Journal of Communication and Computer 9 (2012) 1218-1225

Modeling of Groundwater Regime Changes That May be Caused by Building of Transportation Tunnel in Riga, Latvia

Aivars Spalvins, Janis Slangens and Inta Lace

Faculty of Computer Science and Information Technology Environment Modelling Centre, Riga Technical University, Riga LV-1007, Latvia

Received: April 5, 2012/ Accepted: May 5, 2012 / Published: November 30, 2012.

Abstract: The publication is devoted to numerical modeling of changes in groundwater regime that may happen during and after building of the 7 km long and 50 m deep underground transportation tunnel in Riga. There are two kinds of changes: the ones caused by the tunnel impermeable body and by harmful effects that may happen during the process of building, for example, impacts of open deep construction trenches. To estimate possible after effects caused by the tunnel and the trenches, the hydrogeological model has been created. Its plane size is 3,500 ×8,000 m and the plane approximation step is 10 m. Model contains twelve grid planes accounting for complex geological structure of the place and the tunnel geometry. By comparing results provided by the undisturbed (no tunnel) and disturbed models, the change of the groundwater regime was found. It contained changes of groundwater heads and flows as hydraulic gradients and meteoric infiltration. These changes were small and the tunnel itself should cause practically no disturbance of groundwater regime. By modeling possible versions of watertight walls for trenches, it was found that deep wrongly built construction trenches may cause considerable harm by lowering groundwater table at the trench surroundings.

Key words: Hydrogeological models, underground tunnel, construction trenches.

1. Introduction

To develop transportation system of Riga (Latvia), building of the underground tunnel is planed. Location of the tunnel track (containing two parallel one way drives) is shown in Figs. 1and 2. The tunnel length is 7 km, the maximal depth of its installation is 50 m, the diameter of the one-way drive is 15.4 m. The distance between the tunnel drives is 15.0 m [1]. It was necessary to estimate changes of groundwater regime that may be caused by building of the tunnel. They contain the permanent change due to the tunnel body and the one caused by deep construction trenches that must be used to build the tunnel [2]. A HM (hydro -geological model) has been built, to estimate the both changes [3]. Location of HM is shown in Fig. 1. The HM size is 3.5 × 8.0km. The plane approximation step 10.0 m enables to account properly for the tunnel dimensions.

Geology of the HM area is rather complex (Fig. 2, Table 1). The area is bedded by the Devonian sandstone aquifer D3gj2. It is covered by the sandstone aquifer D3am which partly ends within the area. The next aquifer D3pl of dolomites exists only in the area southern part. These Devonian aquifers are separated from the quarternary aquifer by the moraine gQ. In surroundings of the Daugava river, the aquifer Q presents a chaotic mixture of fine sand, sandy loam, clay and stones. Bellow the Daugava old valley, the area of coarse sand exists.

Corresponding author: Aivars Spalvins, Dr.sc., research field: computer based modeling of problems regarding groundwater flows. E-mail: emc@cs.rtu.lv.

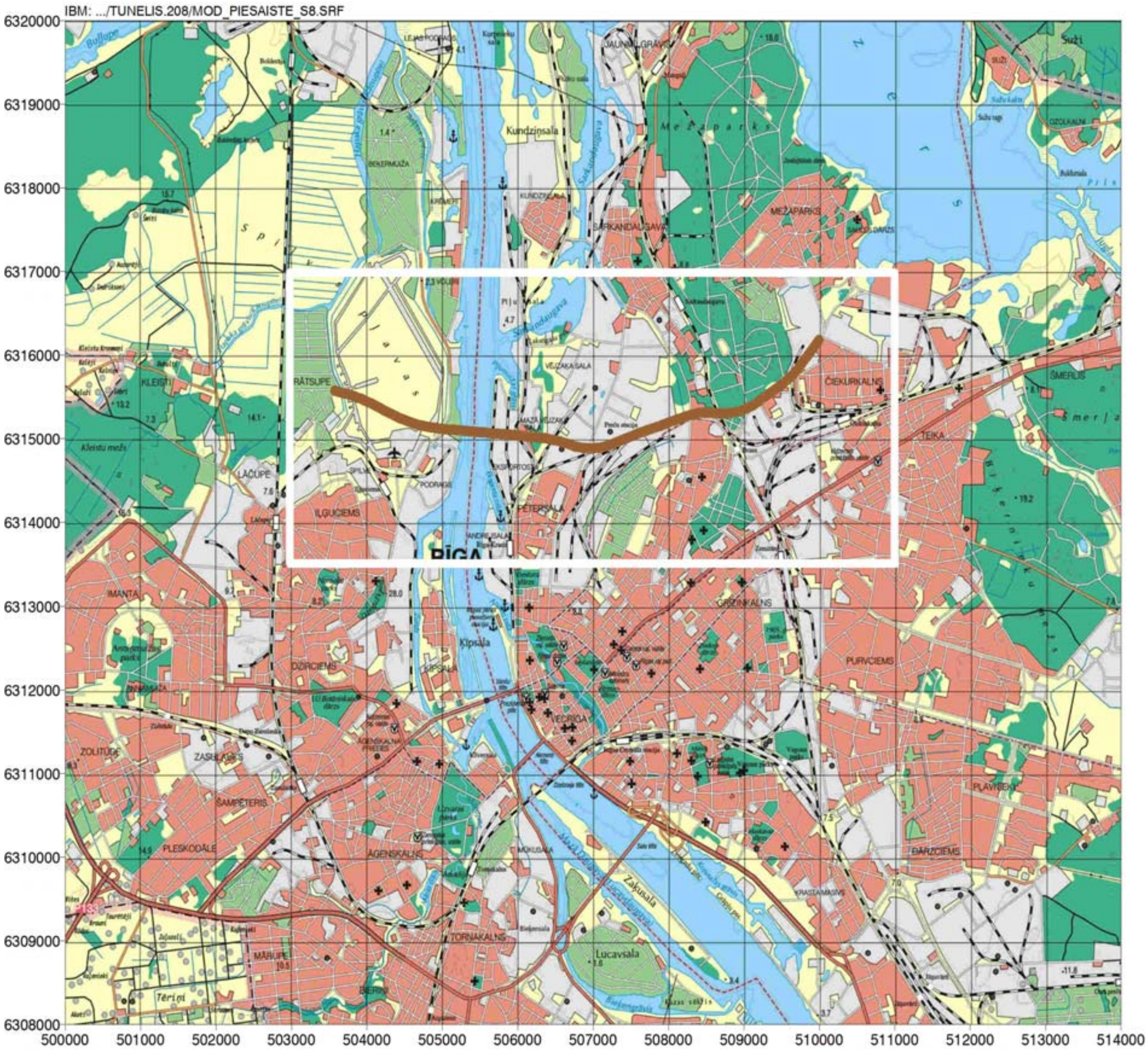


Fig. 1 Location map of model in Riga.

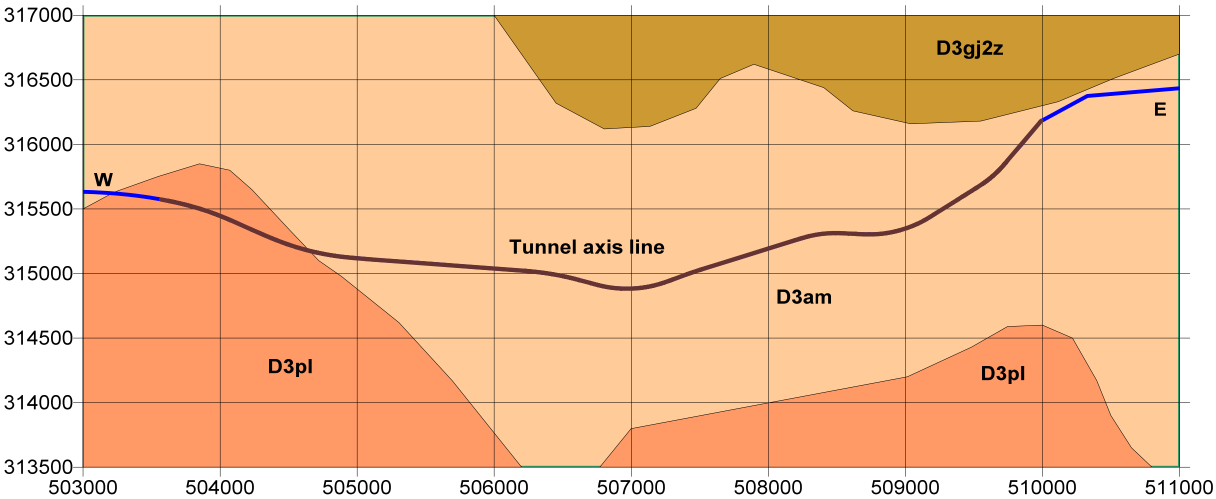


Fig. 2 Geological map of model area.

Table 1 Model vertical schematisation.

Nr.	Name	Plane code
1.	Relief	relh
2.	Aeration zone	aer
3.	Quarternary	Q1
4.	Quarternary	Q2
5.	Quarternary	Q3
6.	Quarternary	Q4
7.	Quarternary moraine	gQ
8.	Plavinu aquifer	D3pl
9.	Amata aquitard	D3amz
10.	Amata aquifer	D3am
11.	Gauja 2 aquitard	D3gj2z
12.	Gauja 2 aquifer	D3gj2

In Fig. 3 the cross section WE of the HM area is presented. On the section, four variants of tunnel road beds are shown in Ref. [2]. Only the version 1 (deep tunnel) is considered there, because its influence on the groundwater regime is the largest one [3].

HM was created in the groundwater vstas environment [4].

2. Hydrogeological Model

As it follows from Fig. 3, in the Daugava river area, the tunnel bottom will nearly reach the D3gj2z aquitard (the tunnel bottom lies 5.8 m under the road bed). For this reason, the D3gj2 aquifer head distribution φ_{D3gj2} was applied, as the HM boundary condition. Unfortunately, the current φ_{D3gj2} distribution is in process of rising, because after-effects of the former deep depression cone there will disappear, approximately, after (5-7) years. In HM, this expected future distribution φ_{D3gj2} is applied, because the tunnel will exist for a long time.

To account for the tunnel geometry, the Q aquifer is divided into four parts (Table 1): above tunnel (Q_1), tunnel body (Q_2), below tunnel (Q_3), coarse sand layer (Q_4). It is shown in Fig.4, how the parts Q_1, Q_2, Q_3 are used, to approximate the two tunnel drives.

In Table 2, parameters of permeability for the undisturbed HM (no tunnel) layers are given. For the tunnel body, the constant permeability $k_t = 10^{-3}$ m/day is applied.

The ground surface elevation map φ_{rel} was used as the boundary condition, on the plane 1 of HM. Then the model creates the flow q_{aer} , through the aeration zone:

$$q_{aer} = (\varphi_{rel} - \varphi_Q)\, g_{aer} = \Delta_{aer}\, g_{aer} \qquad (1)$$

where Δ_{aer}, g_{aer} are the thickness and hydraulic

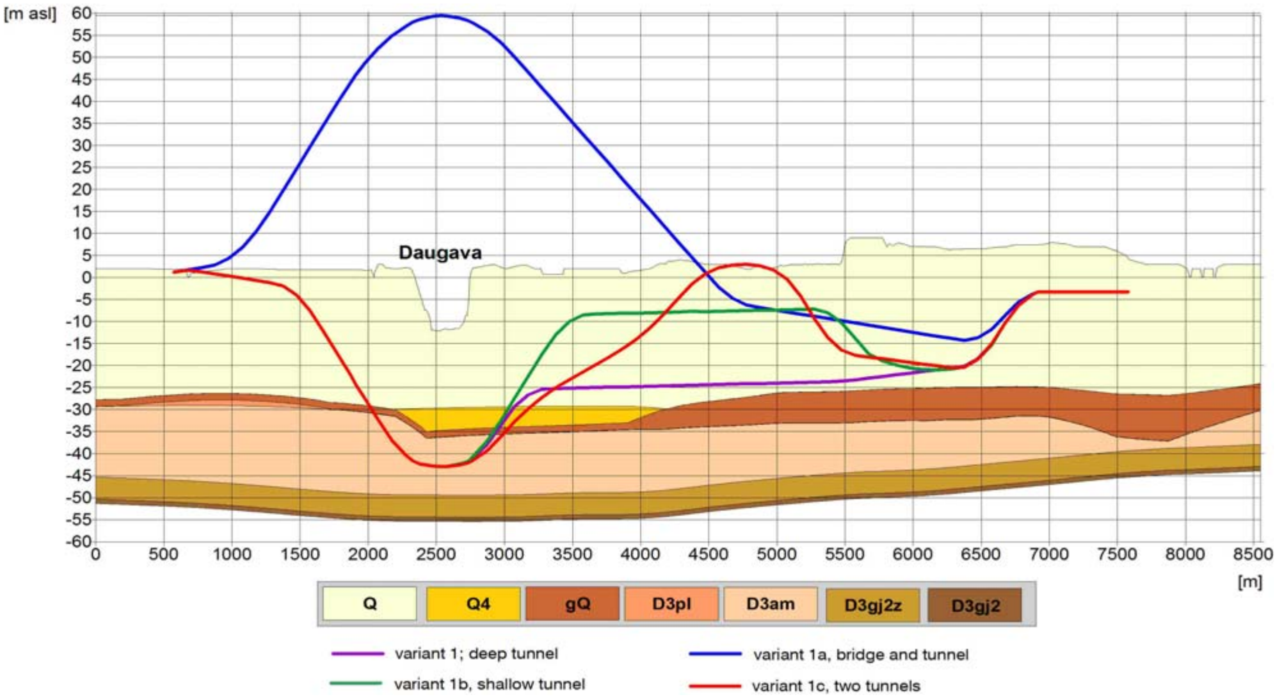


Fig. 3 Cross section WE; variants of tunnel road base.

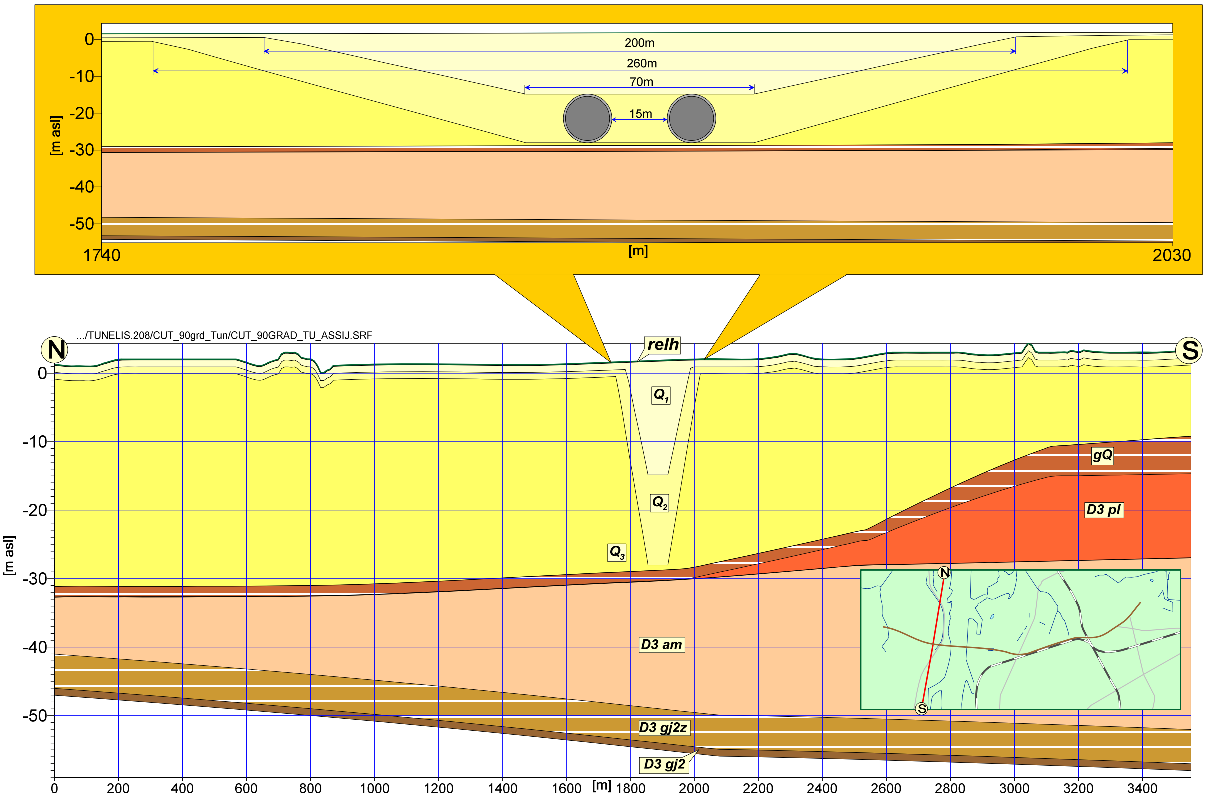


Fig. 4 Cross section NS; approximation of tunnel system and its surroundings.

Table 2 Permeability of model layers.

Aquifers (permeability k)			
Nr.	Plane code	k [m/day]	Notes
1.	relh	10.0	Boundary conditions φ_{rel}
3.-5.	Q_1-Q_3	0.5	Weakly permeable
6.	Q_4	10.0	Coarse sand
8.	D3pl	20.0	Connected to D3am plane
10.	D3am	4.0	Simulates flow below gQ plane
12.	D3gj2	3,000	Boundary conditions φ_{D3gj2}
Aquitards (leakance k/m)			
Nr.	Plane code	k/m [1/day]	Notes
2.	aer	0.84×10^{-4}	0.84×10^{-2} for hydrographical network
	gQ	$1.5\times 10^{-3}/m_{gQ}$	Depends on variable thickness m_{gQ}
9.	D3amz	16.7	Joining D3pl un D3am aquifers
11.	D3gj2z	0.2×10^{-4}	Constant value

conductivity of the aeration zone, accordingly. For nodes of hydrographical network (Daugava, ditches, lakes), $g_{aerh} = 100\ g_{aer}$ (Table 2).

To calibrate the infiltration flow, the condition $\Delta_{aer} \geq h_{cr}$ is checked, and the following correction matrix C is obtained ($h_{cr} = 4.5$ m):

$$C_i = 1.0 \text{ if } \Delta_{aer} < 4.5$$

$$C_i = 4.5 \ / \ \Delta_{aer} \text{ if } \Delta_{aer} \geq 4.5 \quad (2)$$

The matrix C is used, as follows: $g_{aer} = C\ g_{aer}$, where the value $(g_{aer})_i$ at the i-th node, is multiplied by the correction coefficient $C_i \leq 1.0$.

In Fig. 5, the computed head distribution φ_Q of undisturbed HM is shown. This distribution rightly accounts for influence of the ground surface and of the hydrographical network, because the φ_{rel} map is applied, as the boundary condition.

In Fig. 6, the computed graphs of φ_{rel}, φ_Q, φ_{D3am}, φ_{D3gj2} are shown, along the cross section WR. At surroundings of the Daugava river and at the eastern part of the HM area, the ascending (discharge) and discending (recharge) vertical flows are present, correspondingly.

In Table 3, the summary of undisturbed HM flows is given. It follows from Table 3 that the total flow through perimeter of the Q aquifer is almost nonexistent

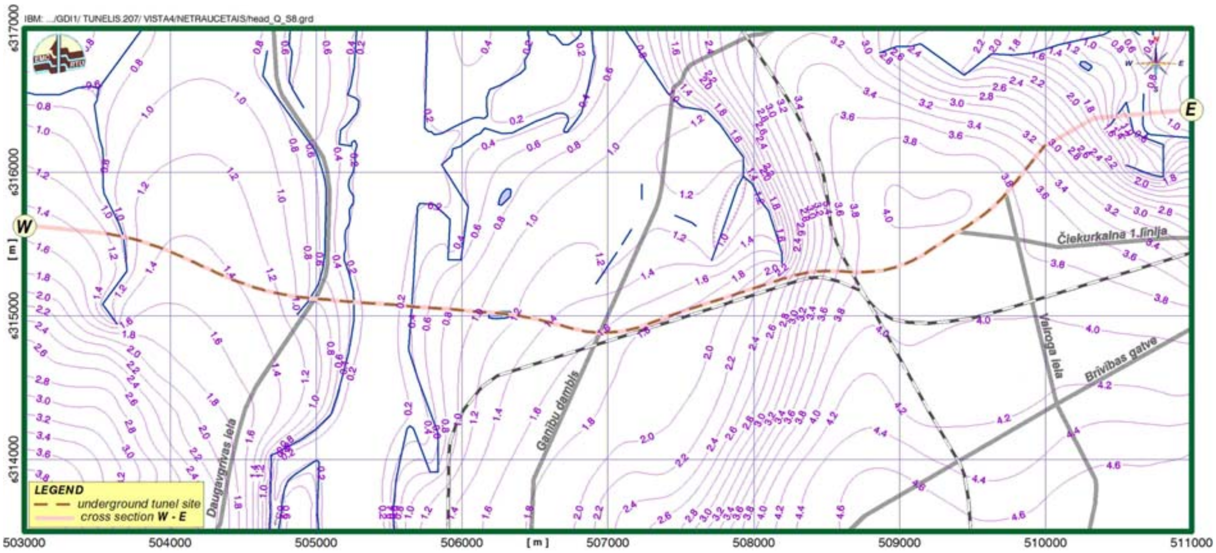


Fig. 5 **Head distribution (m asl) of the Q aquifer to account for the tunnel geometry, the Q aquifer is divided into four parts (Table 1): above tunnel (Q_1), tunnel body (Q_2), below tunnel (Q_3), coarse sand layer (Q_4). It is shown in Fig.4, how the parts Q_1, Q_2, Q_3 are used, to approximate the two tunnel drives.**

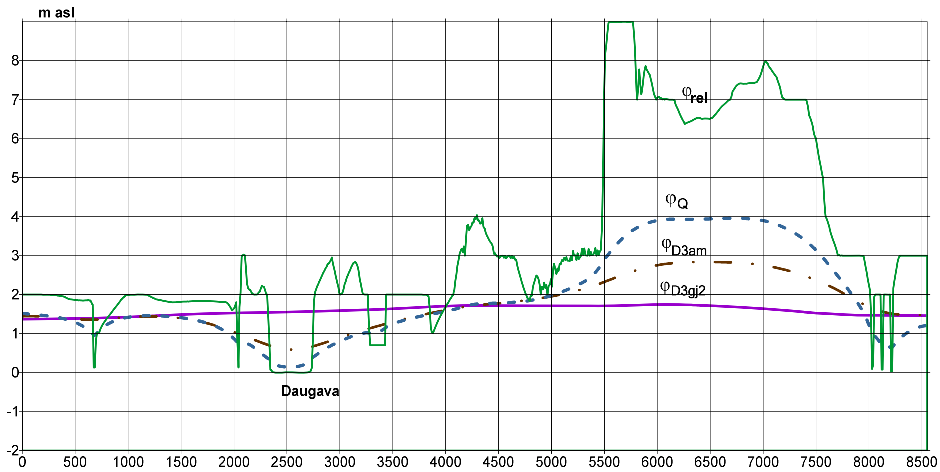


Fig. 6 **Cross section WE; gaphs of ground surface φ_{rel} and heads φ_Q, φ_{D3am}, φ_{D3gj2} are shown.**

Table 3 **Summary of undisturbed model flows (m^3/day).**

Plane codes	Plane top	Plane bottom	Perimetre	Total
aer	850.8	-850.8	0.0	0.0
Q1	850.8	-833.5	-17.3	0.0
Q2	833.5	-833.5	0.0	0.0
Q3	833.5	-826.4	-7.1	0.0
Q4	826.4	-847.5	21.1	0.0
gQ	847.5	-847.5	0.0	0.0
D3pl+D3am	847.5	-1091.3	243.8	0.0
D3gj2z	1091.3	-1091.3	0.0	0.0

(-17.3 – 7.1 + 21.1) = -0.3 (m^3/day), and the (D3pl + D3am) aquifer gives the main perimeter inflow (243.8 m^3/day). The total perimeter flow is 240.5 m^3/ day and it is in balance with the flows through the model top and bottom (243.5+850.8- 1091.3=0), accordingly.

More information about other undisturbed HM features (hydraulic gradient of layers, infiltration, computed head distributions φ_{D3am}, φ_{D3gj2}, HM geometry, etc.) can be found in Ref. [3].

3. Change of Groundwater Regime

To evaluate changes caused by the tunnel, results provided by two kinds of HM (undisturbed, disturbed) must be compared. Disturbed HM contains the tunnel. It was found out that both HM must have identical geometries of surfaces used to approximate the tunnel.

For disturbed HM, in locations of the two tunnel drives, their permeability $k_t \rightarrow 10^{-3}$m/day. Before the tunnel is introduced, k_t have values of permeability given by Table 2. Initially, the above rule of the HM geometry identity was ignored. However, it was found out that different geometries caused unexpected side-effects. They considerably disturbed main results that were obtained due to the tunnel influence.

It was necessary to evaluate changes of groundwater heads and flows, of hydraulic gradients and meteoric infiltration. It was found out that the head change $\Delta\varphi_Q$ for the Q aquifer was the maximal one. For this reason, it is considered here.

For the Q aquifer, the tunnel installation gives the change $\Delta\varphi_Q = \varphi_Q - \varphi_{Qt}$, where φ_{Qt} is the head distribution of the Q aquifer when the tunnel is introduced. In Fig. 7, the graphs of $\Delta\varphi_Q$ are given for surroundings of the tunnel. The graphs of Fig. 7a represent the change $\Delta\varphi_Q$, on the axis of the tunnel track and on two lines located at the ±55 m distance from the axis. On the axis, $\Delta\varphi_Q$ reaches its maximal values 0.14 m and 0.08m, at locations of a ditch and a small pool, accordingly (Fig. 5). The two other graphs confirm an expected reaction of groundwater flow when the tunnel body partially blocks its way: the groundwater head rises and falls down before and after the obstacle, correspondingly. This phenomenon is even more evidently confirmed by the graphs of Fig. 7b where the change $\Delta\varphi_Q$ is shown along orthogonal cross sections. The modelled changes $\Delta\varphi_Q$ are small, therefore, the underground tunnel influence on the groundwater flow is insignificant. Ref. [3] provides more information about the possible changes in the D3am aquifer and of the groundwater gradient change in the Q aquifer and of the meteoric infiltration flow change. None of these changes are of practical importance.

4. Impact of Construction Trenches

To build the tunnel, open construction trenches are necessary [2]. To keep the trench dry, groundwater should be pumped out from its bottom part. This causes lowering of groundwater table in surroundings of the trench. If this drawdown exceeds an allowable limit then buildings and roads there will be damaged. The most harmful is the trench at the Exporta street [2]. The expected size of the trench is 400×70m and its depth may reach 25 m.

It is evident that a watertight wall should be used, to prevent damage caused by a trench. If no wall is applied then the trench depression cone (Fig. 8a) will harm buildings and roads at the distance 500-1,000 m.

Effectiveness of a watertight wall was estimated. Two wall parameters were accounted for:

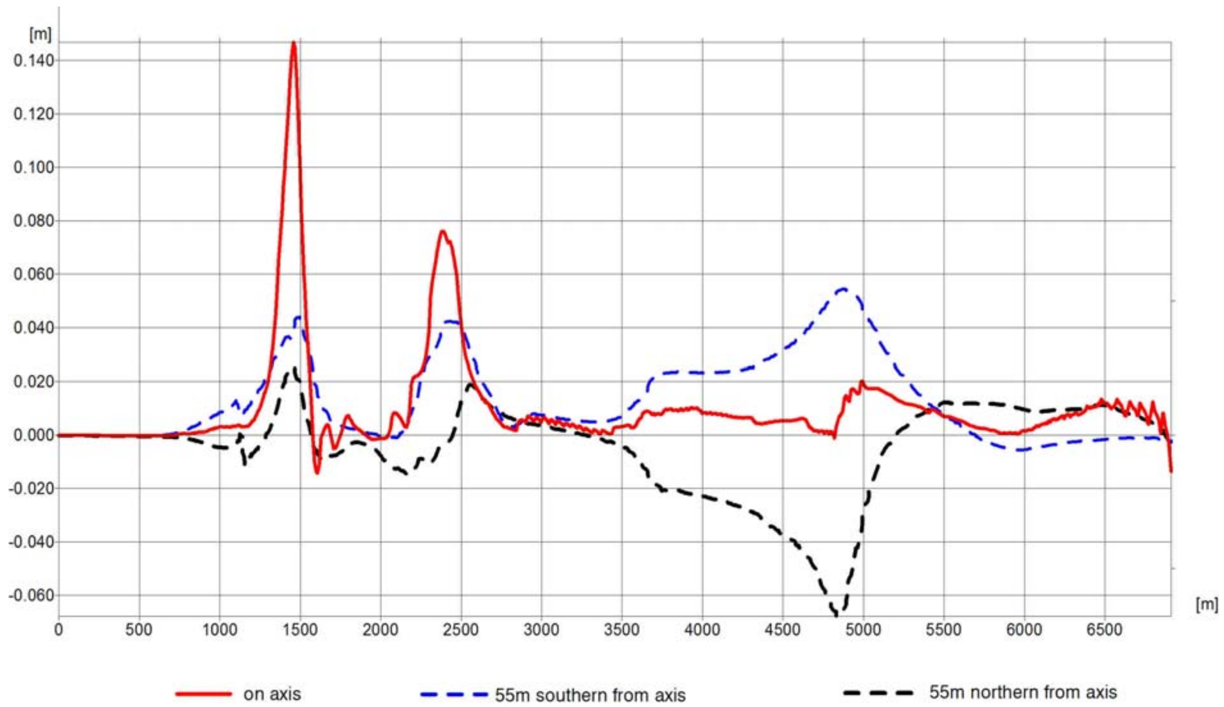
- the leakance $l_w = k_w / h_w$ (k_w, h_w–permeability and thickness of a wall, accordingly); the values ∞, 10^{-3}, 10^{-5} were tried;
- the wall bottom location: Q_4, gQ and D3gj2z layers were tried.

Parametres of the tested wall versions are given by Table 4. If the wall bottom is sited on the Q_4 layer (versions 1, 2) then even a perfect wall ($l_w = 10^{-5}$) can only slightly decrease the drawdown d_t caused by the trench (d_t= 22m→17m), because no wall can stop groundwater inflow through the trench bottom sandy area (Table 5).

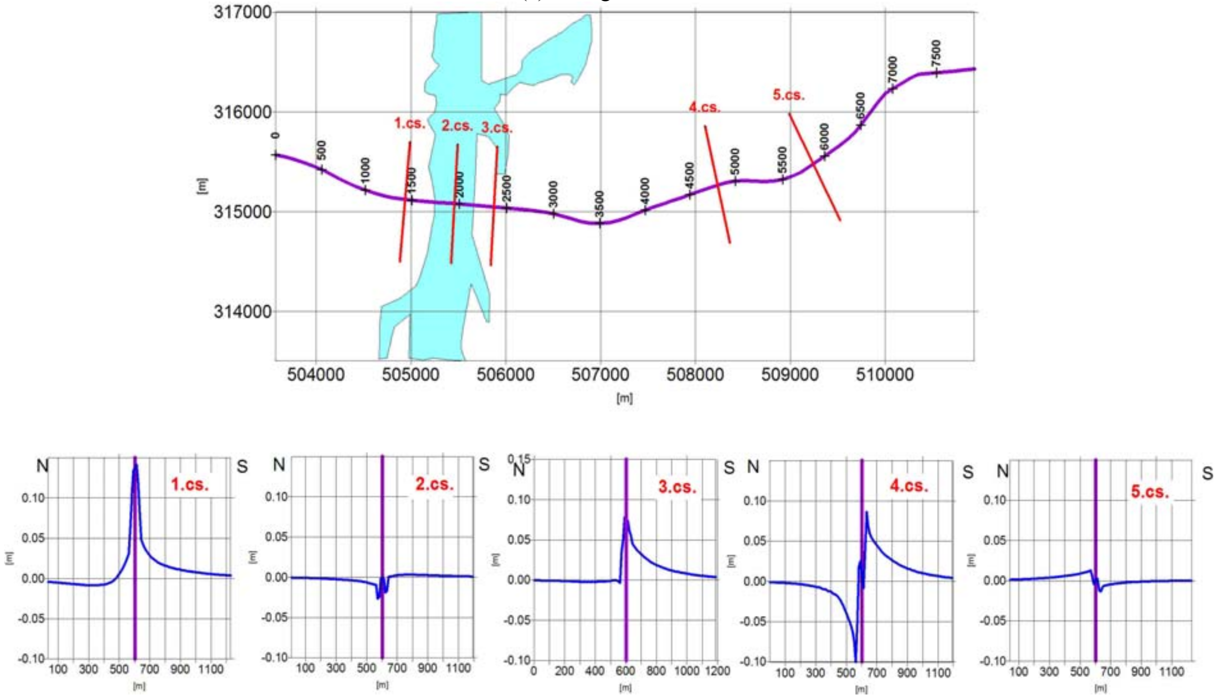
If the wall bottom reaches the gQ aquitard (version 3, 3a), then the wall reduces the drawdown tenfold (d_t = 22.0m→2.2m) with respect to the no wall version1.

In Fig. 8b, drawdown graphs along the cross section NS are shown. It follows from these graphs that the wall leakance $l_w < 10^{-3}$ provides sufficient isolation of the trench, because further perfection of the wall ($l_w = 10^{-3} \rightarrow 10^{-5}$) provides small effect (d_t = 2.2m→1.6m). Unfortunately, the gQ aquitard is thin, at the trench area (Fig. 3). For this reason, this aquitard is no safe base for the wall bottom.

Only the D3gj2z aquitard may serve, as the reliable base for the wall bottom (versions 4, 4a). Then d_t <0.72m ($l_w = 10^{-3}$ 1/day) and if $l_w = 10^{-5}$ 1/day then the wall behaves as an impermeable obstacle (dt = -0.2m).



(a) Along tunnel axis



(b) In cross sections orthogonal to tunnel axis

Fig. 7 Groundwater head changes $\Delta\varphi_Q$.

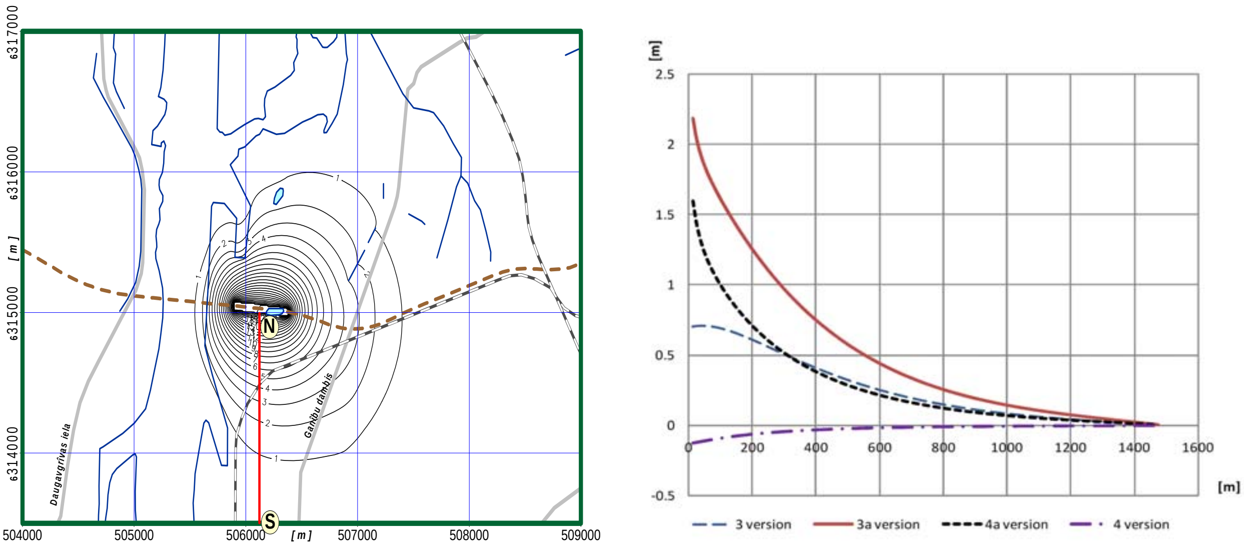
Table 4 Parametres of construction trench wall.

Version Nr.	1.	2.	3.	3a.	4.	4a.
Leakance*)	∞	10^{-5}	10^{-5}	10^{-3}	10^{-5}	10^{-3}
Wall bottom	Q4	Q4	gQ	gQ	D3gj2z	D3gj2z

*leakance–k_w/h_w [1/day], k_w, h_w wall permeability and thicknes.

Table 5 Flow summary (m^3/day) of construction trench.

Version Nr.	Bottom inflow	Wall inflow	Pump out	Total
	1	2	3 (1 + 2)	1 + 2 + 3
1.	-3835.5	-3802.5	7638.0	0.0
2.	-5948.2	0.0	5948.2	0.0
3.	-666.6	-4.9	671.5	0.0
3a.	-745.1	-398.6	1143.7	0.0
4.	-134.5	-5.1	139.6	0.0
4a.	-305.1	-397.7	703.8	0.0



(a) No watertight wall used (b) Cross section NS watertight wall applied

Fig. 8 Depression *dt* (m) caused by the construction trench.

However, the wall depth reaches 50 m (Fig. 3). Making of such a wall is the very complex task.

In Table 5, the summary of trench flows is presented. To keep the trench dry, the pump-out flow must be large enough to compensate groundwater inflow through the trench bottom area and its wall. It follows from Table 5 that the wall considerably reduces the groundwater discharge when the wall bottom sits on an aquitard. The minimal and maximal discharges 139.6m^3/day and 1143.7m^3/day are for the versions 4 and 3a, accordingly. For the no wall case (version 1), 7,638m^3 should be pumped out each day.

It follows from the above results than making of open deep construction trenches is expected to be a difficult task.

5. Conclusions

The hydrogeological model has been created to estimate groundwater regime changes that may be caused by building of the underground tunnel in Riga, Latvia. The tunnel body has practically no effect on the groundwater regime. A wrongly built deep trenche may cause not allowable lowering of a groundwater table at their surroundings.

References

[1] Topographical maps on the proposed versions of the underground tunnel. Basler and Hofman, Deutschland GmbH, February 2008

[2] Report on proposed versions of the underground tunnel. Basler and Hofman, Deutschland GmbH, February 2008 (in Latvian)

[3] Final report on hydrogeological modelling results for the Riga Northern transportation corridor (the 2nd link). Riga Technical University, Riga, July 2008. (in Latvian)

[4] Guide to using Groundwater Vistas, 2004, version 4, Environment Simulations Inc.