PROSPECTS FOR REMEDIATION OF CONTAMINATED GROUNDWATER AT THE INCUKALNS DISTRICT OF LATVIA

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ABSTRACT

At the Incukalns district of Latvia, two gravels pits from 1956 until 1981 were filled up by liquid sulphuric goudron (mixture of sulphure acids, oil products and other hazardous substances). These dump sites were informatively named as the Northern and Southern pools. During sixty years, the pools are polluting groundwater that moves towards the Gauja river. Waste from the pools will be excavated in the near future. However, the contaminant plumes will continue their movement. Scientists of Riga Technical University have modelled mobility of contaminants, especially, of surface active substances. It was found out that the contaminant plumes of the Northern and Southern pools will reach the Gauja river after about 25 and 76 years (since 2015), accordingly. Luckily, the inflow of contaminants will have no real influence on the quality of river water, because its flow is much stronger than of the contaminated groundwater flow from the pools. This feature encourages development of cost effective remediation methods that will be based on interception of contaminated groundwater that without treatment can be discharged into the river. Without help of the methods, self-purification of the area contaminated by the Northern plume will take about 100 years.

Keywords: hazardous substances, hydrogeological model, modelling of contaminant mass transport

INTRODUCTION

Since 1956, at the Incukalns district of Latvia (see Figure 1), two abandoned gravel pits were used for storing of highly toxic waste that was created by the oil processing factory of Riga. The pits become waste pools, each covering 1.0-1.5 ha. The pools were named as the Northern and Southern ones, which were formed during 1956-1965 and 1964-1981, accordingly [1]. In 2015, the pools still act as contaminant sources and their expanding contaminant plumes are carried by groundwater towards the Gauja river (see Figure 2).

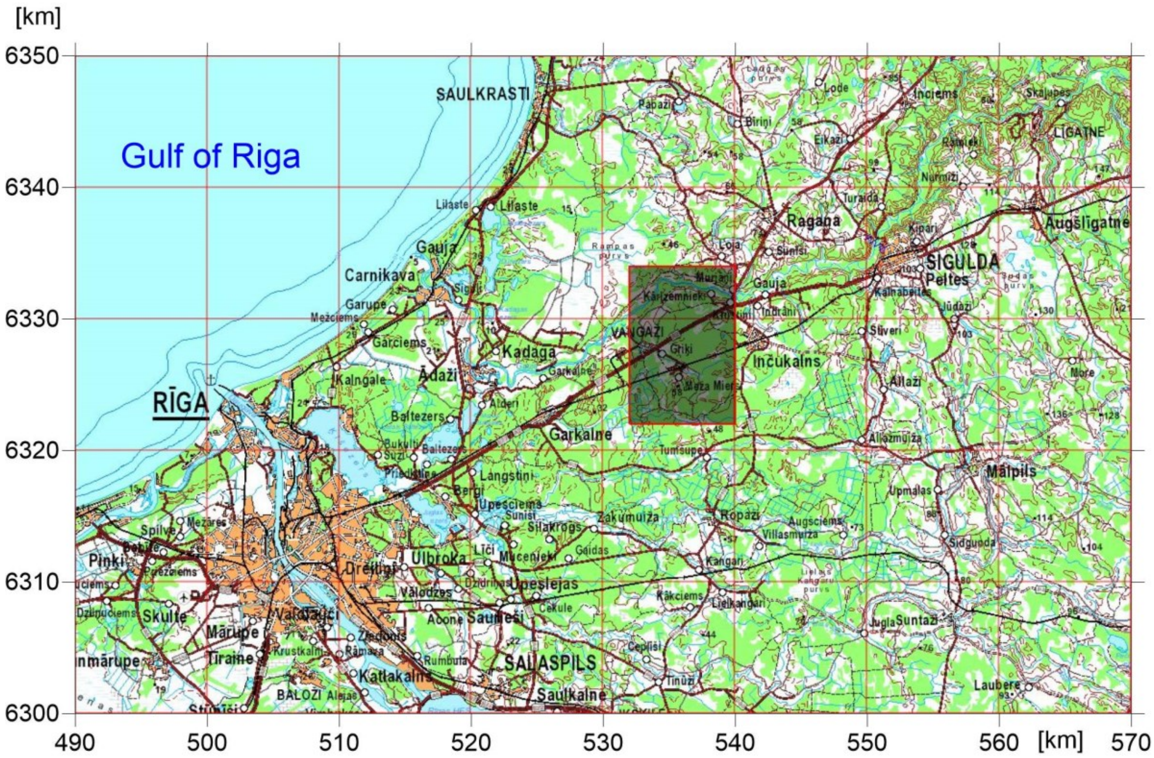

Figure 1. Location of the Incukalns modelled area

By using computer based modelling, scientists of Riga Technical University (RTU) have investigated prospects for remediation of contaminated groundwater. The research was done as the task drawn up by the company "Intergeo Baltic" [2].

Due to their high toxicity, as the pilot contaminant, the surface active substances (SAS) were used. For industrial and drinking water, the SAS concentration must be below 0.3 mg/l and 0.03 mg/l, accordingly [3]. In 2015, the mean SAS concentrations for the Northern and Southern pool plumes were 2.8 mg/l and 12.7 mg/l, accordingly. Areas of these plumes were 108 ha and 91 ha, respectively [2].

To investigate migration of contaminants, the hydrogeological model (HM) was created for driving transport models (TM) of contaminants.

It is assumed that the waste of the both pools has been excavated. Future of the SAS plumes was modelled for optimistic and pessimistic scenarios with and without the SAS decay, accordingly. The decay speeds up remediation of the polluted place. The following issues are considered:

- when will the SAS plumes reach the Gauja river;
- estimation of the SAS mass changes versus time;
- modelling of the SAS plume movement;
- influence of SAS inflows on the Gauja river water quality;
- prospects for self-remediation of the contaminated place.

The publication may be of interest for specialists dealing with the contamination cases when sources of pollution have acted for a long time.

HYDROGEOLOGICAL MODEL

Three successive versions of Incukalns HM (INC1, INC2, INC3) were created in 1998-2016. The size of HM was 8000 metre×12000 metre (see Figure 2). The summary on the HM versions is presented in Table 1 where the software systems used for HM, TM and Rivers are shown and data on the space approximation are provided.

Table 1. Versions of Incukalns HM

Name of version	Year of completion	System used for			Approximation of space		
		HM	TM	Rivers	Plane step [metre]	Number of HM layers	Number of HM blocks×10^6
INC1	1998	REMO	GV2	REMO	100	6	0.059
INC2	2005	GV3	GV3	REMO	100	11	0.108
INC3	2016	GV6	GV6	GV6	10	11	10.582

For HM of INC1 and INC2, INC3, the original system REMO "Large Riga" [4] and the commercial system Groundwater Vistas (GV) [5] were used, accordingly. The GV system consists of the following modules: MODFLOW for running of HM [6]; MODPATH for particle tracking [7]; MT3D for modelling of mass transport [8]. The modules MODPATH and MT3D represent the TM simple and complex versions, respectively.

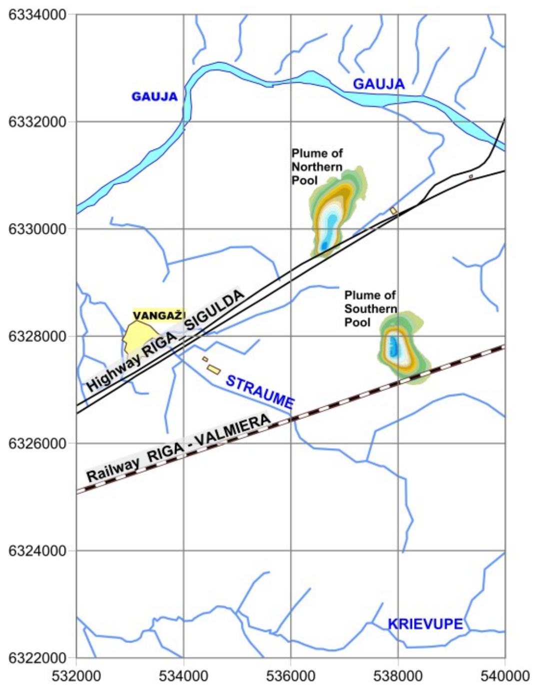

Figure 2. The area of Incukalns HM. The SAS plumes in 2015 are shown.

Table 2. Vertical schematization and parameters of Incukalns HM 2016

No	*	Name of layer	Code of layer	m_{mean}	k_{mean}
1		Relief	relh	0.02	10.0
2		Aeration zone	aer	1.6	4.6×10^{-4}
3	**	Quaternary	Q1	1.5	6.0
4		Quaternary	Q2	3.0	6.0
5		Quaternary	Q3	3.0	6.0
6		Quaternary	gQz	4.0	5.5×10^{-2}
7		Upper Gauja	D3gj21	23.6	7.8
8		Upper Gauja	D3gj22	23.6	7.8
9		Upper Gauja	D3gj23	10.0	7.8
10		Lower Gauja	D3gj1z	21.2	2.0×10^{-4}
11		Lower Gauja	D3gj1	1.0	10.0
*		Aquitard			
** Layer Q1 exists only at vicinity of pools					
m_{mean} , k_{mean} - mean thickness [metre] and permeability [metre day^{-1}] of layers					

The system REMO used the semi 3D finite difference approximation of the geological space. The scheme accounted for the four aquifers (Q, D3am, D3gj2, D3gj1) and for two surfaces of boundary conditions relh and D2ar. For this reason, INC1 contained only six HM layers; the plane approximation step was 100 metres [9].

The full 3D approximation was applied for the INC2 and INC3 versions. For the latest INC3 version, the plane approximation step is reduced from 100 metres to 10 metres and for all its elements (HM, TM, Rivers) the GV6 system is used [10].

The vertical schematisation and parameters of INC3 (HM 2016) are presented in Table 2. The schematization is shown graphically in Figure 3.

The current HM version differs considerably from the INC1 version: the aquifers D3am and D2ar are excluded; in order to improve the spatial approximation, the aquifers Q and D3gj2 are divided in three subaquifers each. The subaquifer Q1 of sand exists only at vicinity of the pools. Its thickness 1.5 metres roughly corresponds with the depth of pools that are located in the subaquifer Q1. The subaquifers Q2, Q3 of sand are equal. Due to stratification of SAS, the subaquifer D3gj23 serves as the location of SAS plumes. The thickness of the subaquifer is ten metres. The subaquifers D3gj21 and D3gj22 are equal. They simulate the upper part of the Devonian sandstone aquifer D3gj2.

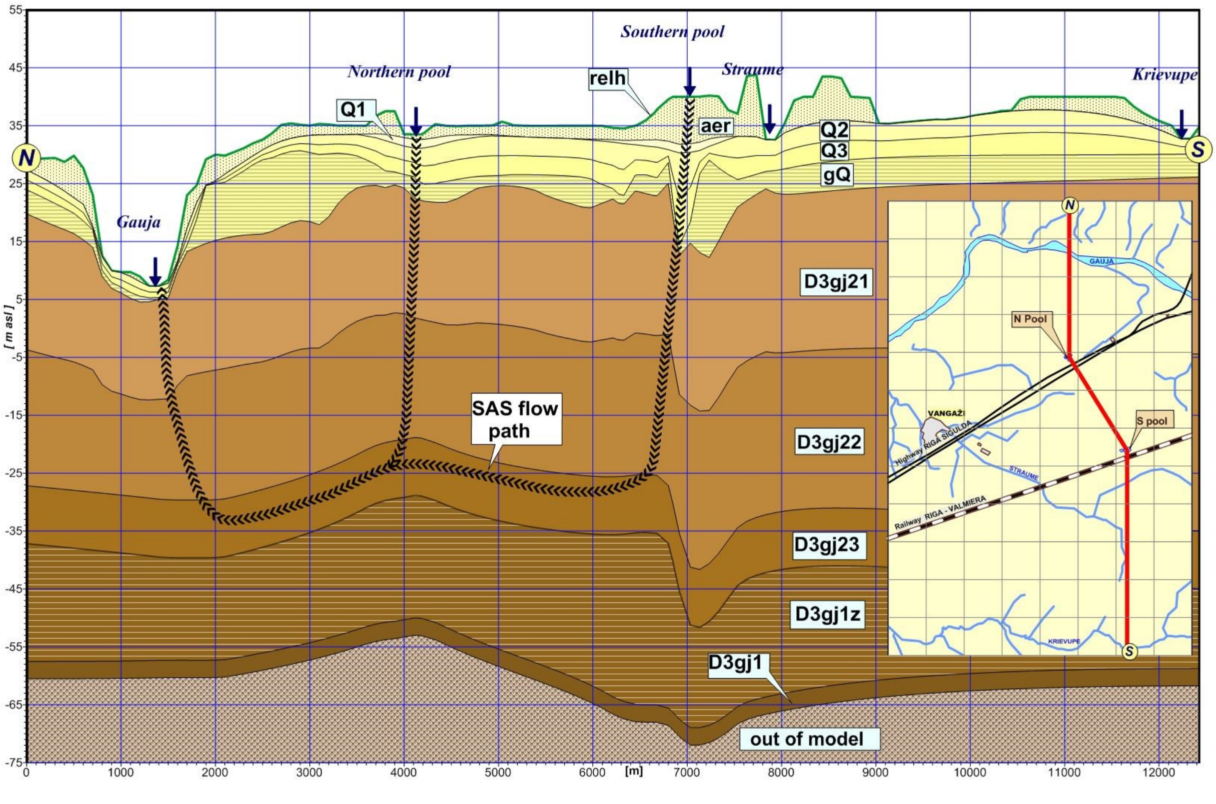

Figure 3. Cross section N-S; SAS plumes are located within the subaquifer D3gj23.

The formal aquifers Nos 1 relh and 11 D3gj1 carry boundary conditions of fixed heads [m asl] ψ_{rel} and ψ_{D3gj1}, accordingly. They represent the ground relief map and the distribution of heads for the aquifer D3gj1, respectively. The fixed heads are set on the outer border of HM (shell) for the subaquifers Q3 and D3gj22. The aeration zone aer is the aquitard that controls the infiltration flow on the top of HM.

The waste from the pools leaks down through the moraine gQ, sinks in the subaquifer D3gj23, moves towards the Gauja river and surfaces into the river (see Figure 3). The aquifer Q is contaminated only beneath the pools. At the vicinity of both pools the lateral groundwater flows are very slow. For this reason, surroundings of the pools in the aquifer Q are contaminated insignificantly [2]. When HM was used for driving TM, the porosity 0.27 was applied for all layers of HM.

MOBILITY OF SAS PLUMES

In order to obtain estimates on the travel time of SAS from the pools up to the Gauja river, the MODPATH program was used. It follows from Figure 4 that the travel times are 80 and 130 years, accordingly, for the Northern and Southern pools, since their appearance in 1956 and 1964. After roughly 1000 years, through the aquitard D3gj1z, SAS may reach the aquifer D3gj1. Therefore, it is believable that the Devonian aquifer D3gj1 will not be contaminated.

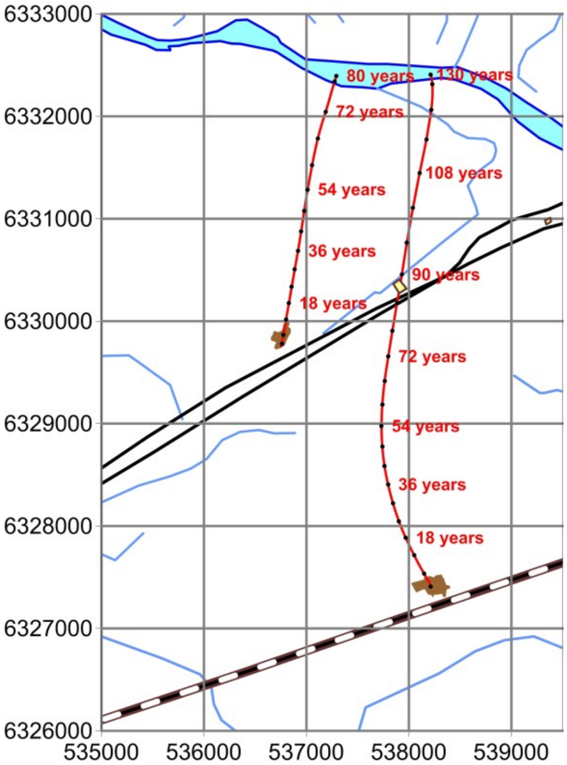

Figure 4. Pathlines on contaminant movement from pools

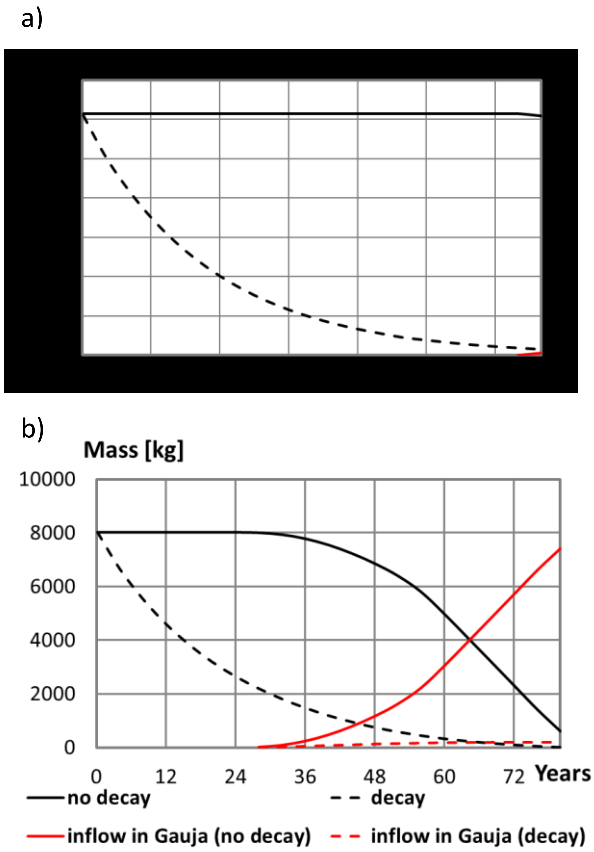

Figure 5. The SAS mass graphs M_a and M_r for aquifer and river;
a) Southern plume; b) Northern plume

By using the SAS plumes of 2015 as the initial concentration distributions in the subaquifer D3gj23, the system MT3D computed the SAS mass M_t versus time for the Northern and Southern pools. The MOC (method of characteristics) was applied [10]. The time step 0.2 years (73 days) was used for TM. The dispersion and decay options were applied. No sorption was accounted for. The result is shown in Figure 5. The initial SAS mass M_0 is 8020 kg and 30500kg, accordingly, for the Northern and Southern plumes.

The Gauja river will act as the sink that removes a contaminant from groundwater. The Northern and Southern plumes will reach the river after 25 and 76 years (since 2015), accordingly. Until this time, M_0 will not change for the "no decay" case (see Figure 5). For the "decay" case $M_0 \rightarrow M_t$; M_t decreases, as follows [3]:

$$M_t = M_0 / \exp(\ln 2t / t_{0.5}) \qquad (1)$$

where $t_{0.5}$ is the half life time of a contaminant; for Incukalns SAS, $t_{0.5}$ =15 years [3]; t is the time when plume will reach the river. Afterwards, due to the SAS discharge into the river, M_t will be smaller than prescribed by (1).

The summary on M_t that is located in the aquifer D3gj2 (M_a) and is discharged in the river (M_r) is presented in Table 3. Two estimates (after 40 and 80 years, since 2015) are provided.

Table 3. Summary on the SAS mass M_a in the aquifer D3gj2 and M_r discharged into the Gauja river after 40 and 80 years.

Name of pool	After 40 years (in 2055)				After 80 years (in 2095)			
	No SAS decay		SAS decay		No SAS decay		SAS decay	
	M_a [kg]	M_r [kg]	M_a [kg]	M_r [kg]	M_a [kg]	M_r [kg]	M_a [kg]	M_r [kg]
Northern	7549	471	1185	75	603	7417	7	193
Southern	30500	0	4809	0	30272	278	736	20

The most important is the Northern plume, because it will reach the Gauja river sooner. After 40 years, 471 kg (6% of M_0) will enter into the river (no decay case), because only the low SAS concentration front of the plume has been discharged (see Figure 6, year 2055). After 80 years, 7417 kg (92% of M_0) will enter the river. Only the plume rear part (see Figure 6, year 2095) will remain within the aquifer. If the SAS decay takes place, only 7 kg and 193 kg (0.09% and 2.4% of M_0) will remain within the aquifer and will be discharged into the river, accordingly. It may be expected that the Northern plume will cease after 100 years.

It follows from Figure 5a and Table 3 that the self-purification of the area polluted by the Southern plume is possible only due the SAS decay, if no special remediation methods are used.

Presently, the area contaminated by the Southern plume is relatively small. For this reason, some attempt should be taken to stop further movement of the plume and to shorten the remediation time of the place.

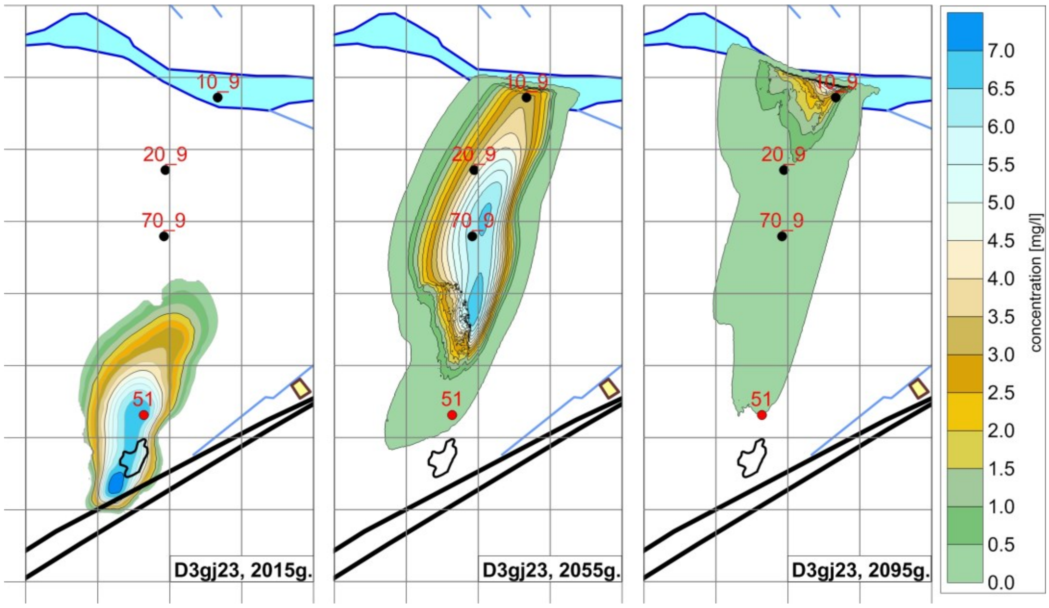

Figure 6. The Northern plume (no decay) in 2015, 2055 and 2095

To investigate closer the Northern plume central part, hydrographs (Figure 7) of four monitoring wells were obtained. Locations of the wells are shown in Figure 6. The well No 51 is the real one, but Nos 70-9, 20-9, 10-9 are the virtual wells in the subaquifer D3gj23 (9-th layer of HM).

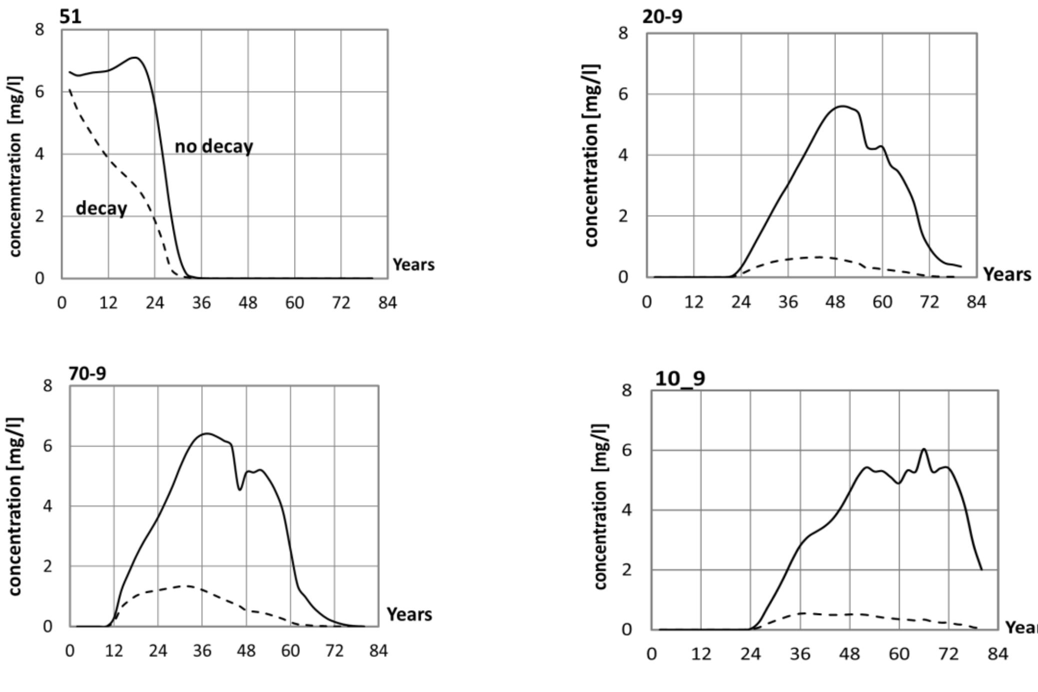

Figure 7. The SAS concentration [mg/l] for monitoring wells Nos 51, 70-9, 20-9, 10-9 of the SAS no decay and decay cases

For the no decay case, the maximal SAS concentration is close to 6 mg/l for the all wells. If the SAS decay takes place then the concentration maxima shift back in time (in comparison with the no decay case) and they decrease versus time, as it should be.

PROSPECTS FOR REMEDIATION OF THE CONTAMINANT PLUMES

By considering the graphs of M_t for the Northern plume (see Figure 5b), one can conclude that its self-remediation is due to two independent factors: the decay of SAS; the discharge of SAS into the Gauja river. The discharge process for the "no decay" case is presented in Table 4.The main result is the SAS concentration C_r in water of the Gauja river:

$$C_r = M_r / V_r \tag{2}$$

where M_r [kg] is the SAS discharge in the river (Figure 5b); V_r is the volume [m^3] of the river water during the time step Δt (year). If the mean flow of the Gauja river v_r= 8.5×10^6 m^3/day then

$$V_r = \Delta t\ 8.5\times10^6 \times 365 = \Delta t\ 3.1\times10^9\ [\mathrm{m}^3/\mathrm{year}]. \tag{3}$$

In table 4, seven successive time steps Δt are used: 20, 5×12 and 60 years. During the first step (Δt =20 years) the plume will not reach the river (M_r = 0). During the next five steps (Δt =12), M_r increases from 86 kg to 2599kg for the time step. The seventh step (Δt =60 years) represents the full SAS discharge of 7417 kg when C_r = 39.9 ng/l. It follows from Table 4 that even for the "no decay" case, the inflow of SAS cannot worsen the river water quality, because the maximal concentration is only C_r ~ 70 ng/l.

Table 4. Discharge of SAS [kg] into the Gauja river from the Northern pool. Concentrations of SAS [ng/l] in river water (no SAS decay)

No of time step t_i	From t_i until t_{i+1} [year]	Length of step [year]	M_r [kg]	V_r ×10^9 [m^3]	C_r [ng/l]
0	0-20	20	0	62.1	0.0
1	20-32	12	86	37.2	2.3
2	32-44	12	699	37.2	18.8
3	44-56	12	1441	37.2	38.7
4	56-68	12	2592	37.2	69.8
5	68-80	12	2599	37.2	69.8
6	20-80	60	7417	186.0	39.9

This feature encourages development of the new cost-effective methods for remediation of the Incukalns site. The methods may be founded on idea of interception of contaminant plumes when contaminated groundwater must be pumped out from the aquifer and without treatment through pipelines it can be discharged into the Gauja river.

Due to interception of contaminated water, the further movement of the plumes will be stopped. It was found out in 2005 [11] that the contaminant plume could be stopped if discharge wells were applied. However, then groundwater was treated and infiltrated back into the aquifer. For the new methods, it is necessary to find optimal regimes of the groundwater discharge: duration of action, productivity and disposition of discharge wells.

It is possible to carry out short time remediation actions (duration about 5 years), because the Gauja river has considerable capacity to dilute contaminants. For example, if the allowed waste concentration in river is 10 µg/l than during one year, 31000 kg of contaminants can be discharged into the river.

Interruption of the contaminant migration is very helpful for the Southern plume, because pollution of the considerable area will be prevented.

CONCLUSION

Hydrogeological and mass transport models were used to investigable prospects for remediation of the contaminated place at the Incukalns district of Latvia. During sixty years, the place is being contaminated by toxic waste leaking in groundwater from two dump sites named as the Northern and Southern pools. Contaminated groundwater moves towards the Gauja river. The Northern and Southern contaminant plumes will reach the river after 25 and 76 years (since 2015), accordingly. In the near future, waste of the pools will be excavated and, due this event, the self-remediation process for the contaminated areas was considered. It is possible due to decay of contaminants and to the groundwater discharge in the river. It was found out that the discharge of polluted groundwater into the river cannot worsen its water quality, because the river flow is much stronger than the one of groundwater.

This feature encourages development of cost-effective remediation methods for the Incukalns place. The methods will apply interception of the contaminated groundwater flows of the Northern and Southern plumes. Contaminated groundwater have to be pumped out and without any treatment through pipelines it can be discharged into the river. Appliance of the methods will stop movement of the contaminations plumes and considerably shorten the time of remediation for the Incukalns place.

If the new methods will not be used then the self-remediation of the area contaminated by the Northern pool will be completed about after 100 years. The remediation of the Southern plume is possible due to the decay of contaminants, because the discharge of groundwater in the river will take place only after 76 years.

In the course of calibration of the HM 2016 of Incukalns, information provided by the hydrogeological model of Latvia LAMO4 was used. Development of LAMO4 was supported by the Latvian National Research program EVIDEnT.

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