SCIENTIFIC PROCEEDINGS OF RIGA TECHNICAL UNIVERSITY
Series - *Computer Science* *Boundary Field Problems and Computer Simulation* - 43rd thematic issue
2001

Modelling of dissolved oil product migration in groundwater at the former Rumbula airbase, Latvia

A. Spalvins, J. Slangens, R. Janbickis & I. Lace
Environment Modelling Centre, Riga Technical University, Latvia

Keywords: hydrogeology, modelling

ABSTRACT: To estimate the risk caused by migration of dissolved in groundwater jet fuel products to the Daugava river, the 3D-hydrogeological model (HM) has been created for the former Rumbula airbase. The nearby Getlini waste disposal site is also included. Due to a bioremediation, only a small part of fuel reaches Daugava. Contaminants coming from Getlini are mostly caught by two ditches falling into this river.

1 CASE HISTORY

The former Rumbula airbase was selected as the pilot site for the project *Cooperation between Latvia and Denmark on transfer and know-how concerning investigation and remedy of oil pollution in groundwater*. The airbase is located not far from the centre of Riga. The sandy aquifer of the site is contaminated with immiscible and dissolved jet fuel products (subsequently referred to as oil). The airbase was operational over a 25-year period and was shut down in 1978.

The project commenced in 1996 and was performed by the Hedeselskabet from Denmark, the VentEko Ltd., and the Environment Modelling Centre (EMC) of the Riga Technical University from Latvia. Presently, only investigations regarding the immiscible oil products are completed and recovery of free oil is on-going. The following research studies have been performed (Report 1996, Report 1998, Report 2000):

- six oil plumes (*b6, b9, b12, b15, b23, b34*) were identified (Fig. 1) and volumes of the contaminated soil and oil were estimated; for the largest *b6* plume, the soil and oil volumes are about 18,000m^3 and 1,500m^3, respectively; The oil plumes are not moving, and they cannot reach the Daugava river;
- monitoring in wells of an apparent thickness for the oil plumes; its value depends strongly on natural fluctuations of the groundwater table;
- creation of 2D and 3D HM of the site to investigate dynamics of free and dissolved oil, respectively.

Remediation of the largest *b6* plume has provided valuable knowledge about vacuum-enhanced, skimmer and Auto Pump recovery technologies. Presently, the vacuum based one is used, and ~ 100 m^3 of oil have been recovered during 1998-2000. However, the clean-up of Rumbula is far from being completed - the other five smaller plumes are still untouched, and dissolved oil products continue to contaminate the site water table as they migrate towards the Daugava river. Modelling has shown that, due to a natural bioremediation, only ~ 50g/day of oil enter the Daugava river, and likely, no special remediation is needed if the river protection is considered. Conservative contaminants of the Getlini site can interfere with the *b12* plume and a considerable part of Getlini waste gets caught by the melioration ditches falling into the Daugava river (Fig. 1, Fig. 3). These ditches, not the slow groundwater motion, are mostly responsible for transport of pollutants from the Getlini place.

This paper amply uses materials of (Report 2000). All data needed for creating and calibrating of the model were provided by the VentEko, Ltd, Latvia.

2 THE SUMMARY ON MATHEMATICS AND MODELLING METHODOLOGY APPLIED

Semi-3D steady state HM, describing mean annual conditions of the Rumbula place, is applied. The *xyz*-grid of HM is built of ($h * h * m$)-sized blocks (h = 30 metres is the block plane size; m is a variable block height). They constitute a rectangular *xy*-layer system covering the 3.66 km $*$ 2.37 km = 8.6742 km^2 area. As it follows from the vertical cross section (Fig. 2), HM contains seven layers. The four vertical sides of HM compose its shell. In HM, the vector φ of the piezometric head is approximated, in nodes of the 3D grid of HM, by the following algebraic equation system:

$$A * \varphi = \beta - G * \psi , \qquad A = A_{xy} + A_z - G, \qquad \beta_\psi = G (\psi - \varphi) \tag{1}$$

where the matrices A_{xy}, A_z, G represent, correspondingly, the horizontal links of the four aquifers (*rel, qo, qb, pl*), the vertical ties originated by the three aquitards (*aer, is, gq*), the elements connecting nodes of the grid with the piezometric boundary conditions ψ; for Rumbula HM, only the conditions of the ψ-type are used, and no fixed boundary flows β are applied; β_ψ is the computed flow passing through elements of G.

In Rumbula HM, the ground elevation *rel* map of Fig. 1 and the piezometric head surface of the Devonian *pl* aquifer are applied, correspondingly, as the ψ_{relh} and ψ_{pl} boundary conditions. The aeration zone *aer* (unsaturated part of the Quaternary *q* aquifer) is treated, as an formal aquitard. The saturated part of *q* is conditionally composed of the upper *qo* and lower *qb* aquifers (Fig. 2). In *qo,* bodies of the oil plumes are floating. The *gq* aquitard joins the Quaternary and Devonian aquifers. The formal *is* aquitard accounts for the vertical transmissivity of the water saturated part of the *q* aquifer.

The elements a_{xy} and a_z of the matrices A_{xy} and A_z, (the corresponding elements g_{xy} and g_z of the matrix G), accordingly, are computed by using digital maps of the thicknesses *m* and permeabilities *k*, as follows:

$$a_{xy} = k * m \;, \quad a_z = h^2 * l \;, \quad l = k / m \;; \\ m_i = z_{i-1} - z_i \geq 0 \;, \qquad i=1,\dots,6,7 \tag{2}$$

where z_{i-1} and z_i are top and bottom surfaces of the *i*-th stratum, respectively; z_0 represents the ground surface *rel* and *l* is the leakance of an aquitard. For the Groundwater Vistas (GV) system applied for modelling mass transports processes, the *z*-surfaces, the *k*- and *l* - maps of aquifers and aquitards are applied, as the input data (Environmental simulations, 1997).

When the calibrated φ-distribution of (1) is obtained then HM is applied, as the driver for the transport model (TM). In TM, processed by the MT3D'99 code (Papadopulos, 1999), the dissolved contaminant transport in groundwater versus time *t* is described by the concentration distribution $c(x, y, z, t)$. For Rumbula TM, no dispersion and sorption processes are accounted for, due to reasons explained later. In nodes of the TM grid, the *c*-distribution is obtained, as the numerical solution of the following boundary problem:

$$\partial c / \partial t = \partial(v_x c)\, \partial x + \partial(v_y c)\, \partial y + \partial(v_z c)\, \partial z + \theta^{-1}\beta_s c_s - \alpha c, \\ v_x = - \theta^{-1} k_x \,\partial \varphi / \partial x \,, \quad v_y = -\theta^{-1} k_y \,\partial \varphi / \partial y \,, \quad v_z = -\theta^{-1} k_z \,\partial \varphi / \partial z \;. \tag{3}$$

The following basic elements of the contaminant transport are accounted for:

- by the term $\partial c / \partial t$ - the transitory nature of this transport, even if HM provides steady φ-distribution ($\partial \varphi / \partial t = 0$);
- via the Cartesian velocities v_x , v_y , v_z of the groundwater flow - the directed motion of contaminants; θ - the porosity of the soil ($\theta = 0.3$ is applied for TM of Rumbula); the permeabilities k_x , k_y , k_z and values of the gradients $\partial \varphi / \partial x$, $\partial \varphi / \partial y$, $\partial \varphi / \partial z$ are provided by HM;
- by the parametre α - the contaminant decomposition processes; in GV, $\alpha = ln2 / t_{0.5}$; $t_{0.5}$ - is the half life time of the contaminant;
- by c_s , β_s - the contaminant source concentration and rate, accordingly; the flow β_s is specified automatically by the $\beta_{\psi aer}$ and the lateral flow of *qo*;
- c_{in} ($t = 0$) is the initial concentration distribution for; Rumbula TM, $c_{in} = 0$ is applied.

The form (3) does not account for a difference between densities of pure and contaminated groundwater. This drawback of the MT3D type codes may result in serious errors when this difference is large. Dispersion and sorption processes are not account for (in (3) the corresponding terms are omitted) because a considerable uncontrollable numerical dispersion dominates the solution of (3), and no sorption has been observed experimentally for the Rumbula case (Hedelskabet, 2000).

The MT3D code offers four different solution methods of (3). The method of characteristics (MOC) was applied for the case reported.

3 THE MODEL GEOMETRY

The size and location of the modelled area (Fig. 1) were slightly corrected with respect to the ones applied for modelling migration of the free oil phase (Report, 1996) and a little finer plane approximation step h (40 $\rightarrow$ 30 metres) was also applied. Instead of the single Quaternary aquifer q, the new Rumbula 3D-model contains seven geological layers (Fig. 2), and the aquifers there is modelled by four grid planes. Each of them contains 124×80 = 9,920 nodes. Thus, the grid of HM is composed of 4×9,920 = 39,680 nodes. The upper and lower grid planes are used for specifying boundary conditions ψ_{relh} and ψ_{pl} , on the HM top and bottom, accordingly. In two planes representing qo and qb, the solution φ of (1) is obtained. The upper qo layer is used as a place where the contamination sources accounted for by the MT3D code may be located. To simplify the HM geometry , the constant ratio: $(m_{qo} + m_{qb}) / m_{qo} = 7$, is used everywhere (Fig.2). For the formal $relh$ and pl aquifers, the applied thicknesses are $m_{relh} = 0.02$ and $m_{pl} = 1.0$ metres, correspondingly, and they support the solution process of (1) in the GV environment.

In Rumbula, the layers q and gq are discontinuous, because their bodies have been eroded by the Daugava river ($m_q = m_{gq} = 0$ there). In HM, to overcome some computational problems caused by this discontinuity, the thicknesses $m_q + 0.2$, $m_{gq} + 0.02$ were applied, instead of the original ones. The basic top elevation z-surfaces of HM were obtained by the GDI program (Spalvins & Slangens 1995)

Initially, the real thicknesses m_{aer} , $m_{qo} + m_{qb}$ are unknown They can be obtained when the calibrated φ-distribution is available. During the HM calibration, the formal initial thicknesses $m^{(0)}_{ae}=m^{(0)}_{qo}=0.02$ metres, and $m_{qb} = z_{relg} - z_{gq} + 0.2$ are applied, in order not to disturb the initial HM geometry, until the targets of the calibration have been achieved. In Fig. 2, the top surface of the qo aquifer represents the profile of the calibrated φ - distribution, when the real HM geometry is applied.

4 PERMEABILITY MAPS

The k-maps of (2) were generated by the GDI program. They were used for obtaining the transmissivity and leakance maps for aquifers and aquitards, correspondingly. No permeability calibration was performed for the q and gq layers. The recommended values $k_q = 20$ m/day and $k_{gq} = 10^{-4}$ m/day were applied, accordingly (Report 2000) The is aquitard accounts for the vertical permeability component k_{zq} of the q aquifer. It is assumed that, due to the anisotropy, $k_{zq} = 0.1 * k_q = 2.0$ m/day. Because the formal thickness $m_{is} = 0.02$ metres, the leakance l_{is} of should be computed, as follows:

$$l_{is} = k_{is} / 0.02, \quad k_{is} = 2 * 0.02 / m_{qb} = 0.04 / m_{qb}, \qquad l_{is} = 2/ m_{qb} \tag{4}$$

where the corrected k_{is} distribution is used. Similarly, the permeability k_{qo} must be corrected (not calibrated!), to keep the HM geometry unchanged, during the HM calibration (Spalvins 2000).

The k_{aer} map is the main tool to calibrate Rumbula HM. As the start try, the following permeability values: $k_{aer} \sim 10^{-3}$ m/day and 1 m/day were applied, accordingly, for the areas of descending (infiltration) and ascending (discharge) flows of the aeration zone. The ascending flows are caused by elements of the hydrographical network. For Rumbula HM, searching for the proper k_{aer} values of the melioration ditches was the major task of the calibration.

5 COMMENTS ON MODELLING PROGRAMS

For Rumbula HM and TM, two basic modelling programs: REMO (Spalvins et al. 1996) and GV were used. The REMO code were applied for creating HM, due to its following advantages (Spalvins et al. 2000):

- the impact of human errors is considerably reduced, because all necessary maps are obtained digitally from initial data by the GDI program, which is synchronised with REMO;
- on the HM top, the reliable map of the rel surface is always used for governing the infiltration flow;
- REMO is handy for a modeller, to assist the calibration of HM.

When results of HM are obtained, they are imported into the GV system where HM and TM are interlinked. In GV, the MODFLOW code environment (Mc. Donald & Harbaugh 1988) carries HM, but the MT3D'99 program runs TM. It is also possible to use the MODPATH program (included in GV) to obtain the first rough prognoses regarding the contaminant migration (Pollock 1989).

The SURFER code (Golden software 1997) was applied for graphing simulation results and for running the necessary mathematical operations with data files.

6 RESULTS PROVIDED BY THE HYDROGEOLOGICAL MODEL

The hydrogeological model serves, as the driver for TM. The following HM results are needed:

- the HM geometry (z – maps);
- calibrated transmissivity a_{xy} of aquifers;
- calibrated leakance l of aquitards;
- computed φ - distributions of the *qo* and *qb* aquifers;

The lateral groundwater flow of the q aquifer is directed forwards the Daugava river. The flow is also under considerable influence of the local melioriation ditches, which may catch some part of contaminated groundwater coming from the Getlini place and the *b12* oil spill (Fig. 1, Fig. 3).

The infiltration flow, passing through the *aer* zone, is of the utmost importance for HM and TM, because it dominates the φ-distribution of (1) and also acts, as a part of the contaminant dissolution rate β_s of (3), at places where the contaminant sources are located. In Rumbula HM, the infiltration flow is specified by the reliable ψ_{relh}-surface applied, as the boundary condition of Rumbula HM.

For the Rumbula HM calibration the main targets are, as follows:

- to minimize differences between observed and computed head values;
- to obtain natural images of computed head distributions; available knowledge regarding observed trends of contamination migration should also be accounted for;
- to keep under control values of groundwater flows, especially, the ones passing through aquitards; the values of the flows for the hydrographical network must be adjusted for, to match realistic discharge rates;
- to adjust HM, by taking into consideration the results of mass transport modelling.

The above goals are interdependent. Therefore, the HM calibration is always an iterative one. For Rumbula HM, these goals have been achieved:

- the mean head difference is 0.22 metres; the maximal one is 0.57 metres;
- the φ-distribution (Fig.3) behaves naturally; no false trends of contaminant migration are observed there;
- in HM, no extreme, unnatural values of the groundwater flows are existent;
- the first results of MODPATH suggested that the flow through the *gq* aquitard should be decreased to match the observed trends of the contamination migration.

7 EXPERIMENTS ON MASS TRANSPORT MODELLING

The MODPATH and MT3D'99 codes (included in GV) were used to investigate the contaminant mass transport. The MODPATH results provide rough estimates for travel times of conservative contaminants and expose particle traces from sources to groundwater recharge areas. The MODPATH computed travel times are given by Table 1 (Report 2000). For example, it takes ~ 20 years for the *b*6 spill contaminants to reach the Daugava river. In Table 1, the *bT* plume is accounted for. Its travel time is very short (~2.0 years). Probably, due this reason, no free oil phase is detected nowadays at this area.

In order to obtain more general results, relative concentrations [%] were computed by the MT3D code (100%=10g/m^3). Rather robust assumptions were used, to run the MT3D code:

– oil sources were sited in the *qo* aquifer, their locations, sizes, and concentrations c_s were assumed to by constant versus time;
– to account for the natural bioremediation, the bulk estimates of the parametre $t_{0.5}$ were used for all layers of HM;
– the relative source concentrations c_s [%]were computed as: $c_s = 100\ m_s\ /\ m_{smax}$ (m_s , m_{smax} mean and maximum thicknesses, accordingly, for the oil spills). The applied source concentrations given in Table 2 were based on (Report 1996).

The oil (jet fuel) monitored concentrations provided by (Hedelskabet 2000) were used to calibrate TM. The following main results were obtained (Report 2000):

– characteristic distributions of concentrations (Fig.3);

- in the *q* aquifer, the travel times of a conservative contaminant matched the ones computed by the MODPATH code;
- the parametre $\alpha = 0.001$ ($t_{0.5} \sim 600$ days), proposed in (Hedelskabet, 2000), did not provide to match the monitored oil concentrations (due to fast decomposition then nearly no oil entered Daugava); $t_{0.5} = 1800$ days provided the best match of computed and observed concentrations; perhaps, this value represented the upper bound of $t_{0.5}$ (Fig.3);
- In the upper *qo* aquifer, the computed concentration was always higher than in the *qb* one (Table 3);
- at time $t \sim 5000 - 7000$ days, some equilibrium of the oil migration processes took place; this result followed from graphs of Fig.4 (computed mass of dissolved oil), Fig.5 (concentrations at observation wells) and from a comparison of the concentration distributions at successive moments of time;
- due to oil decomposition processes, bodies of contamination plumes narrowed in comparison with the case of conservative contaminants;
- the main axis of the computed *b*6 spill area did not coincide with the line formed by the observation wells 17, 107, 108, 109, 110, 111 used for the TM calibration (Fig. 3);
- the total oil dissolution rate (for all sources together) was ~ 300 g/day; during 10,000 days, $\sim 3 * 10^3$ kg of oil was dissolved and $\sim 1.5 * 10^3$ kg of oil was the equilibrium total mass after ~ 6000 days (Fig.4); therefore, the oil spills could not get dissolved in groundwater during a reasonable period of time at least $1500 * 10^3/0.3 \sim 5 * 10^6$ should pass!);
- about ~ 54 g/day of oil were being discharged into the Daugava river; the *b*6 and *b*12 plumes had the largest discharge rates ~ 15 g/day each (Table 4); some part of oil reached the *pl* aquifer; however, only the isolines ($c \sim 1\% = 0.1$ mg/l) entered this aquifer, and ~ 16 g/day of oil discharged there;
- contaminants from the Getlini place entered the Western, Eastern and Railroad ditches; the influence of the Getlini contaminants, on the *b*12 spill, was insignificant (Fig.3).

8 CONCLUSIONS AND RECOMMENDATIONS

The hydrogeological and transport 3D-models have been developed to simulate migration of dissolved oil products for the Rumbula place. These models have provided the following main results:

- the further search for reliable hydrogeological and hydrochemical data is necessary, because the simulation results indicate that some unknown important factors (melioration systems located along the runway, buried ditches forming lenses of high permeability along the line of observation wells) have considerable influence on the oil contaminant motion for the *b*6 and *b*9 plumes; if some melioration system of the airbase is still acting, a considerable part of dissolved oil may be quickly discharged into the Daugava river;
- although the sorption processes are not accounted for they may worsen the pollution of the Rumbula place; therefore, field data for the oil sorption should be obtained, to use them for further simulation purposes;
- the Getlini place has no real influence on the oil contaminated airbase area; a large part of contaminants emitted by Getlini site gets caught by the melioration ditches of Rumbula;
- the current simulation results cannot be used, as an absolute truth, because the assumptions applied for TM are very robust; more information is needed, to improve reliability of simulation results, especially, for the *b*6 and *b*9 influence areas;
- for further investigations, Rumbula HM and TM may serve, as powerful tools enabling to make right decisions about the best remediation schemes applied.

Table 1. MODPATH computed contaminant travel times

Source name	Getlini[1)]	*b6*	*b9*	*b12*[1)]	*b15*	*b23*	*b34*	*bT*
Time [years]	20.0	20.5	23.0	2.5	16.5	12.5	12.5	2.0

[1)] - Eastern ditch is reached; Contaminants from sources *b6, b9, b15, b23, b34*, and *bT* travel to Daugava river.

Table 2. Source relative concentrations [%] applied by MT3D'99 code

Source name	b6	b9	b12	b15	b23	b34	bT [1)]
Mean [2)] thickness [m]	0.43	0.48	0.15	0.11	0.05	0.20	-
Concentration [%]	89	100	31	23	10	41	10

[1)] - no free oil existent, c_s =10% specified conditionally;
[2)] - thicknesses m_s are taken from (Report, 1996)

Table 3. Observed and computed oil (jet fuel) relative concentrations [%] in *q* aquifer after 10,000 days

Well No	*73*	*17*	*107*	*108*	*109*	*110*	*111*
Observed concentration [%]	89	22	40	15	3.2	3.6	-
Computed concentration [%] in qo aquifer	89	19	10	7	4.0	3.5	3.0
Computed concentration [%] in qb aquifer	11	10	8	6	3.5	3.0	2.0

$t_{0,5}$ = 1,800 days; 100% = 10mg/l

Table 4 . Computed discharge rates of dissolved oil products from the q aquiferinto the Daugava river

Source name	*b6+b23*	*b9*	*b12*	*b15+bT*	*b34*
Water discharge rate [m^3/day]	150	60	50	90	90
Mean oil concentration [g/m^3]	0.1	0.1	0.3	0.1	0.1
Oil discharge rate [g/day]	15	6	15	9	9

total: 54 g/day

elapsed time 10,000 days, $t_{0.5}$ = 1,800 days

References

Spalvins, A. & Slangens, J. 1995. Updating of Geological Data Interpolation Programme. *Proc. of International Seminar on "Environment Modelling". Bondary Field Problems and Computers. Riga - Copenhagen* 36(2): 175 - 192.

Spalvins, A., Janbickis R., Slangens, J., Gosk, E., Lace, I., Viksne, Z., Atruskievics, J., Levina, N., and Tolstovs, I. 1996. Hydrogeological Model “Large Riga”. Atlas of Maps. *Boundary Field Problems and Computers. Riga – Copenhagen* (37).

Golden Software, Inc. 1997 *Surfer 6.0 for Windows. User's manual.*

Environmental Simulations, Inc. 1997. *Groundwater Vistas. Guide to using.*

Pollock, D. 1989. *Documentation of Computer Programs to Compute and Display Pathlines Using Results from the U. S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow Model*. U. S. Geological Survey. Open File Report: 89-381. Reston, Virginia.

McDonald, M. & Harbaugh, A. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. *U. S. Geological Survey, Open File Report Washington*: 83-875.

MT3D’96. 1996. *Documentation and Input Instructions*. - S. Papadopulos & Associates, Inc.

Spalvins, A. 2000. Landscape Elevation Map as Reliable Boundary Conditions for Hydrogeological Models. *Scientific Proc. of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation* 4 (42): 47-50.

Modelling the Groundwater Flow Dynamics and the Contaminant Movement for the Rumbula Airbase Place by Spill-CAD, ARMOS, BioTRANS. 1996. *Contract N 6153/96 report of Riga Technical University*.

Mathematical Processing of Data Obtained During the Free Oil Phase Recoving at the b6 Spill Area of the Rumbula Airport Site. 1998. *Contract N 6190/97 report of Riga Technical University*.

Hydrogeological and Transport Models of Contaminants for Rumbula Airbase Area, Latvia. 2000. *Contract report of Riga Technical University*.

Spalvins, A., Slangens, J., Janbickis, R., Lace, I. & Gosk, E. 2000. Methods for Improving Verity of Groundwater Modelling, *Proc. of 16 th IMACS World Congress 2000, Lausanne, Switzerland, 21-25 August 2000.* 6 pages on CDROM.
Hedelskabet, report. 2000. *Rumbula airbase pollution study*.

Aivars Spalvins, Dr.sc.ing., **Janis Slangens**, Dr.sc.ing., **Romans Janbickis**, M.sc.ing., **Inta Lace,** M.sc.ing.
Riga Technical University, Faculty of Computer Science and Information Technology
Environment Modelling Centre
Address: 1/4 Meza str., Riga, LV-1048, Latvia
Phone: +371 7089511
E-mail: emc@egle.cs.rtu.lv

Spalviņš A., Šlangens J., Janbickis R., Lāce I. Ūdenī izšķīdušo naftas produktu kustības modelēšana bijušajā Rumbulas lidostas teritorijā Latvijā.
Lai novērtētu risku, kuru rada ūdenī izšķīdušās aviācijas degvielas migrācija Daugavas virzienā, ir izstrādāts 3D - hidroģeoloģiskais modelis (HM) bijušās Rumbulas lidostas teritorijai. Arī Getliņu atkritumu izgāztuve ir ietverta HM, lai izpētītu tās mijiedarbību ar Rumbulas piesārņojumu. Modelēšanas rezultāti liecina, ka pateicoties attīrīšanas procesiem, tikai maza daļa no izšķīdušās degvielas sasniedz Daugavu. Getliņu izgāztuves piesārņojumu galvenokārt uztver divi meliorācijas grāvji, kuri ievadīti šajā upē.

Спалвиньш А., Шлангенс Я., Янбицкис Р., Лаце И. Моделирование миграции растворенных в воде нефтяных продуктов для бывшего аэропорта Румбула, Латвия.
С целью оценки степени риска представленного миграцией и направлении реки Даугава нефтяных продуктов (растворенных в воде), была построена 3D –гидрогеологическая модель (ГМ) бывшего аэропорта Румбула.Свалка отходов Гетлини также включена в ГМ для оценки возможного взаймодействия с загрязняющими веществами Румбулы.Моделирование этих процессов показало, что из за естественного разложению нефтяных продуктов, только их незначительная часть попадает в Даугаву. Загрязнение поступающее от Гетлини в большой степени перехватывается двумя мелиоративными канавами, которые впадают в эту реку.