not and is excavated. If the pool is not excavated then the total SAC mass decreases twice after 15 years and then remains unchanged (graph 1). The SAC mass drops faster if the pool has been excavated (graph 2).

RESULTS AND RECOMMENDATIONS

The hydrogeological model of the contaminated Incukalns place has been considerably improved and by applying the model, the following results have been obtained:

- the current parameters (year 2005) for the anion SO_4 and the surface active components of contamination plumes have been obtained (Table 1);
- the worst case (no sanitation) is considered;
- rough parameters of main sanitation methods are obtained (Table 2).

The maximal effect may be archived if cleaning of polluted groundwater takes place. Blocking of infiltration flows may considerably reduce dissolution of waste pool bodies. Excavation of pools is effective in combination with cleaning of their pollution plumes.

These results are preliminarily, because more field data and economic considerations are needed to use the methods examined. However, the model may serve as a powerful tool helping to answer many difficult questions arising during of sanitation for the Incukalns place.

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