Modelling of remedy process for the hazardous liquid waste deposit area at the Jelgava town, Latvia

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Abstract Hydrogeological modeling has been applied to simulate the principal stages of the planned sanitation of the former waste deposit area “Cosmoss” of the Jelgava town, Latvia. The Groundwater Vistas system was used for creating the necessary models and for investigating contaminant migration in groundwater.

Four hydrogeological models representing the consecutive stages of sanitation have been developed. The models have the size of 800m×800m and they contain six flat model layers (planes). The plane approximation step is 2.0 metres.

The information provided by the publication may be useful for specialists dealing with cleaning of contaminated soil and groundwater.

Key words hydrogeological model, sanitation of waste deposit area

INTRODUCTION

The former waste deposit area “Cosmos” is located in outskirts of the Jelgava town, Latvia (Fig.1). The area has been closed as an active deposit place for about 15 years. However, the process of waste dissolution and spreading into groundwater continues and the contaminated area is enlarging (Fig.2).

The decision has been made that the abandoned waste deposit site should be sanitized.

The hydrogeological modelling for the contaminated area of the hazardous liquid waste deposit area has been accomplished, in order to estimate effectiveness of the main sanitation measures proposed by the plan outlined in the report (GeoConsultants, 2005):

- clearing out of open liquid waste pools; covering the most contaminated central deposit area by a watertight sheet;
- enclosing the central area by a drainage ditch;
- introducing a watertight vertical wall, to encapsulate polluted groundwater within the central area;
- in situ cleaning of groundwater, within the encapsulated area.

To consider the above measures, it was necessary to simulate migration of contaminants dissolved in groundwater before and after the sanitation measures taken. To support the necessary groundwater models and to simulate the contaminant migration, the Groundwater Vistas system was used (Environmental Simulations, 2004).

SITE DESCRIPTION AND PARAMETERS OF THE MODEL

The ground surface rel of the area considered is almost even ((2 – 4) m asl), with the exception of the historical waste mound. It includes open liquid waste pools and solid waste deposits.

The groundwater table lies near (0.2 -0.7 metres) to the ground surface. The mean thickness m_Q of the sandy Quaternary Q aquifer is m_Q=5.5 metres, the permeability k_Q =2.0m/day. Below the Q aquifer, the gQ aquitard extends. Its thickness m_0=20 meters, its permeability $k_0=(10^{-4} - 8*10^{-4})$m/day (the real value k_0 is unknown). The gQ aquitard is bedded by the Devonian D aquifer. Its piezometric head $\varphi_D > \varphi_{rel}$ (φ_{rel} – elevations of the ground surface rel). Unfortunately, the real value φ_D is unknown, because no monitoring well on the deposit area reaches the D aquifer (GeoConsultants report, 2005).

In Fig. 2, the 800m×800m area of the hydrogeological model (HM) is shown. It includes zones of contaminated groundwater. The zones 6, 7 are clean.. In Table 1, parameters of the contaminated zones 1 -5 are given.

Table 1 Parametres of contaminated groundwater zonation

Zone Nr.	Area [ha]	Groundwater volume [thous. m^3]	Dissolved substances [tons]			
			Chlorides	Organic carbon	Total nitrogen	Total chromium
1.	2.3	23	90	7	16	0.01
2.	1.8	18	30	2	8	0.002
3.	7.2	72	70	7	11	0.004
4.	3.8	38	20	3	1	0.002
5.	8.9	89	30	3	0.5	0.001
total	**24**	**240**	**240**	**22**	**36**	**0.02**

The zone 1 is the most contaminated one. It covers the area of the solid waste deposit (see Fig. 3., Fig. 5). The mildly contaminated zone 5 is adjacent to the clean areas 6, 7. Although, the area pollutant spectrum is wide (report GeoConsultants, 2005), Table 1 presents data only for the four main pollutants: chlorides, organic carbon, total nitrogen, total chromium.

Due to the contaminant sedimentation, groundwater in the lower part of the Q aquifer contains larger amount of contaminants then in its upper part.

To simulate the measures of sanitation, the following parameters of steady state HM were chosen (Riga Technical University, 2008):

- the area of HM was 800m×800m;
- the plane approximation step h=2.0 metres; 3D approximation scheme was used;
- the Q aquifer was divided into four parts Q_1, Q_2, Q_3, Q_4; their thicknesses were m_{Q1}=0.5m, m_{Q2}=1.0m, m_{Q3}=2.0m, m_{Q4}=2.0m;
- six flat HM layers were used: Q_1, Q_2, Q_3, Q_4, gQ, D;
- the layer 6 (D aquifer) served as the constant head boundary condition φ_D=5.0 m asl;
- on the perimeter of the four Q – type layers, the calibrated boundary head distribution was applied;
- drainage ditches (see Fig.3) No. 1, 2, 3, 4, MD (magistral ditch) and DD (new ditch) were accounted for, as boundary head conditions, on the 1 st HM plane (Q_1);
- on the 1st HM plane (Q_1), the mean annual infiltration rate 10mm/year was used;
- the porosity value n=0.2 was used for all HM layers.

Four versions of HM groundwater table distributions were applied (see Fig.3), to estimate effectiveness of the main sanitation measures:

- Fig. 3a, the present situation (no measures taken);
- Fig.3b, the open waste pools were removed;
- Fig. 3c, the drainage ditch DD was applied; meteoric water infiltration was blocked, on the waste deposit central area;
- Fig. 3d, in order to reduce contaminated groundwater outflow from the encapsulated area, the watertight wall W was introduced; the wall bottom was sited on the gQ aquitard top.

Fig. 1 Location map of the waste deposit area.

It follows from Table 1 that the chloride mass M_{cl}=240 tons is much larger than the ones of the other pollutants. For this reason, only the chloride migration was modelled, and the wash out intensity i_o [kg/day] of other pollutant was estimated, as follows:

$$i_o = i_{cl} M_0 / 240$$

where M_0 – the pollutant mass [tons] dissolved in groundwater; i_{cl} - intensity of chloride wash out [kg/day] obtained by modelling.
The initial chloride concentration C_Q , in the four Q layers, is given by Table 2.

Table 2 Chloride initial concentration in HM layers Q_1, Q_2, Q_3, Q_4

Zone Nr.	Chloride concentration C_Q [kg/m^3] $^{*)}$					Mass [tons]
	Mean C_Q	C_{Q1}	C_{Q2}	C_{Q3}	C_{Q4}	
1	3.913	0.000	1.000	2.250	7.000	90
2	1.666	0.000	0.427	0.961	2.989	30
3	0.972	0.000	0.249	0.560	1.743	70
4	0.526	0.000	0.135	0.304	0.945	20
5	0.337	0.000	0.086	0.194	0.602	30
					Total	240

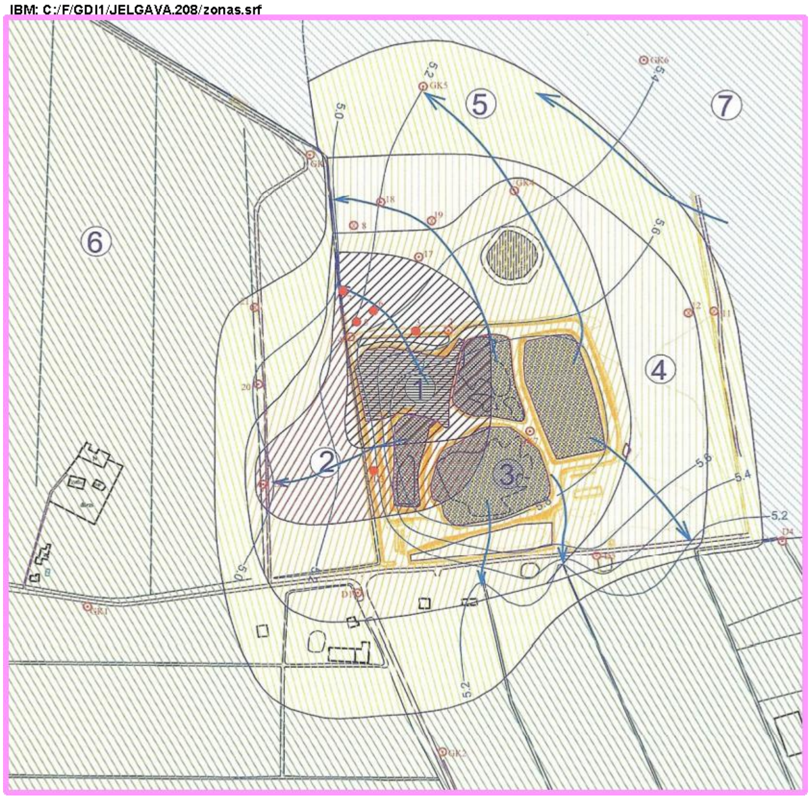

Fig. 2 Model area 800m x 800m with the contaminant zonation shown.

$^{*)}$ C_{Q3}=2.25C_{Q2}; C_{Q4}=7.0C_{Q2}

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$^{*)}$ C_{Q3}=2.25C_{Q2}; C_{Q4}=7.0C_{Q2}

It is assumed that C_Q =0: in the Q_1 aquifer, in the zones 6, 7 of the Q_2 , Q_3 , Q_4 aquifers. For the zones 1, 2, ..,5, C_{Q3}=2.25C_{Q2}; C_{Q4}=7.0C_{Q2}. For the zone 1, C_{Q2}=1.0 kg/m^3. The initial concentrations C_Q of the zones, are proportional to the chloride mass data of Table 1. The ratio C_{Q2} / C_{Q4} =7.0 roughly follows the data observed in monitoring wells. Isometric images of the initial chloride concentration are given by Fig. 5a. The concentration distribution shape is intentionally chosen robust, containing sharp fronts on contamination zonation borderlines. Due to this feature, one can visibly follow changes of the shape during chloride migration (see Fig. 5b). It is assumed that the meteoric infiltration flow and the ascending flow q_D caused by the D aquifer have zero chloride concentration. The value of flow q_D is given by the formula:

$$q_D = (\varphi_Q - \varphi_D) L_0 k_0 / m_0$$

where L_0 is the HM area, k_0 , m_0 – thickness and permeability of the gQ aquitard. The real values k_0, φ_D are not known. The HM basic regimes of Fig. 3 used φ_D =5.0 m asl, $k_0 = 2*10^{-4}$ m/day. For various modelling experiments, the value k_0 were changed from 10^{-4} m/day to $8*10^{-4}$ m/day.

ANALYSIS OF SANITATION MEASURES

To consider main sanitation measures, four basic groundwater head distributions of Fig. 3 were applied. These distributions correspond to four HM versions used.

The version 1 describes the present state when no sanitation has been done (Fig. 3a). Due to intense infiltration flow caused by the open liquid waste pools 1, 2, 3, 4, the head φ_Q distribution contains the uplift area, beneath the pools. It follows from Fig. 2, Fig. 3a that only the ditches 1, 2 are collecting some part of contaminated groundwater. Its other part moves away from the uplift head area. Due to this phenomenon, the contaminated area continues to enlarge. The infiltration flow from the pools is dissolving the solid waste beneath them. Within the central deposit area, the contamination process of groundwater goes on.

The HM version 2 (Fig.3b) simulates the conditionally undisturbed groundwater table when the waste pools are removed. The uplift area of groundwater table has disappeared. Due to this change, enlargement of the contaminated area is not expected, the dissolution intensity of solid waste will decrease greatly. Therefore, removal of waste pools is obligatory. However, the existing worn out drainage system is not able to clean the contaminated area. A large part of pollutants will pass out through the HM area northern border.

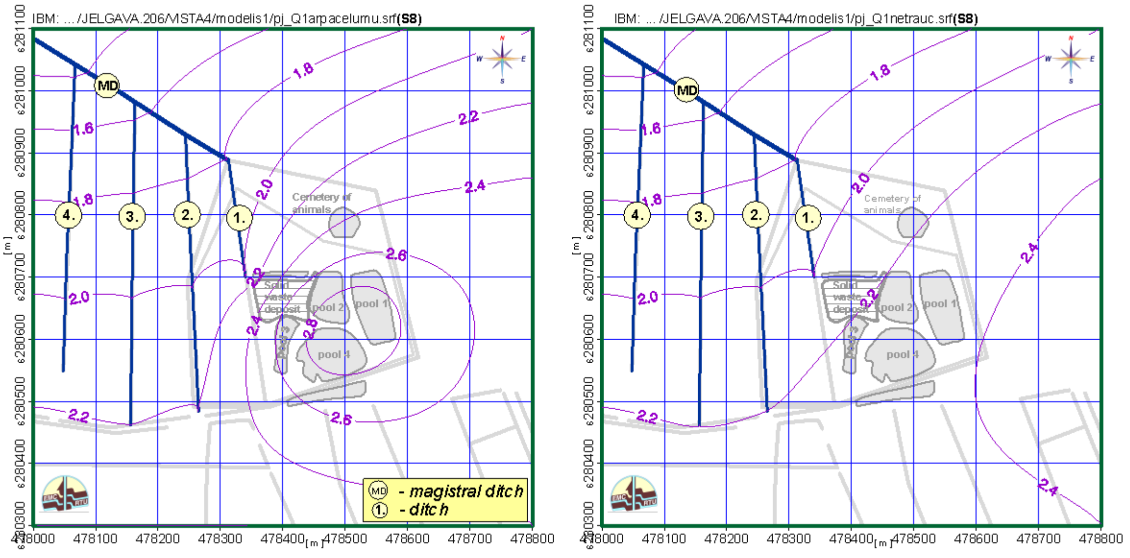
The HM version 3 (Fig. 3c) accounts for modernisation of the area drainage system: repairing of the magistral ditch MD and adding of the new ditch DD that surrounds the most contaminated part of the deposit. The waste mound is covered with a watertight sheet that stops the meteoric water infiltration. To obtain the unknown important parameters k_0 and φ_D , the well D reaching the D aquifer must be fixed up. The well D, as the artesian one, may provide some amount of water that feeds the ditch DD. For this reason the well should be located beside the ditch DD, as shown in Fig.3c. The above activities are the obligatory ones. Without performing them, no satisfactory sanitation of the place is possible.

The HM version 4 (Fig.3) was applied to investigate effectiveness of the watertight wall W. Before considering details of this sanitation measure, it is preferable to consider the summary of groundwater flows for HM versions (Table 3).

The infiltration flow is the largest one (43.24 m^3/day), for the version 1 (open waste pools acting). After removal of the pools (version 2), the infiltration decreases (43.24→17.38) greatly. Blocking of infiltration flow within the waste mound area, results only in the slight decrease (17.38→14.87) of infiltration (versions 3, 4).

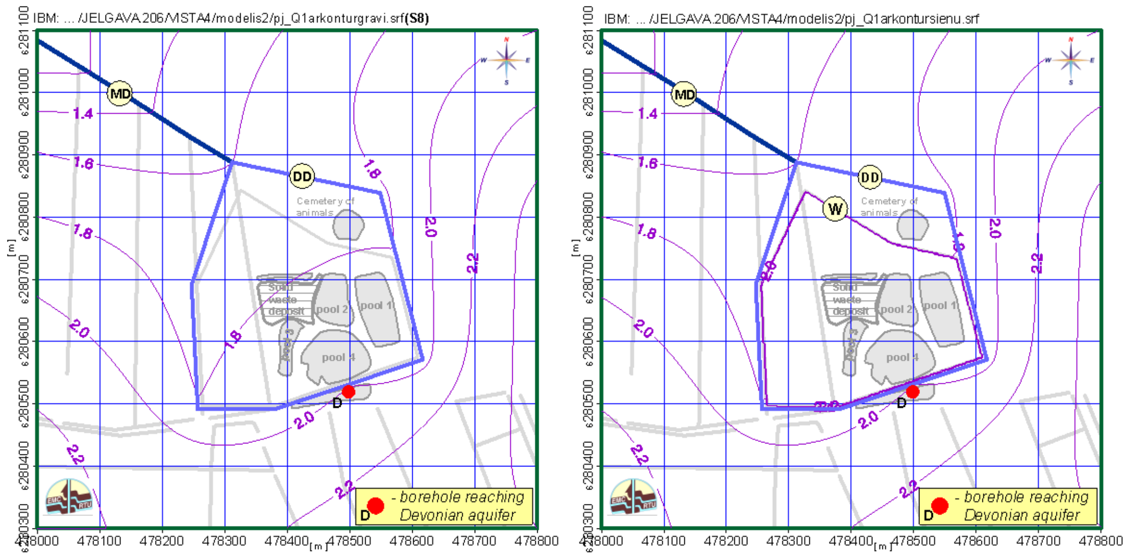
Values of the Devonian flow q_D only slightly depend on the HM version. The flow through the HM area perimeter is negative for the versions 1, 2. It means that groundwater from the Q aquifer flows out of the area through its borderline. Even for the version 2, contaminated groundwater will pass out via the northern borderline.

For the versions 3 and 4, the perimeter flow is positive and no contaminated groundwater can pass out through the borderline. It follows from Table 3 that the flow of ditches is considerably larger for the versions 3, 4. There contaminants can be carried out from the HM area only by the ditch MD.



a) present situation

b)waste pools removed



c) drainage ditch DD applied

d) watertight wall W introduced

Fig. 3 Distributions of groundwater head [m asl] applied for modelling of the area sanitation measures.

Table 3 Summary of groundwater flows [m^3/day] for HM versions (k_0=2*10^{-4} [m/day])

Nr.	Flow type	HM version			
		1.	2.	3.	4.
1.	Infiltration	43.24	17.38	14.87	14.87
2.	From Devon	17.92	18.48	19.58	20.56
3.	Perimeter	-26,16	-13.07	14.85	14.89
4.	Ditches	-35.00	-22.79	-49.30	-50.32
	Total	0.00	0.00	0.00	0.00

for version 4 - l_s=5*10^{-6} [1/day]

The flows of the versions 3 and 4 are practically identical. That means that the wall W only slightly affects the groundwater regime, if the ditch DD is performing rightly.
The principial parameter of the wall W is its leakance $l_s = k_s/m_s$ [1/day] where k_s , m_s are permeability and thickness of the wall. If $l_s = \infty$ then no wall exists.

Table 4 HM version 4. Groundwater head [m asl] within the encapsulated area

l_s [1/day]	k_0 [m/day]			
	10^{-4}	$2*10^{-4}$	$4*10^{-4}$	$8*10^{-4}$
$2.5*10^{-6}$	2.45	2.85	3.40	3.90
$5*10^{-6}$	2.15	2.45	2.85	3.40
10^{-5}	2.00	2.15	2.45	2.85
$2*10^{-5}$	1.90	2.00	2.15	2.50
$4*10^{-5}$	1.88	1.90	2.00	2.20

Table 4 gives values of the groundwater head φ_Q, within the encapsulated area, when various l_s and k_0 values are applied. If φ_D>3.2 m asl then encapsulated groundwater will run over the wall top. This unexpected phenomenon is caused by the Devonian flow q_D, within the area. If l_s values are small (perfect wall) and k_0 are large (intense q_D flow) then the wall stops to perform properly. For this reason, the decision about introduction of the watertight wall is possible only after obtaining real data about the Devonian flow (parameters k_0 , φ_D).

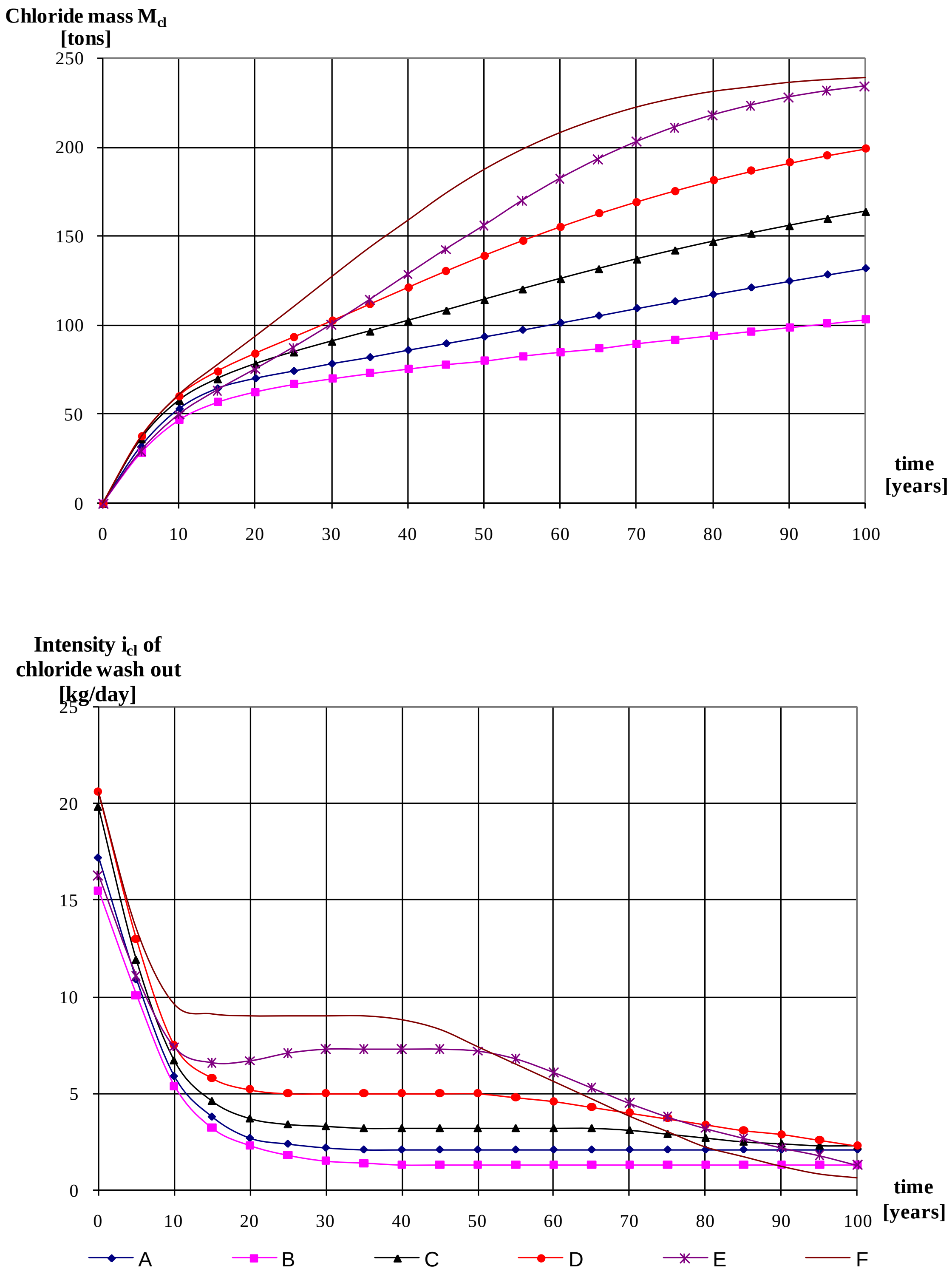
MODELLING OF CHLORIDE WASH OUT

Modelling of the chloride wash out from the contaminated area was carried out by the MT3D program as a part of Groundwater Vistas.
The main results of these numerical experiments are presented by the graphs M_{cl} (mass) and i_{cl} (intensity) of Fig.4, for the sanitation versions A, B, C, D (wall applied) and E, F (no wall). These versions have different combinations of the parameters l_s and k_0.
It follows from Fig.4 that during the first ten years, the graphs M_{cl} and i_{cl} are quite similar for all versions considered (M_{cl} =(45-65) tons; i_{cl} =(15-21) kg/day, when t=0). During this period, the wash out is rather fast, because the ditch DD then cleans mainly these parts of the contaminated zones 4 and 5 which are located outside the place surrounded by this ditch. It follows from the isometric concentration images of Fig. 5b (version A, t=25 years) that the above mentioned parts are practically clean in all HM layers Q_1, Q_2, Q_3, Q_4 .
After the first (10-15) years, the wash out gets slower, especially, for the versions A, B, C. In Table 5, the maximal concentration (in the zone 1, version A) are given versus time. Decrease of the concentration in the Q_4 layer is partly due to the assumption that the flow q_D is clean.

Table 5 Version A. Contaminated zone 1. Maximal chloride concentration [kg/m^3] versus time

Q planes	Time [years]					
	0	2	10	25	50	100
Q_1	0	0.02	0.10	0.20	0.40	0.80
Q_2	1.00	1.03	1.20	1.45	1.90	2.10
Q_3	2.25	2.38	2.75	3.10	3.20	2.00
Q_4	7.00	6.69	5.60	4.00	2.30	0.70

$k_0 = 2*10^{-4}$ m/day; $l_s = 5*10^{-6}$ 1/day



A - k_0=2*10^{-4} [m/day] ; ls=5*10^{-6} [1/day]

B - k_0=10^{-4} [m/day] ; ls=5*10^{-6} [1/day]

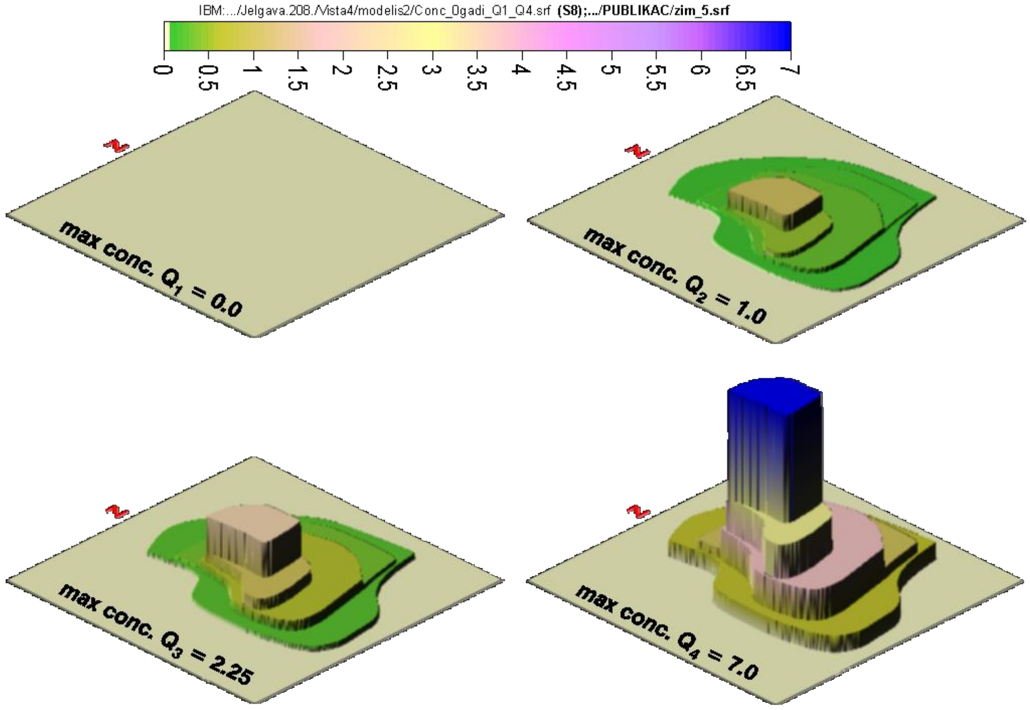
C - k_0=2*10^{-6}[m/day] ; ls=10^{-5} [1/day]

D - k_0=4*10^{-4} [m/day] ; ls=4*10^{-5}[1/day]

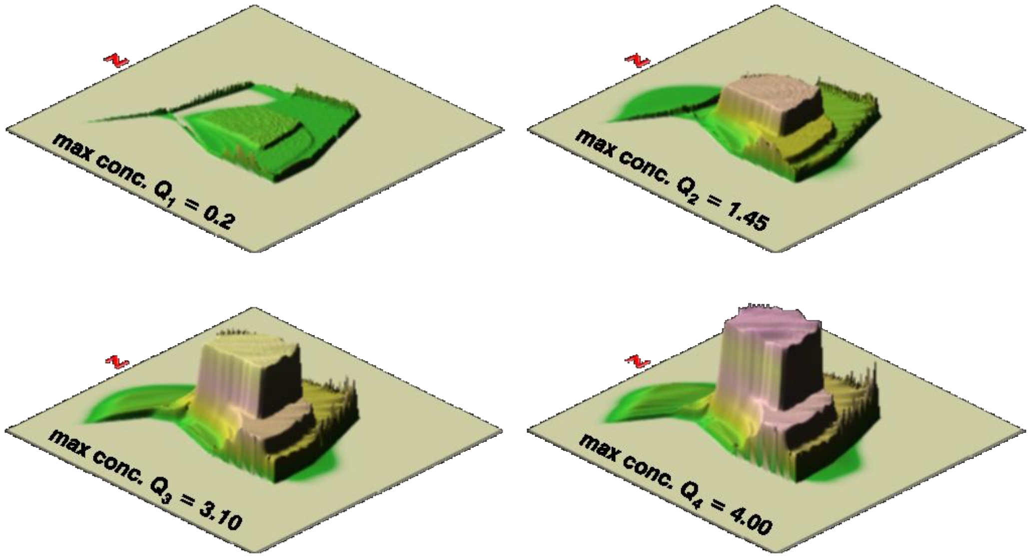
E - k_0=2*10^{-4} [m/day]; $ls=\infty$ [1/day]

F - k_0=4*10^{-4} [m/day]; $ls=\infty$ [1/day]

Fig. 4. Wash out of chlorides versus time for the sanitation versions A, B, C, D, E, F.



a) initial concentration



b) concentration after 25 years

Fig. 5. Sanitation version A. Isometric images of chloride concentration [kg/m^3] versus time.

The water flow at the end point of the ditch MD (HM area western border), is at least 100 m^3/day. It follows from the graphs i_{cl} of Fig. 4 that the chloride concentration C there will never exceed allowable values. For any sanitation version considered, C=(150-200) mg/l, t=0; C=(50-100)mg/l, t=10 years. It is true even for the “fastest’ version F which during 100 years cleans the place (M_{cl}~240 tons, t=100 years).

It follows from the graphs of Fig. 5 that only after 10-15 years the watertight wall may start to reduce the wash out intensity of contaminants (version A, B, C, D), especially, if the parameters l_s, k_0 are small (versions A, B). However, the wall is not helpful during the first (10-15) years, when the wash out intensity reaches its maximum. Therefore, the need to introduce the wall is doubtful.

It follows from Table 1 that the amount of the main contaminants is relatively small. For this reason, no need in situ cleaning of contaminated groundwater is necessary.

RESULTS AND RECOMENDATIONS

Hydrogeological modelling has been performed, in order to evaluate sanitation measures proposed to recultivate the liquid waste deposit site “Cosmos” of the Jelgava town. The results of modelling confirm effectiveness of: removing open waste pools, blocking the meteoric water infiltration on the most contaminated area, appliance of the drainage ditch surrounding the place.

Further field investigations are needed to evaluate effectiveness of the watertight wall. There is no need to perform in-situ cleaning of contaminated groundwater, because the total amount of dissolved contaminants is rather small.

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