HYDROGEOLOGICAL MODEL FOR SIMULATION OF CONTAMINANT MIGRATION FOR THE AREA OF THE 3RD AND 10TH INFILTRATION POOLS OF THE BALTEZERS WATERWORKS, LATVIA

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Keywords: hydrogeological model, modeling of contaminant migration

1 INTRODUCTION

For the Baltezers waterworks, artificial groundwater recharge is used to keep high productivity of siphons taking water from the Quaternary aquifer ***Q***. Infiltration pools are filled by water of the Mazais Baltezers lake, and pollutants present here may reach the siphons. For example, during the summer period blooming of blue-green algae takes place and high- toxic substances are released in the lake water [1]. A hydrogeological model (HM) has been created to investigate contaminant migration from the pools. The area of the 3rd and 10th pools was chosen for HM. There migration processes are rather complex, because the siphon changes its direction within the area (Fig. 1).

Initial data for creating HM were taken from regional HM of the Baltezers, Rembergi and Zakumuiza water supply complex [2]. Migration of algae toxins was investigated.

The GROUNDWATER VISTAS (GV) system [3] was applied for supporting HM and tools used for simulation of migration. In this paper, methodology of contaminant migration simulation is considered. Results of simulation are reported.

2 DESCRIPTION OF HYDROGEOLOGICAL MODEL

Steady state 3D HM, describing mean conditions of the Baltezers siphon area, is applied. The *xyz*- grid of HM is built of ($h\times h\times m$) –sized blocks (h=11 metres is the block plane size, m is a variable block height). They constitute a rectangular xy-layer system covering 550m × 880m area which is part of regional HM described in [2]. As it follows from the vertical cross section (Fig. 2), HM contains four *xy*-grid planes simulating ***relh, aer,*** $\boldsymbol{Q_1}$ and $\boldsymbol{Q_2}$ layers. The four vertical sides of HM compose its shell. In HM, the vector φ of the groundwater head is approximated, in nodes of the 3D grid of HM, by the following algebraic equation system:

$$A\,\varphi = \beta - G\,\psi\,, \qquad A = A_{xy} + A_z + G, \qquad \beta = \beta_w + \beta_{in} + \beta_{sh} + \beta_{bot}\,, \qquad \beta_\psi = G(\psi - \varphi\,), \qquad (1)$$

where the matrices A_{xy} , A_z and G represent, correspondingly, the horizontal links (transmissivities) of the four layers (***relh, aer,*** $\boldsymbol{Q_1}$,$\boldsymbol{Q_2}$**),** the vertical ties between them, the

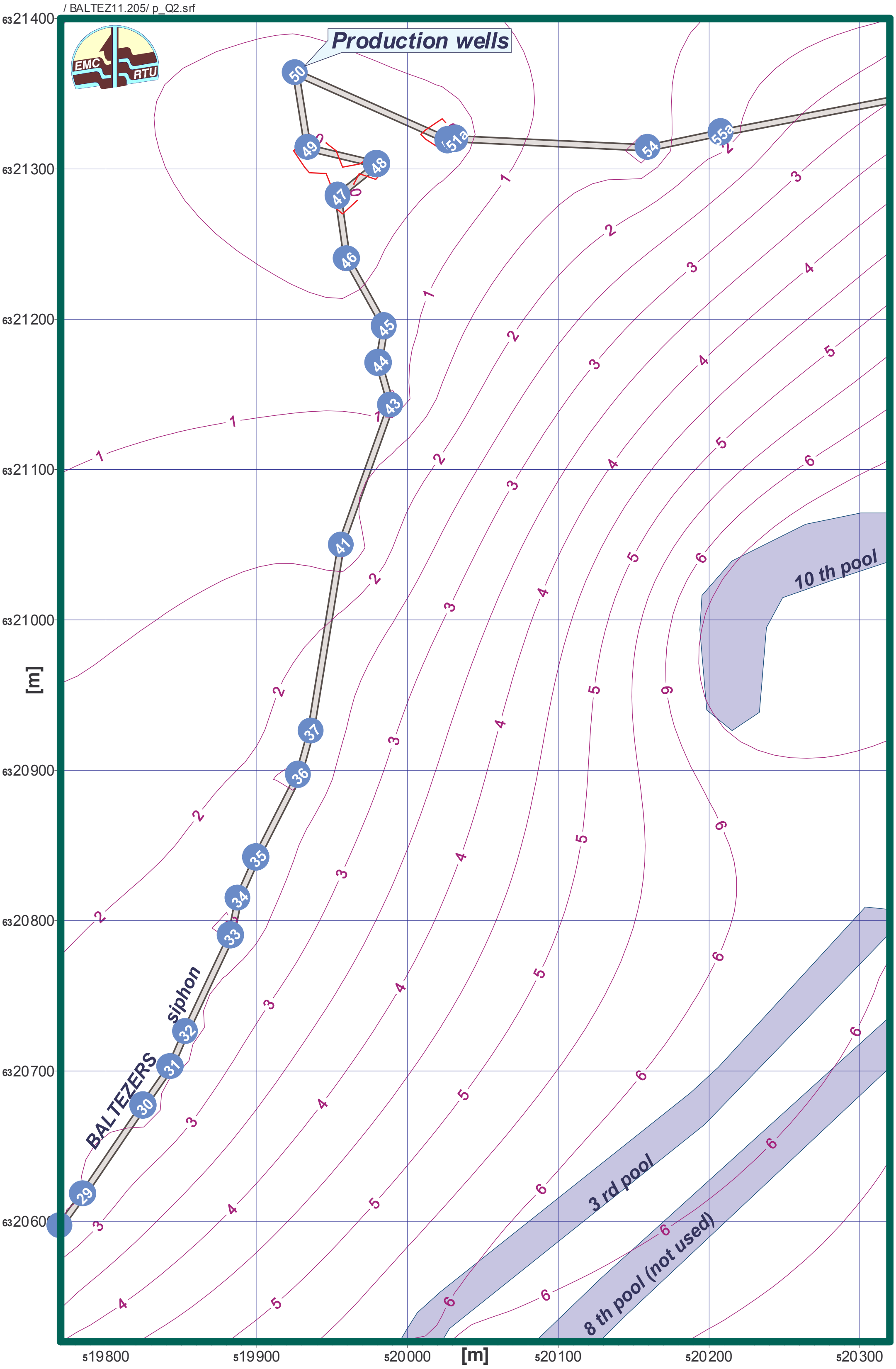


Fig. 1. The area of hydrogeological model applied for simulation of contaminant migration from 3 rd and 10 th infiltration pools towards the Baltezers siphon. The head distribution [m asl] of the ***Q*** aquifer is shown

elements connecting nodes of the grid with the piezometric boundary conditions ψ ; β is the vector of fixed boundary flows: β_w - the water production rate of wells, β_{in} is the flow of infiltration, β_{sh} and β_{bot} are the flows through the shell and the bottom surfaces of HM, respectively, β_ψ is the computed flow passing through the elements of G .

The ***aer*** zone and the two subaquifers ***Q$_1$*** and ***Q$_2$*** of equal thicknesses represent the unsaturated and saturated parts, correspondingly, of the sandy unconfined aquifer ***Q*** . For the HM area, the mean transmissivity of the ***Q*** aquifer is ~1000m^2/day (permeability k_Q =40m/day). The bottom surface of the ***Q$_2$*** aquifer is assumed to be impermeable (β_{bot} =0).

Instead of the fixed boundary flows β_{in} and β_{sh} , the ψ - type flows $\beta_{\psi in}$ and $\beta_{\psi sh}$ are applied by using the ψ_{relh} and ψ_{sh} boundary conditions, respectively. The ψ_{relh} condition presents the ground surface elevation map which is incorporated in HM by the ***relh*** layer.

The aeration zone ***aer*** simulates a formal aquitard where k_{aer} =$3 \cdot 10^{-4}$m/day and k_{aer} =0.9m/day are used, accordingly, for the natural infiltration and pool areas. The thickness m_{aer} ~ 1.0 metre is chosen, beneath the infiltration pools. This value represents the mean regime during the first 30 days, when the recharge flow is maximal [4]. Due to colmatation processes on the pools bed, the flow through if gradually decreases, and after 180 days the pool bottom should be cleaned by removing the silt coat clogging the artificial recharge of groundwater.

The siphon is connected with the set of wells which intake screens are located in the ***Q$_2$*** aquifer (Fig.1). Production rates β_w of the wells are distributed evenly along the siphon.

In Fig. 1, the computed groundwater table φ_Q of the ***Q*** aquifer is shown. The full distribution of φ , provided by HM, is applied for simulating contaminant migration from pools towards wells of the siphon.

3 METHODOLOGY OF CONTAMINANT MIGRATION SIMULATION

In the GV system, two tools for investigating contaminant migration are included: the MODPATH [5] and MT3D [6] systems. MODPATH provides rough estimates of migration where only pathlines of advective mass transport are obtained. The MT3D code computes the contaminant concentration *c(x,y,z,t)* by accounting for dispersion, sorption and degradation processes. The *c* - distribution is found, as the numerical solution of the following equation:

$$R\partial c / \partial t = \partial (D_x \partial c / \partial x) / \partial x + \partial (D_y \partial c / \partial y) / \partial y + \partial (D_z \partial c / \partial z) / \partial z -$$
$$- \partial (v_x c) \partial x - \partial (v_y c) \partial y - \partial (v_z c) \partial z + \theta^{-1} \beta_s c_s - \alpha R c ,$$

$$R = 1 + \theta^{-1} \rho_b k_d , \quad v_x = - \theta^{-1} k_x \partial \varphi / \partial x , \quad v_y = - \theta^{-1} k_y \partial \varphi / \partial y , \quad v_z = - \theta^{-1} k_z \partial \varphi / \partial z \ . \quad (2)$$

The concentration *c* is computed in nodes of the 3D HM grid. The (eq. 2) accounts for the following parameters of the dissolved mass transport in groundwater:

- the transience of migration ($\partial c / \partial t \neq 0$) even if the φ - distribution is steady ($\partial \varphi / \partial t = 0$) ;
- the mass transport at the velocity of the groundwater flow (advection) by using θ - the porosity of the soil, v_x , v_y , v_z and k_x , k_y , k_z - Cartesian components of the flow velocity and the soil permeability, accordingly; these data are extracted from HM; θ = 0.3 is used for the ***Q*** aquifer;

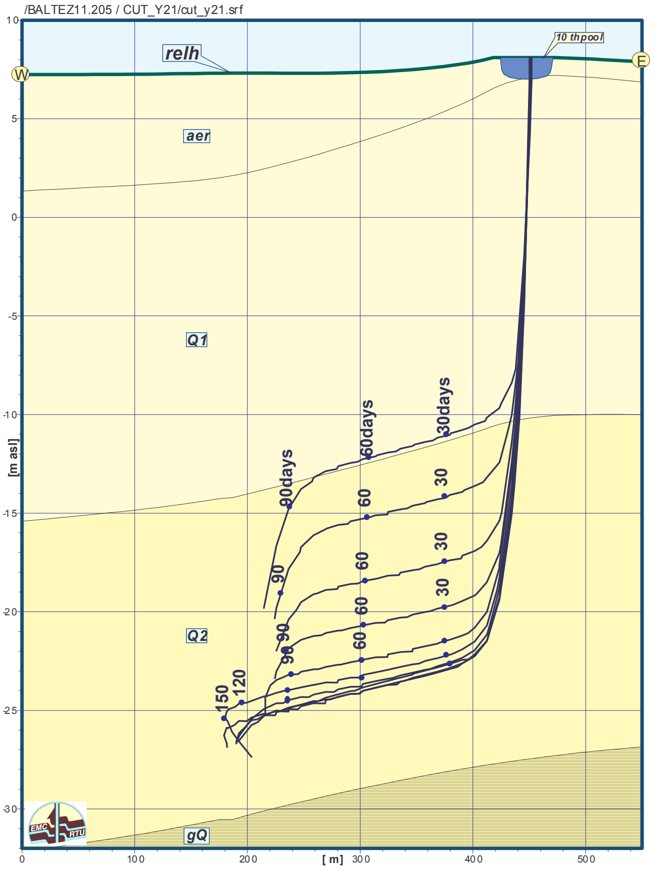


Fig. 2. The MODPATH vertical cross section W_E with pathlines started from the 10 th pool

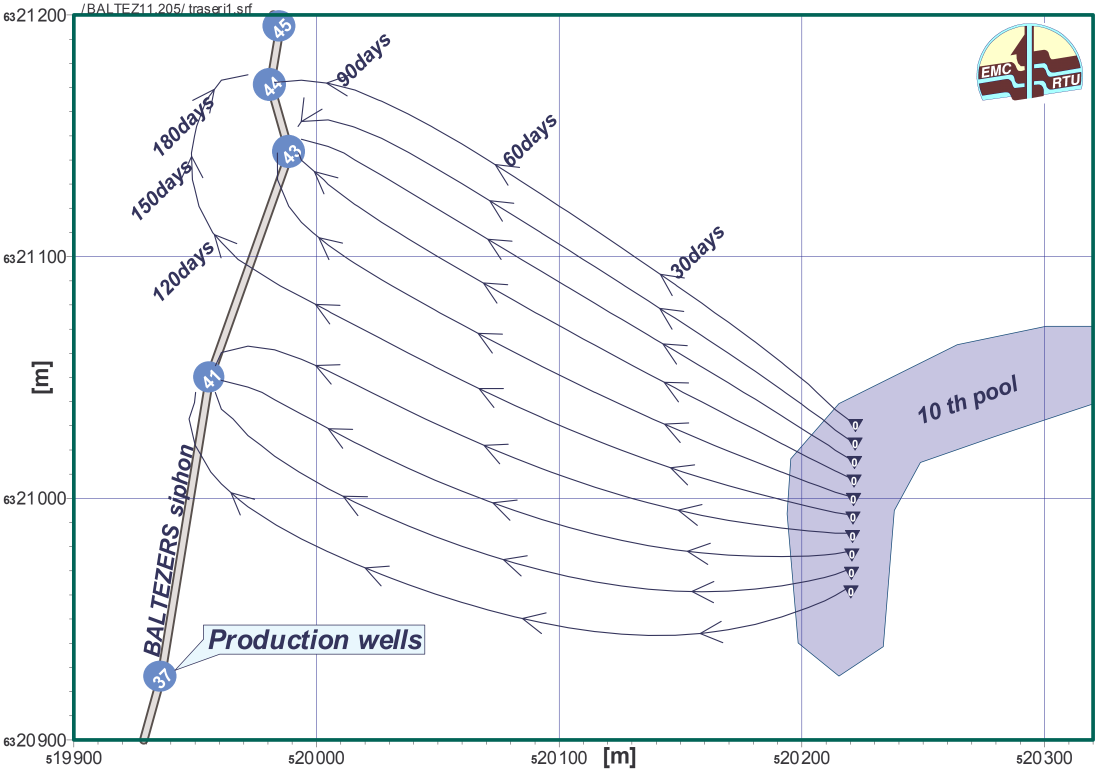


Fig. 3. The MODPATH xy-projection of pathlines started from the 10 th pool

- the contaminant sorption slows migration for R times; in R, ρ_b and k_d are the soil bulk density and the sorption coefficient; for example, if θ =0.3, ρ_b = 1.67, k_d = 0.2 then R = 2.11;
- contaminant degradation, by its velocity constant α ; in GV, the time parameter $t_{0.5} = \alpha^{-1} \ln 2$ is applied; during $t_{0.5}$ (for linear degradation) one half of the contaminant mass deteriorates;
- the dispersion, by the coefficients D_x , D_y , D_z ;
- the contaminant mass intake and extraction sources (pools and wells for reported HM) by the function - $\theta^{-1}\beta_s\, c_s$; β_s , c_s – the source rate and concentration, accordingly;
- the initial concentration distribution c_{in} .

The worst case scenarios of the algae toxin migration is considered. It is based on the following assumptions:

- the concentration c_s = 1.0 mg/l for the pool area is very high; for the Baltezers waterworks, c_{in} < 1.0 μg/l [1]; c_s = 1.0 mg/l may occur if the algae mass accumulates on the pool bottom;
- the first 30 days after cleaning of a pool is used to simulate the contaminant source; during this time period, the mean β_s rate is maximal;
- the migration time of contaminants is short (t = 90-120 days); no retardation, due to sorption is considered;
- the biodegradation speed, within the ***Q*** aquifer, is slow ($t_{0.5}$ = 60 days) [7]; no fast biodegradation ($t_{0.5}$ = 1.5 days) for the ***aer*** zone is accounted for.

During migration, concentration decreases also due to dilution of contaminants by fresh water. To estimate influence of the dilution, the pure advection case was considered if the constant concentration c_s= 1.0 mg/l was hold in the 10th pool.

4 RESULTS OF MIGRATION SIMULATION

For rough estimation of the migration time, the MODPATH system was applied. Two experiments were perform. The first one is represented by Fig. 2 and Fig. 3. There the vertical and *xy* – projections of pathlines, started from the 10th pool, are shown. It takes (90-120) days to reach the wells **Nr 41, 43, 44, 45** of the siphon.

In Fig. 4, the general *xy* – projection of pathlines is presented. There the pathline starting points are evenly distributed along the pools. It follows from Fig. 4, that the minimal travelling time have the pathlines started from the lower part of the 10th pool. For this reason, the experiments with the MT3D code was performed, for this part where 2 × 7 = 14 fixed concentration cells c_s = 1.0 mg/l were located, in the aeration zone ***aer*** beneath the 10 th pool (the GV system does not permit to put these sources into the ***relh*** layer, as the MODPATH allows). It follows from the MODPATH tests that only ~ 0.35 days are spent to migrate through the ***aer*** zone. Therefore, the shift of the concentration sources from the ***relh*** layer to the ***aer*** one has no practical influence on simulation results. The number of the initial concentration sources is limited due to restrictions of the MT3D code: if this number is too large then the simulation process may stop.

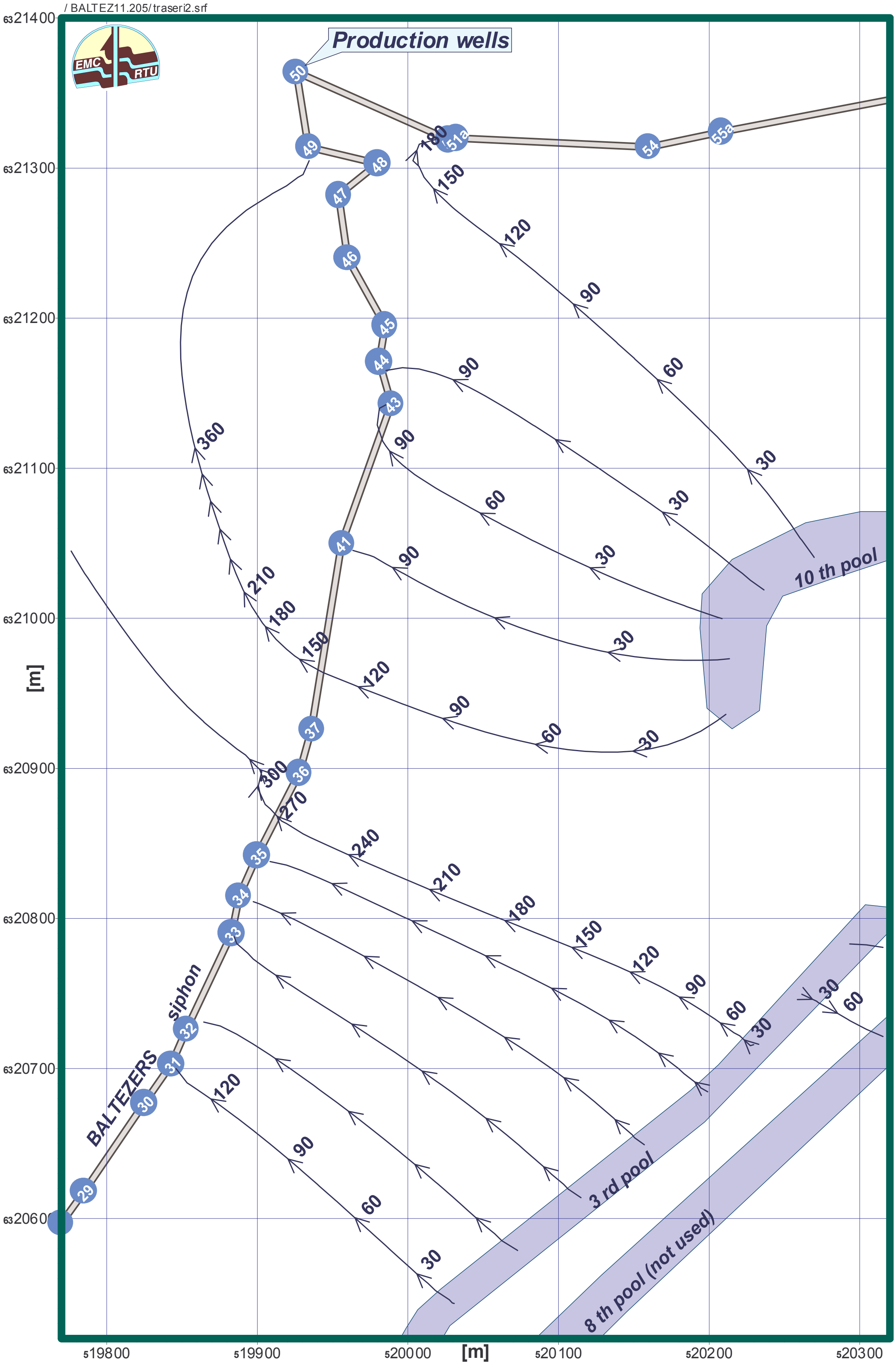
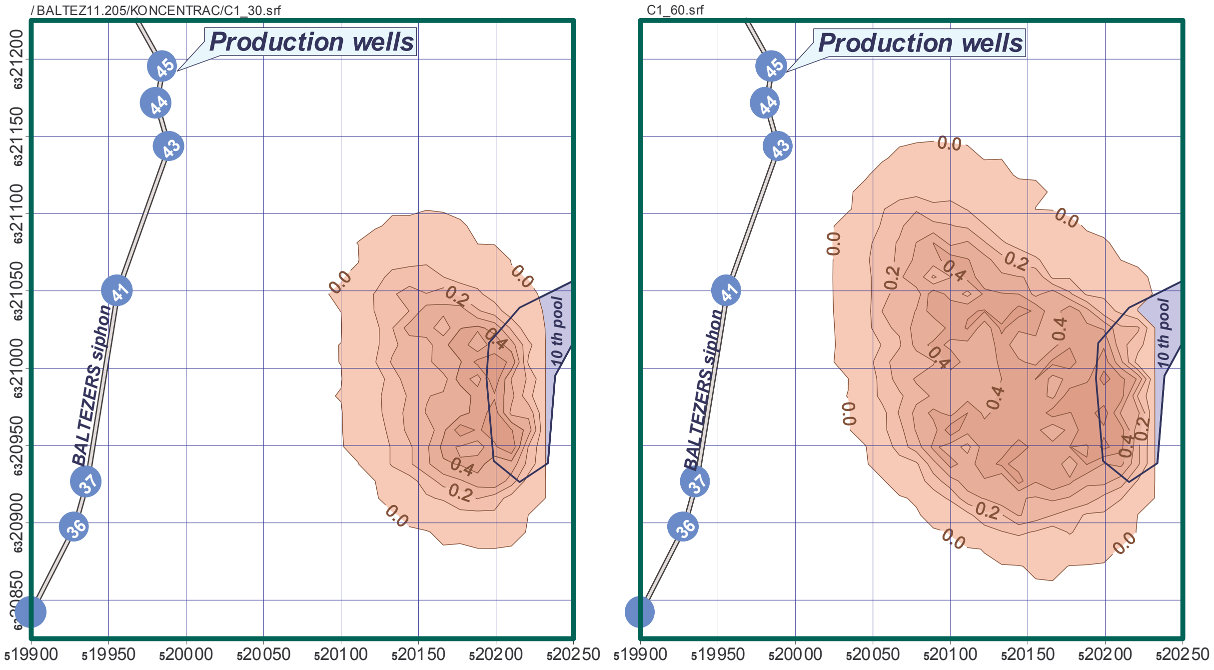
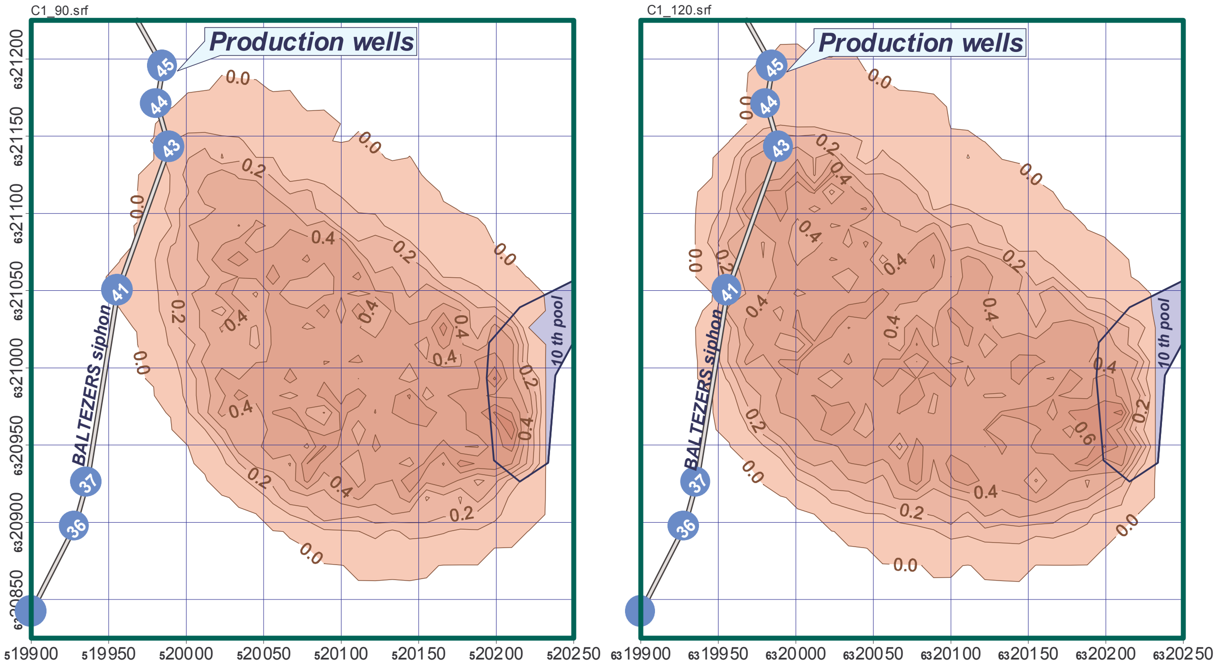


Fig. 4. The MODPATH xy-projection of pathlines started from 3 rd and 10 th pools



after 30 days

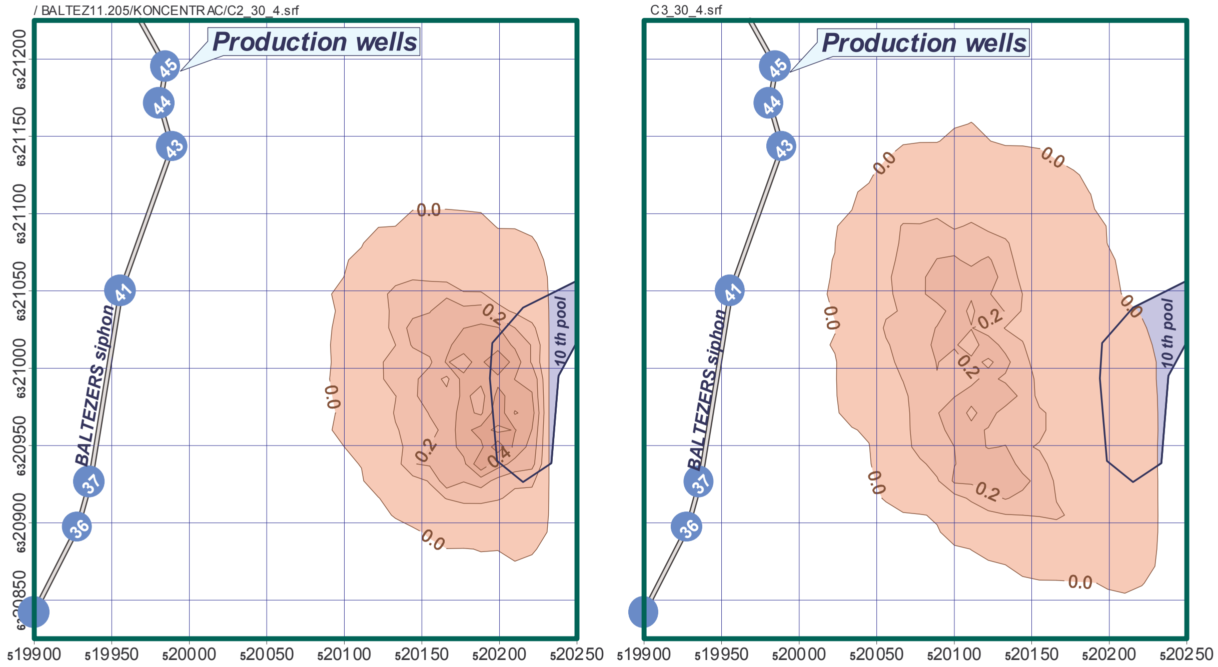
after 60 days



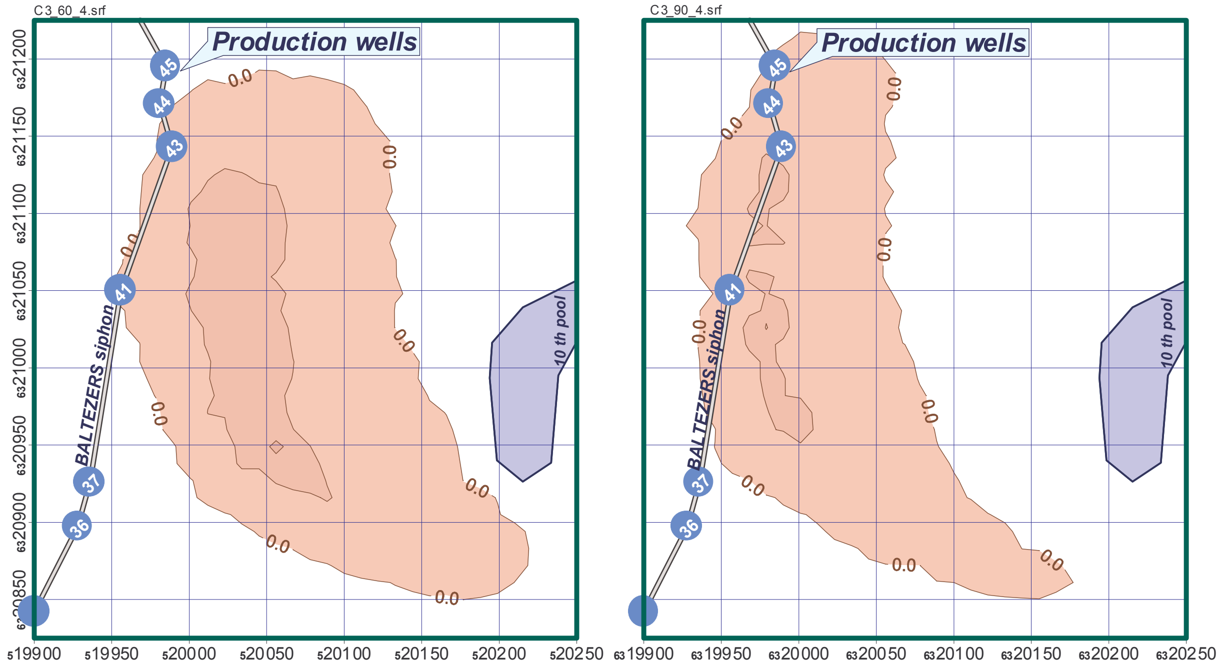
after 90 days

after 120 days

Fig. 5. The contamination concentration [mg/l] disribution versus time for the Q_2 aquifer.
Fixed concentration c = 1.0 mg/l in the 10 th pool.
Only advection accounted for



after 30 days after 60 days



after 90 days after 120 days

Fig. 6. The contamination concentration [mg/l] disribution versus time for the Q_2 aquifer. Concentration c = 1.0 mg/l is fixed in the 10 th pool only for 30 days. Biodegradation ($t_{0.5}$= 60days) is accounted for

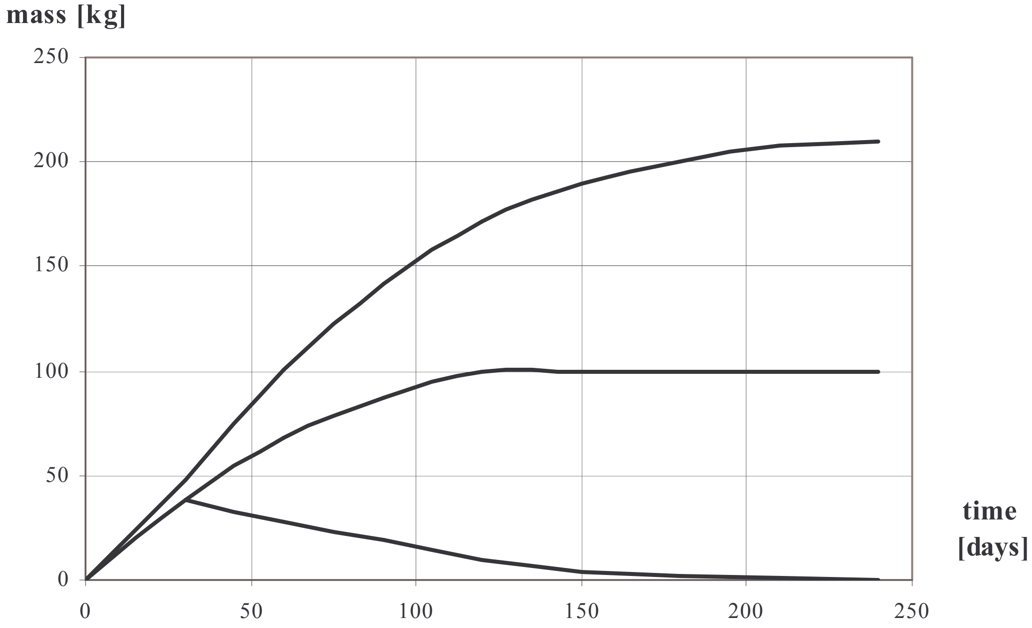


Fig. 7. The computed contaminant mass [kg] versus time [days] for the Q aquifer. The graphs 1 and 2: constant contaminant source - advection and biodegration, accordingly; the graph 3 - biodegradation, source exists 30 for days.

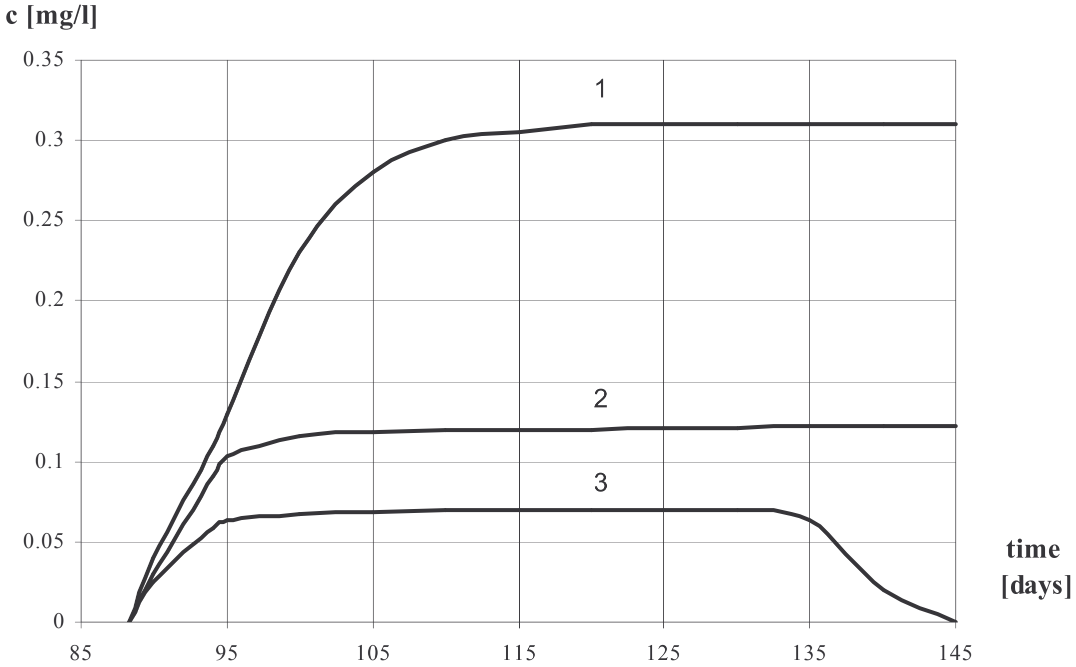


Fig. 8. The concentration [mg/l] versus time [days] in the well Nr 41. The graphs 1 and 2: constant contamination source - advection and biodegration, accordingly; the graph 3 - biodegradation, source exists for 30 days.

The method of characteristics (MOC) with the time step 0.5 days was applied for computing concentrations in nodes of the HM grid.

In Fig. 5, the set of computed concentration versus time for the $\boldsymbol{Q_2}$ aquifer is shown if the fixed concentration is used for the 10th pool. No dispersion, sorption and degradation are accounted for. Comparison of Fig. 3 and Fig. 5 confirms good concurrence of results provided by the MODPATH and MT3D systems. The graph 1 of Fig. 7 shows that the migration gets stable after ~180 days when the amounts of contaminants recharged by the pool and extracted by the wells become equal (no rise of total mass). Due to dilution, the concentration, in the well **No 41**, decreases ~3 times (Fig. 8). The graph 2 of Fig. 7 shows that due to biodegradation, the total contaminant mass decreases ~2 times. The concentration in the well **No 41** is ~0.12 mg/l. In Fig. 6, the set of concentrations versus time for the $\boldsymbol{Q_2}$ aquifer is shown if the concentration of the 10th pool is fixed only for the first 30 days (the length of time when the algae toxins are present in the pool). The biodestruction ($t_{0.5}$ = 60 days) [7]) is accounted for. It follows from Fig. 6 and from the graph 3 of Fig. 8 that concentrations of at vicinity of the siphon is considerably smaller (~ 0.07 mg/l), as for the case of the permanently active contaminant sources. The mass of contaminants decreases (Fig.7, graph 3).

The graphs of Fig. 7 are in good concurrence (t < 90 days) with results given by the formula:

$$m_{mob} = m_{init} \cdot exp(-\alpha t) + m_{st}\,(1-exp(-\alpha t))/\,\alpha t \qquad (3)$$

where m_{mob}, m_{init}, m_{st} are the contaminant masses migrating in groundwater, present in groundwater initially (t = 0), recharged by contaminant sources during the time t, correspondingly. For the reported case, m_{st} ~ 1.4 [kg] provided by 14×121~1700m^2 area of the 10th pool where 14 concentration sources are located.

5 CONCLUSIONS

The local hydrogeological model has been created to simulate contaminant migration for the area of 3rd and 10th infiltration pools of the Baltezers waterworks. Migration of algae toxins from the pools for the worst case scenarios has been investigated by applying the MODPATH and MT3D systems. Due to dilution and bio degradation processes, the concentration of toxins in production wells is at least ten times lower than in the pools. Therefore, even in the case of short migration time and slow biodegradation, considerable decrease of the toxin impact may be expected.

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Spalviņš A., Šlangens J., Janbickis R., Lāce I., Juhna T. Hidroģeoloģiskais modelis piesārņojuma migrācijas pētīšanai 3. un 10. infiltrācijas dīķu apgabalā Baltezera ūddensgūtnei, Latvijā.

Izveidots hidroģeoloģiskais modelis 3. un 10. infiltrācijas dīķu apgabalam Baltezera ūdensgūtnei. Modelis izmantots aļģu toksīnu migrācijas pētīšanai ar MODPATH un MT3D modelējošo sistēmu palīdzību. Pateicoties atšķaidīšanas un hidrodegradācijas procesiem, toksīnu koncentrācija sifona aku tuvumā ir vismaz 10 reižu mazāka nekā infiltrācijas dīķos. Tātad arī toksīnu maza migrācijas laika un lēnas biodegradācijas gadījumā, toksīnu ietekme tiek būtiski vājināta.

Spalviņs A., Slangens J., Janbickis R., Lace I., Juhna T. Hydrogeological model for simulation of contaminant migration for the area of the 3rd and 10th infiltration pools of the Baltezers waterworks, Latvia

The local hydrogeological model has been created to simulate contaminant migration for the area of 3rd and 10th infiltration pools of the Baltezers waterworks. Migration of algae toxins from the pools for the worst case scenarious has been investigated by applying the MODPATH and MT3D systems. Due to dilution and bio degradation processes, the concentration of toxins in production wells is at least ten times lower than in the pools. Therefore, even in the case of short migration time and slow biodegradation, considerable decrease of the impact of the toxins may be expected.

Спалвиньш А., Шланген Я., Янбицкий Р., Лаце И., Юхна Т. Гидрогеологическая модель для исследования миграции загрязнений для области 3. и 10. инфильтрационных бассейнов водозабора Балтезерс, Латвия.

Создана гидрогеологическая модель для области 3. и10. инфильтрационных бассейнов водозабора Балтезерс. Модель использована для исследования миграции загрязнений с применением моделирующих систем MODPATH и MT3D. Благодаря процессам разбавления и биодеградации, концентрация загрязнений в области сифона будет по меньшей мере во 10 раз меньше чем в бассейнах. Таким образом, даже в случае малых времен миграции и медленной биодеградации, влияние токсинов будет значительно ослаблено.

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