Hydrogeological Model of Latvia, First Results

Aivars Spalvins[1], Janis Slangens[2], Inta Lace[3], Olgerts Aleksans[4], Kaspars Krauklis[5], Viesturs Skibelis[6], Natalja Levina[7], Antons Macans[8],
[1-8]*Riga Technical University, Environment Modelling Centre*

Abstract **– The countries of the world and of the European Union (EU) are developing hydrogeological models (HM) where by means of computer modeling the information necessary for the groundwater management is obtained. In 1996, Riga Technical University (RTU), upon the assignment of the former State Geological Survey, established regional HM REMO for the central part of Latvia. REMO does not meet demands of modern water management for the whole country; the REMO plane approximation step of 4,000 meters is too crude. In 2010-2012, RTU has established HM LAMO that includes the whole territory of Latvia and border areas of the neighboring countries. LAMO is a part of the Latvia Shared Environmental Information System. It is supported by the Latvian Environment, Geology and Meteorology Centre. The model comprises geological and hydrogeological information provided by the centre. LAMO accounts for 25 geological layers and its plane approximation step is 500 metres. To ensure compatibility with models of other countries, the worldwide used commercial program Groundwater Vistas is applied for running LAMO.**

The following results are provided by LAMO: surfaces of geological layers; the digital relief map (terrain) of Latvia with the hydrographical network included; distribution of heads for aquifers; distribution of vertical groundwater flows between aquifers (the infiltration flow is also obtained); the full spatial groundwater flow balance is estimated. LAMO is a powerful tool not only for modeling groundwater resources of Latvia, but it also enables account for interaction between groundwater and surface water sources (meteoric water, lakes, rivers).

Creation of LAMO is the first step in its future development as the tool for managing water resources of Latvia. LAMO will also serve as the basis for creating more detailed local models and for implementing transboundary projects with the neighboring countries.

Keywords **–hydrogeological models, computer based modeling, management of groundwater resources**

I. Introduction

The activity of Latvia in the surface water and groundwater resource management is regulated by the Water Management Law [1] and by the subordinated regulations and orders of the Cabinet of Ministers. Latvia is implementing the aims laid down by the European Union (EU) Water Framework Directive [2] for sustainable use of water resources. The Directive provides a unified procedure for the management of water resources in EU member countries: the use, in conforming to natural laws, the river catchment area principle (the territory of Latvia comprises four cross-border type river basins: those of Venta, Lielupe, Daugava and Gauja rivers); interdisciplinary approach to planning and its continuity. In Latvia, three planning stages are foreseen: the years 2004-2015, 2015- 2021 and 2021-2027.

At present, Latvia is in the first planning stage. Some of its results are reflected in the document [3]. The conditions of groundwater resources in Latvia, before it joined the EU, are described in [4]. In general, the groundwater resources in Latvia are in good condition. However, shallow groundwater is poorly protected from surface sources of pollution (waste dumps, territories of former military bases, oil product storage, agricultural activities, etc.). Incorrect and excessive use of groundwater has resulted in worsening of its quality (in Liepaja sea water intrusion took place; in Jelgava the quality of artesian groundwater is worsening, the well field Baltezers is endangered by economic activities in its vicinity, etc.).

Water management plans are drawn up and adjusted by the Latvian Environment, Geology and Meteorology Centre (LEGMC) upon the assignment of the Ministry of Environmental Protection and Regional Development of the Republic of Latvia. The Centre has to establish and develop the shared environmental information system of Latvia that would also include water management.

The countries of the world: the USA [5], Canada [6], Russia [7]; and of the EU: Denmark [8], the Netherlands [9], Great Britain [10], Lithuania [11], etc. are developing hydrogeological models (HM) of country and its regions where by means of computer modelling the information necessary for the water management planning is obtained (distribution of groundwater heads, stratigrafic profiles, characteristics of water filtration for geological layers, directions and velocities of groundwater flows, spread and volume of contaminants in groundwater, etc.).

In 1996, Riga Technical University (RTU), upon the assignment of the former State Geological Survey established the regional HM REMO for the central part of Latvia [12]. The data of the model have been used by the university for obtaining many local HM [13], [14], [15], [16], [17], [18].

In 2010-2012, in the framework of the project co-financed by the European Regional Development Fund, RTU has developed HM LAMO for the whole territory of Latvia. Location of LAMO and REMO is shown in Fig. 1. LAMO generalizes geological and hydrogeological information accumulated by LEGMC. LAMO will be used for management of potable groundwater resources and for evaluating their recovery measures. To solve smaller scale problems, LAMO will serve as the data source for building more detailed local models. LAMO corresponds to requirements of the first planning stage of Latvia for the groundwater management. However, LAMO is open for its further development, as a tool to be used for the second stage.

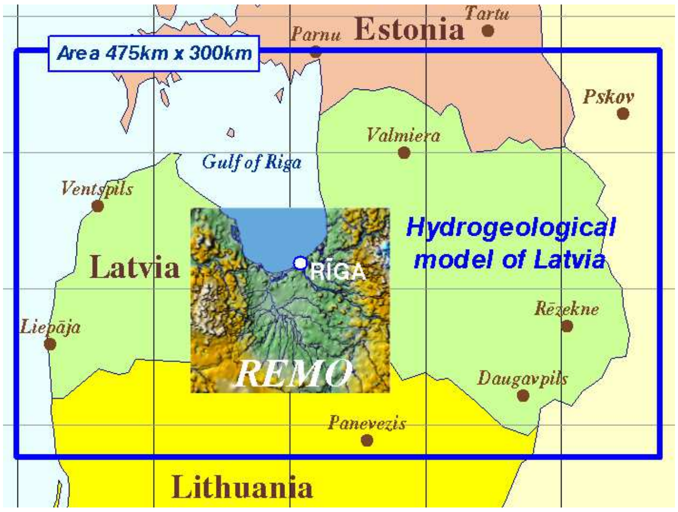

Fig. 1: Location of LAMO and REMO

II. Description Of REMO And LAMO

LAMO covers the area of 475km×300km=142,500km^2. Just like REMO, it simulates the steady state average groundwater regimes for the area of active water exchange that is used in Latvia for drinking water supply. The model is approximated by the spatial (3D) finite difference method; its plane approximation step is 500 meters; the spatial HM grid contains 25 planes (see Fig. 2); therefore, the grid consists of 951×601×25=14.86*10^6 nodes; the active groundwater zone is bedded by the regional Pernava aquifer.

The REMO plane approximation step was 4,000 metres. Its spatial grid contained 10 planes for aquifers, because the cruder semi-3D finite difference method was applied (aquitards were not presented by planes but only by the vertical links joining adjacent aquifers). The REMO grid contained 43×40×10=17200 nodes. Although the semi-3D scheme reduces the number of the HM planes nearly twofold, this scheme is not fully conformable with the commonly used software tools (MODPATH, MT3D) that are based on particle tracing. To avoid this drawback, the 3D scheme is applied to LAMO.

The whole REMO area (168km×156km=26,208km^2) was active. At present, LAMO consists of its active and passive parts. Initially, its active part included the land territory of Latvia and the area of the Gulf of Riga covered by REMO. Presently, the active part of the Gulf is enlarged (see Fig. 2.). The passive part represents border areas of the neighbouring countries. The active and passive parts are separated by 4 km wide border zone where piezometric boundary conditions for aquifers can be fixed.

However, LAMO is open for transboundary modelling projects. The neighbouring country must provide data for activating the HM area involved.

For running REMO, an original modelling program was used. It was developed by RTU scientists. If RTU scientists did not participate in the project, the State Geological Survey would be incapable of supporting and using REMO, and only RTU scientists had successfully used REMO until now. To avoid the above mentioned difficulty, the commercial program "Groundwater Vistas" (GV) is used for running LAMO [20]. The program is being regularly updated (the GV-6 version is available). It contains software tools MODFLOW, MODPATH, MT3D that are applied for groundwater modelling worldwide. The GV system is generally used also in Latvia. Due to application of GV, results of LAMO will be available for public use in Latvia and the LAMO compatibility with HM of other countries will be more possible.

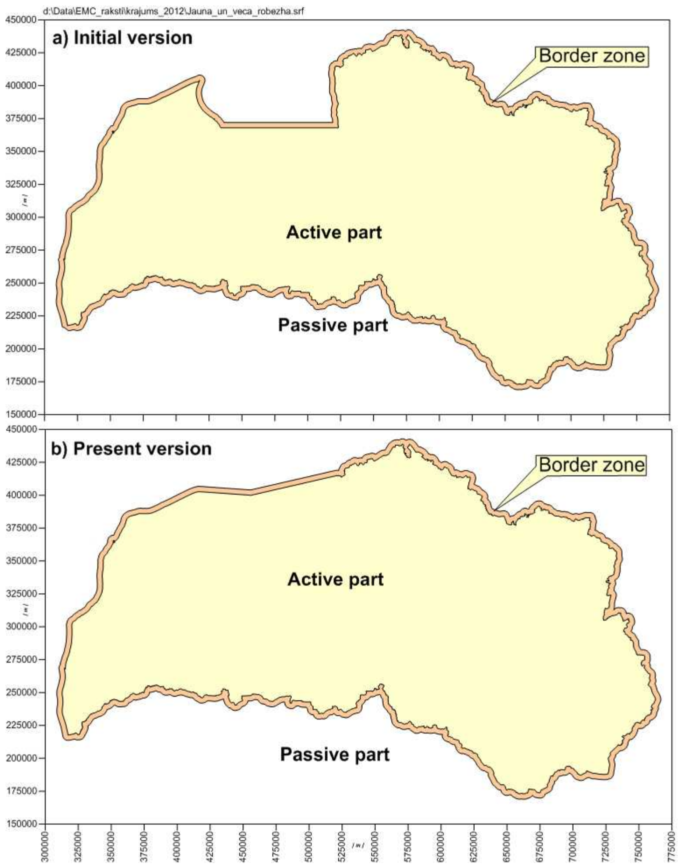

Fig.2. LAMO active and passive parts; a) initial version; b) present version

LAMO vertical schematization is presented in Table I. For the planes 12-25, it coincides with the one of REMO. In REMO, instead of the planes 7-11, the united Famena aquifer (D3fm#) was used for the central part of Latvia. For LAMO, these five planes represent the geological layers of the South-West of Latvia.

The modeled layers are distributed in a way that maximum describes the groundwater conditions in the geological cross section for the extent of aquifers. Secondary role is devoted to the rocks genetic origin and its classification in the stratigraphic scheme. Therefore, the pattern of smaller individual layers was combined in a single layer inside the mathematical model. The main factor which determines the stratums to be combined in the single layer was the permeability properties of sediments that form these layers. In this way, for example, in a single layer (No.7 in the model) less significant and locally distributed stratums as Ketlers (D3ktl), Skervele (D3sk), Carbon (C1) and Perm (P2) deposits were combined. Layers Muru (D3mr), Tervete (D3tr), Svente (D3sv) and Zagare (D3zg) form layer No.9 in the model. That also applies to not permeable deposits. In the one single aquatard, for instance, Amula (D3aml) and Eleja (D3el) sediments (layer No.12 in the model) are merged.

TABLE I

MASS BALANCE OF LAMO

No of HM plane		Name of layer	Geolo-gical code	HM plane code
1.		Relief	relh	relh
2.		Aeration zone	aer	aer
3.		Unconfined Quaternary	Q4-3	Q2
4.		Upper moraine	gQ3	gQ2z
5.		Confined Quaternary or Jura	Q1-3 J	Q1
6.		Lower moraine or Triass	gQ1-3 T	gQ1#z
7.		Perma Karbons Šķerveles Ketleru	P2 C1 D3šķ D3ktl	D3ktl#
8.		Ketleru	D3ktl	D3ktlz
9.		Žagares Svētes Tērvetes Mūru	D3žg D3sv D3tr D3mr	D3zg#
10.		Akmenes	D3ak	D3akz
11.		Akmenes Kursas Jonišķu	D3ak D3krs D3jn	D3krs#
12.		Elejas Amulas	D3el D3aml	D3el#z
13.		Stipinu Katlešu Ogres Daugavas	D3stp D3ktl D3og D3dg	D3dg#
14.		Daugavas Salaspils	D3dg D3slp	D3slp#z
15.		Pļaviņu	D3pl	D3pl
16.		Pļaviņu Amatas	D3pl D3am	D3am#z
17.		Amatas	D3am	D3am
18.		Augšējā Gauja	D3gj2	D3gj2z
19.		Augšējā Gauja	D3gj2	D3gj2
20.		Apakšējā Gauja	D3gj1	D3gj1z
21.		Apakšējā Gauja	D3gj1	D3gj1
22.		Burtnieku	D2brt	D2brtz
23.		Burtnieku Arikula Narvas	D2brt D2ar D2nr3	D2ar#
24.		Narvas Narvas	D2nr2 D2nr1	D2nr#z
25.		Pērnavas	D2prn	D2pr

-united aquifer; #z – united aquitard

- aquitard

In REMO and LAMO, the planes 1 and 2 are used, accordingly, as a place for fixing the relief (terrain) elevation map as the piezometric boundary condition and as a formal aquitard that controls the infiltration flow [21]. In REMO, the Quaternary system was represented by two planes (unconfined Q_2 and the moraine gQ_{2Z}). Four planes of this system are used in LAMO, because two extra layers are accounted (confined Q_1, lower moraine gQ_{1Z}). These two layers are of importance to the hilly areas of Latvia where the Quaternary system is thick. In LAMO, no separate layers are given for representation of the Jura and Triass systems. They are incorporated into the HM layers 5 and 6, accordingly, because their areas are insignificant (South-West of Latvia).

Most of geological layers, comprised by REMO and LAMO, are discontinuous. Discontinuity of the layers and their irregular geological borderlines cause serious problems for building elevation surfaces of the layers [22].

III. METHODS OF HM DEVELOPMENT

To describe the development of the HM, the mathematics of the 3D-steady state model must be introduced. By applying the 3D finite difference approximation, the xyz-grid of the HM is built using ($h \times h \times m$)-sized blocks (h is the block plane size, m is the variable thickness of a geological layer). The model constitutes a rectangular p-tiered xy-layer system where p is the number of layers. HM vertical sides compose the shell of the HM grid. The relief (terrain) and the lower side of the model are its geometrical top and bottom, respectively. The 3D-space volume enveloped by the boundary surfaces constitutes the body of the HM. For the LAMO active part, its shell coincides with the border zone that separates HM active and passive parts. However, the GV system accounts for the whole body of HM.

Vector φ of the piezometric head is the numerical solution of the boundary field problem which is approximated in nodes of the HM grid by the following algebraic expression:

$$A\varphi=\beta-G\psi,\ \mathrm{A}=A_{xy}+A_z \quad (1)$$

where A is the symmetric sparse matrix of the geological environment which is presented by the xy-layer system containing horizontal (A_{xy} – transmissivity) and vertical (A_z – vertical hydraulic conductivity) elements of the HM grid; ψ – the boundary head vector: ψ_{rel}, ψ_{bot}, ψ_{sh} – subvectors on the HM top, bottom and shell, accordingly; G – the diagonal matrix (part of A) assembled by elements, linking the nodes where φ must be found with the ones where ψ is given; β - the boundary flow vector.

The elements a_{xy}, a_z of A_{xy}, A_z (or g_{xy}, g_z of G) are computed as follows:

$$a_{xy} = k \times m,\ a_z = \frac{h^2 \times k}{m}$$
$$m_i = z_{i-1} - z_i > 0,\ i = 1, 2, ...,\ p \quad (2)$$

where z_{i-1}, z_i are elevations, accordingly, of the top and bottom surfaces of the i-th geological layer; z_0 represents the ground surface elevation ψ_{rel}-map with the hydrographical network included; k, m are, accordingly, elements of digital m, k-maps of the computed layer thickness and permeability.

The set of z-maps describes the full geometry of LAMO. It is built incrementally: $z_0 \rightarrow z_1, \ldots, z_p$ by keeping the thickness of the i-th layer $m_i > 0$. If in some areas $m_i=0$, then the i-th layer is discontinuous. To prevent the "division by zero", in the a_z calculation of (2), $m_i=0$ must be replaced by $\varepsilon > 0$ (for LAMO, $\varepsilon=0.02$ metres). In GV, only z-maps (geological layer surface maps) serve as the initial geometrical ones. For REMO, the set of m-maps (geological layer thickness maps) were used and, due to this reason, the model geometry was of lower quality than the geometry resulting from z-maps. In [26] more detailed information is given on how the set of z-maps has been obtained.

Obtaining the right distribution for the infiltration flow q_{inf} on the HM top is a burdensome task. For REMO and LAMO, this task is considerably eased by using the ψ_{rel}-map as the boundary condition for heads. Then the flow $q_{inf}=q_{aer}$ passes through the aeration (vadose, unsaturated) zone:

$$q_{aer} = G_{aer}(\psi_{rel} - \varphi_Q) \qquad (3)$$

where φ_Q is the computed head (subvector of φ) for the first aquifer Q_2; G_{aer} (diagonal submatrix of G) contains the vertical ties g_{aer} of the aeration zone connecting ψ_{rel} with φ_Q. The expression (3) gives the standard result of HM, when ψ-condition is applied. As a rule, even the first run of HM provides feasible results for q_{inf}.

The vertical links, g_{aer} of the diagonal matrix G_{aer}, are controlling the q_{aer} distribution. Values of g_{aer} depend on h^2, k_{aer} and m_{aer} (formula (2)) where k_{aer} , m_{aer} are, respectively, the permeability and thickness of the aeration zone. Initially, k_{aer} and m_{aer} are unknown. In nature, $m_{aer}=\psi_{rel}-\varphi_{Q2}$ if $q_{aer}>0$ and it is the unsaturated part of the unconfined layer Q_2. If $q_{aer}<0$ then m_{aer} ceases to exist, because then $q_{aer}<0$ is controlled by bed conductances of the hydrographical network. Formerly, these conductances were elements of G_{aer}. Just recently the lines and areas of the network have been implemented as the "Rivers" and "Lakes" options of GV [17]. This innovation is used in LAMO. First, the following values of the unknown parameters of the aeration zone for LAMO were tried: $m_{aer}=\varepsilon=0.02$, $k_{aer}=10^{-6}$ [m/day]. To avoid iterative changes of the HM geometry, $m_{aer}=\varepsilon$ must be kept constant, until the calibrated state of the HM is achieved by adjusting the k_{aer} – distribution. In [27], it is explained how the hydrographical network has been linked with HM.

Therefore, for LAMO, only two real thicknesses m_{aer} and m_{Q2} must be restored, if necessary. It can be done by applying the "inverse" transformation of the calibrated $(k_{aer})_c$ and $(k_{Q2})_c$–maps:

$$k_{aer}=(k_{aer})_c\, m_{aer}/\varepsilon\,,\; k_{Q2}=(k_{aer})_c\,(m_{Q2})_c/m_{Q2}\,,\quad m_{Q2}=(m_{Q2})_c-m_{aer}\,, \qquad (4)$$

where $\varepsilon=0.02$ and $(m_{Q2})_c$ are the thicknesses used during the HM calibration. The transformation results from formulas (2), because this operation does not change the calibrated values of elements a_{xy} and a_z for matrix A.

For computing q–flows passing through aquitards, the following matrix formula is used:

$$q_{i,i+2}=G_{i+1}(\varphi_i-\varphi_{i+2}) \quad i=1,3,5,\ldots 23; \qquad (5)$$

where φ_i and φ_{i+2} are computed head distributions (subvectors of φ) for neighbouring i-th and $(i+2)$-th aquifers, accordingly; G_{i+1} is the matrix of vertical links for $(i+1)$ aquitard that joins both aquifers. The formula (5) includes the case of (3) if $\varphi_1=\varphi_{rel}$, $\varphi_3=\varphi_Q$, $G_{aer}=G_2$. The system SURFER [25] is used for computing q–flows of (5).

Obtaining the digital relief (terrain) map ψ_{rel} of Latvia (scale 1:200,000) as the most important item of LAMO was a rather difficult task, because the maps prepared by the Geospatial Information Agency of Latvia still did not account for the hydrographical network existence. In the materials [23], [24] it is shown how a considerably improved ψ_{rel} map has been created. The map provides three types of information: a) the geometrical top surface z=o; b) the distributed piezometrical boundary condition ψ_{rel} ; c) the hydrographical network data (long line profiles of rivers and elevations of lakes) that are used by the options "Rivers" and "Lakes" of GV [27].

Presence of the passive part of LAMO (see Fig. 2) causes the appearance of impermeable surface along the border zone. In [27], it is explained how this feature has been eliminated by creating boundary conditions ψ_{sh} for the border zone.

IV. Examples Of Results Provided by LAMO

LAMO provides the following information necessary for hydrogeologists and specialists dealing with groundwater resources:

- geometry of the model; it is represented by the set of z-maps for surfaces of geological layers; it follows from (2) that these maps are used for computing elements of model matrix A;
- φ-distributions of piezometric heads $\boldsymbol{\varphi}$ (solutions of (1)) for layers of LAMO;
- k-maps of permeability of geological layers; these maps take part in creating matrix A of eq. (2);
- q- distributions of flows passing through aquitards; these distributions are computed by using formula (5);
- other data that can be obtained from LAMO by applying software tools included in the GV system (directions of groundwater flows, pathlines of tracers, mass balances for chosen areas and other services);

LAMO geometry is very complex. This fact is evinced by Fig. 3 and Fig.4, where borderlines of primary geological layers and the geological cross section WE are shown accordingly. Most of geological layers are discontinuous, because they are outcropping in location of their borderlines. Beyond the borderline a layer does not exist (its thickness m=0).

It is reported in [22] how geometrical problems caused by discontinuous layers are worked out when the set of z-maps is created.

The φ-distributions are the main result provided by LAMO for all layers of the model. Of practical importance are the head distributions for aquifers. In Fig. 5 and Fig. 6, the computed distribution of piezometric heads is shown for the 7-th and 23-th aquifers (prequaternary surface and D2ar# aquifer), correspondingly.

The φ-map essence of Fig. 5. Is twofold: 1. It represents only the D3ktl# aquifer; 2. The map is composite of heads representing many primary geological layers.

If the φ-map of Fig.5. represents only the D3ktl# aquifer, only a small area covered by this aquifer is shown (see Fig.3), but the other part of the map gets blanked.

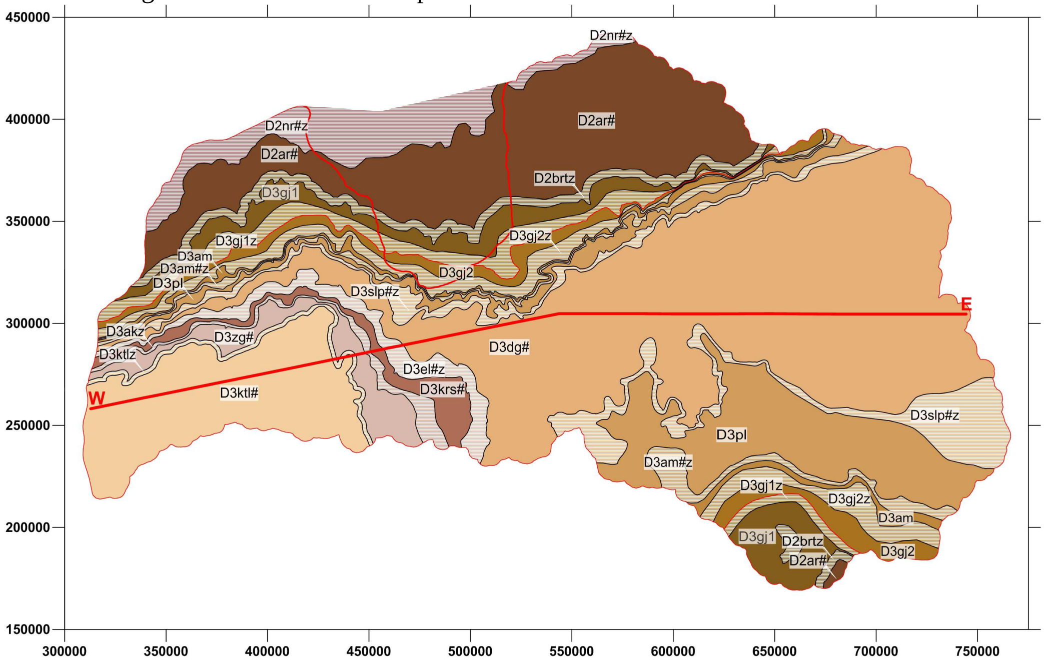

Fig. 3. Boundaries of primary geological strata

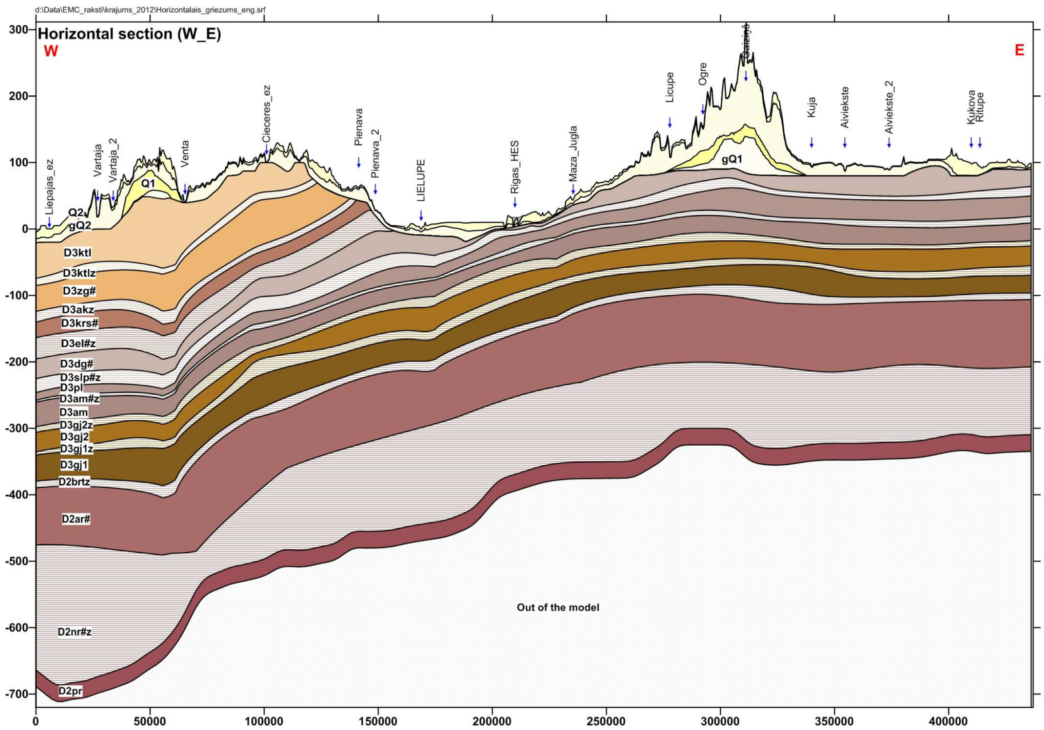

Fig. 4. Geological section W-E; its location is shown in Fig.3.

.

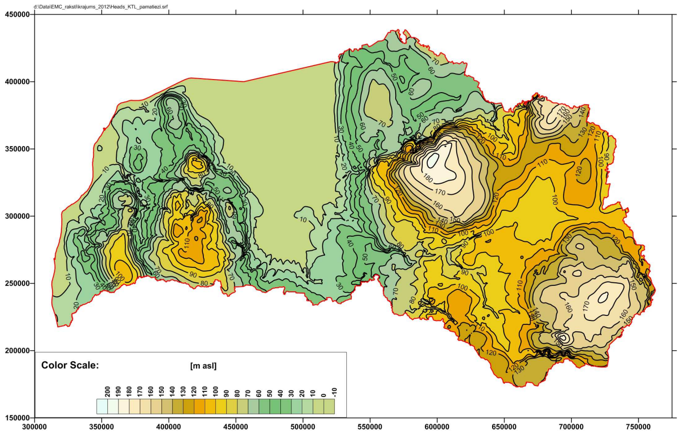

Fig. 5. Distribution of piezometric heads [m asl] for the prequaternary surface

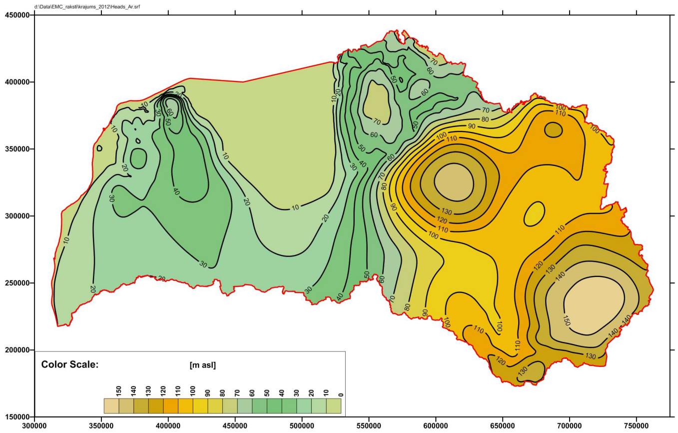

Fig. 6. Distribution of piezometric heads [m asl] for the D2ar# aquifer (for the nonexistent area of aquifer the distribution is blanked)

TABLE II

MASS BALANCE OF LAMO

Name of aquifer	Flows of model aquifers [m^3/day]				
	q_{top}	Q_{bottom}	Q_{border}	Q_{river}	balance
Q2	5738087*)	-3501542	-68963	-2167582	0.0
Q1	3501542	-3399355	-54420	-47767	0.0
D3ktl	3399355	-3308372	-3827	-87156	0.0
D3zg	3308372	-3260878	-33645	-13849	0.0
D3krs	3260878	-3216736	-22134	-22008	0.0
D3dg	3216736	-2395709	-33363	-787664	0.0
D3pl	2395709	-1454625	-95881	-845203	0.0
D3am	1454625	-1325430	-73536	-55659	0.0
D3gj2	1325430	-1067782	-107049	-150599	0.0
D3gj1	1067782	-733346	-153332	-181104	0.0
D2ar	733346	-392594	-304689	-36063	0.0
LAMO	5738087	-392594	=950839	-4394654	0.0

*) (q_{top})Q2=5738087=13018086-7673290

The map of Fig.5 is the composite of head distributions of primary geological layers that are visible from the above (bird's eye view). The visible parts of layers are shown in Fig.3. This kind of φ-map is useful in the course of HM calibration, because it can be compared with the similar map that has been prepared by specialists of LEGMC.

One can observe that in the northern areas of Fig. 5 and Fig. 6 their φ-distributions coincide. This phenomenon is caused by the fact that this part is the visible area of the D2ar# aquifer (see Fig. 3).

Flows passing through aquitards are of considerable importance for understanding groundwater processes. Their q–distributions provide information about arrangement of descending (recharging) and ascending (discharging) groundwater flows and their values [mm/year]. In Fig. 7 and Fig. 8, the q-distributions for the gQ1z and D2brtz aquitards (6-th and 22-th layers of the HM) are given. These flows "feed" the 7-th and 23-th aquifers, (D3ktl# and D2ar#0 are located beneath the two aquitards. For the maps of q-distributions, white coloured areas represent regions of groundwater discharge. In Fig. 7, such discharge is caused by lowlands and elements of hydrographical network (water bodies - rivers, lakes, sea). Most intensive groundwater recharge takes place in highland areas. It is obvious that flows of gQ1z aquitard are much larger than the ones of the D2brtz aquitard. Areas of groundwater discharge are much larger for the D2brtz layer (compare the extent of white areas for the q-distributions of Fig. 7 and Fig.8).

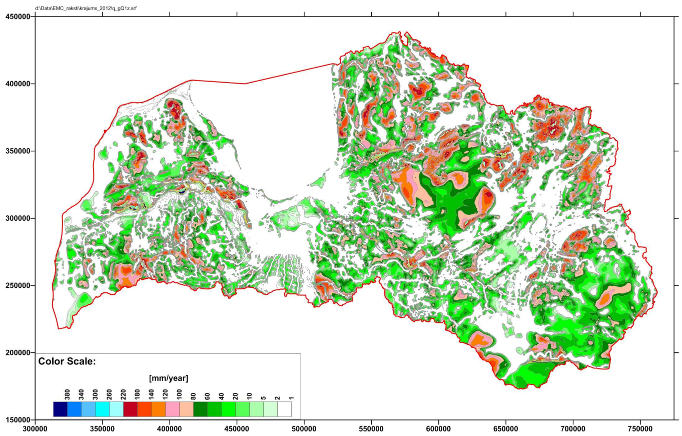

Fig.7. Flow distribution [mm/year] for the gQ1z aquitard

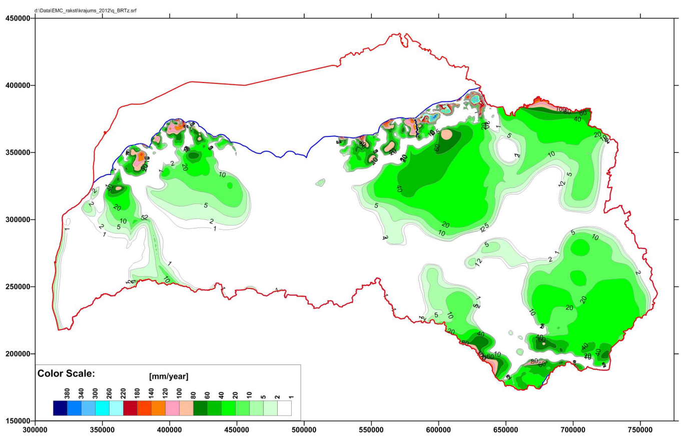

Fig.8. Flow distribution [mm/year] for the D2brtz aquitard (blanked for non-existent part of D2brt aquitard)

Never before such detailed *q*-distributions were available for modellers and hydrogeologists. This important result obtained by LAMO provides new knowledge for understanding groundwater dynamics.

The GV system provides the tool for computing groundwater mass balance of the HM. In Table II, the mass balance summary for LAMO is presented. It follows from Table II that through the surface of the Q2 aquifer about $13\times10^6 m^3$/day of meteoric water enters it and $7.67\times10^6 m^3$/day returns back into atmosphere as evaporation (see white coloured areas of Fig. 7). Only $5.74\times10^6 m^3$/day remains in the Q2 aquifer and feeds the deeper aquifers Q1, D3ktl, …, D2pr.

The bottom row of Table II gives total mass balance of LAMO. Through the top of HM enters about $5.74\times10^6 m^3$/day; about $0.39\times10^6 m^3$/day reaches the D2pr aquifer; $0.95\times10^6 m^3$/day flows out of Latvia through its outer borderline; $4.39\times10^6 m^3$/day is spent by rivers. Table 2 provides similar data for each aquifer.

Such a detailed groundwater mass balance summary has not been available for hydrogeologists. However, Table II provides only the first rough results and much more effort must be spent in future to calibrate links of groundwater with rivers and lakes as sources of surface water.

Presently, LAMO provides data regarding the geometry and permeability of geological layers, 3D distribution of groundwater heads and flows. These parameters include full information necessary for making decisions on sustainable management of groundwater bodies. In the scheme of Fig.9, HM describes processes within the module *groundwater* that is an important part of the hydrologic cycle for the Baltic region.

The next stage of LAMO development will convert the model into a tool that provides information describing links between groundwater and surface water sources. As it follows from Fig.9, the sources include elements of hydrographical network (rivers, lakes, the Baltic Sea) and precipitation (rain, snowfalls).

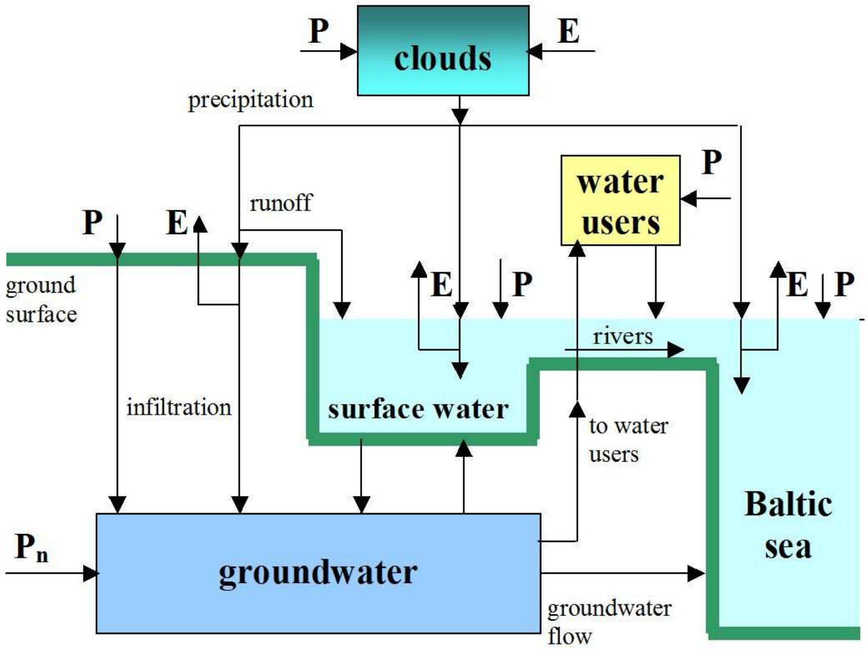

Fig.9. Conceptual model of hydrologic cycle and its pollution sources for Baltic region; E-evaporation; P, Pn-anthropological and natural pollution

Without knowledge about this interaction it is not possible to integrate surface water and groundwater into the hydrologic cycle (atmosphere, groundwater, surface water, atmosphere). Due to the fact that LAMO applies the ground surface elevation map (digital terrain map) and the hydrographical network as the boundary conditions, the HM can compute the amount of water passing between groundwater and surface water bodies. However, it is necessary to feed into the HM extra information regarding measurements of water flow for rivers. In LAMO, this information will be used for adjusting values of elements that join groundwater and surface water bodies.

The expected LAMO further development turns the model into the tool that enables to join groundwater and surface water sources into the connected system (see Fig.9.). Due to this achievement, the quality of water management for Latvia will increase considerably.

V. Conclusions

In 2010-2012, scientists of Riga Technical University have established the regional HM LAMO of Latvia. The model will be applied as the element of the shared environmental information system. LAMO has provided the first results never before available for modelers and hydrogeologists of Latvia. In future, LAMO will be developed as a tool for estimating interaction between groundwater and surface waters.

This publication is a part of the Project untitled (agreement Nr.2010/0220/2DP/2.1.1.1.0/10/APIA/VIAA/011) "Creating of hydrogeological model of Latvia to be used for management of groundwater resources and for evaluation of their recovery measures". The Project is being co-financed by the European Regional Development Fund.

References

[1] Latvijas ūdens apsaimniekošanas likums (Water management law of Latvia), 2002. (spēkā esošs no 15.10.2002.), aktuālā redakcija "LV", 46 (4444), 23.03.11. (in Latvian)

[2] Water Framework Directive (2000/60/EC of the European Parliament and of the Council), 2000. Official Journal of the European Communities L327, 22.12.2000. 72 p.

[3] Upju baseinu apgabalu raksturojums, antropogēno slodžu uz pazemes un virszemes ūdeņiem vērtējums, ekonomiskā analīze (Description of river catchment areas, evaluation of human caused stress on groundwater and surface water, economic analysis). 2005. / Latvijas Vides, ģeoloģijas un meteoroloģijas aģentūra, (in Latvian)

[4] Levins, I., Levina, N., Gavena, I., 1998. Latvijas pazemes ūdeņu resursi. (Latvian groundwater resources) Valsts ģeoloģijas dienests, Rīga, 24 lpp. (in Latvian)

[5] Motz, L. H., Gan, A. 2002. Calibration of the north-central Florida steady – state groundwater flow model / ModelCARE 2002, Proceedings of the 4th International Conference on Calibration and reliability in groundwater modelling, Praque, Czech Republic, 17-20 June 2002, vol. 1, p. 253-256

[6] Sykes, E.A., Sykes, J.F., Sudicky, E.A., Frape, S.K., 2007. Modelling in support of a proposed Deep Geologic Repository in Canada for low and intermediate level radioactive waste / ModelCARE2007, Sixth International Conference on Calibration and Reliability in Groundwater Modelling; Credibility in Modelling, 9-13 September 2007, Pre-published Proceedings, Vol. 2, Copenhagen, Denmark, p. 644-649

[7] Spalvins, A., Slangens, J., Janbickis, R., Lace, I., Loukiantchikova, L., Gosk, E., 2001. The Noginsk District (Russia) Case as an Illustration of Novel Simulation Technologies Developed for Creating Hydrogeological Models / / Proceedings of the 10th International Conference on System-Modelling-Control, Zakopane, Poland, May 21-25, 2001. - Lodz, 2001. - Vol.2. - P.225-230

[8] Muller-Wohlfeil, D.-I., Mielby, S., 2007. Modelling to support the assessment of interlinkages between groundwater and surface water in the context of the EU Water framework directive / ModelCARE2007, Sixth International Conference on Calibration and Reliability in Groundwater Modelling; Credibility in Modelling, 9-13 September 2007, Pre-published Proceedings, Vol. 1, Copenhagen, Denmark, p. 211 217

[9] Snepvangers, J., Minnema, B., Berendrecht, W., Vermeulen, P., Lourens, A., Van Der Linden, W., Duijn, M., Van Bakel, J., Zaadnordijk, W.-J., Boerefijn, M., Meeuwissen, M., Lagendijk, 2007. V. MIPWA: Water managers develop their own high resolution groundwater model tools. / ModelCARE2007, Sixth International Conference on Calibration and Reliability in Groundwater Modelling; Credibility in Modelling, 9-13 September 2007, Pre-published Proceedings, Vol. 1, Copenhagen, Denmark, p. 178-183

[10] Farrell, R., Whiteman, M., Gijsbers, P. 2007. Credibility in groundwater modelling; a national groundwater modelling system for England & Wales, / ModelCARE2007, Sixth International Conference on Calibration and Reliability in Groundwater Modelling; Credibility in Modelling, 9-13 September 2007, Pre-published Proceedings, Vol. 1, Copenhagen, Denmark, p. 166-171

[11] Spalvins, A., Slangens, J., Lace, I., Stuopis, Domasevicius, A., 2010. Creating of regional hydrogeological model for the South-East of Lithuania. *XXXVIII IAH Congress Groundwater Quality Sustainability Krakow, 12-17 September, Extended Abstracts*, University of Silesia, 2010, pp. 1233-1238, ISSN 0208-6336 ISBN 978-83-226-1979-0 (2vol.set+CD)

[12] Spalviņš, A., Janbickis, R., Šlangens, J., Gosk, E., Lāce, I., Atruškievičs, J., Vīksne, Z., Levina, N., Tolstovs, J. 1996a, Hydrogeological model "Large Riga" , Atlas of maps, Boundary Field problems and Computers, 37-th issue, Riga-Copenhagen, RTU, 102 p.

[13] Spalvins, A., Gosk, E., Grikevich, E., Tolstov, J. (Editors). 1996b. Modelling new well fields for providing Riga with drinking water. - Riga-Copenhagen, 1996. - 40 p. (Boundary Field Problems and Computers; 38-th issue).

[14] Spalvins, A., Semjonovs, I., Gosk, E., Gobins, J.,and Aleksans, O., 1999. Development of a Mathematical Model for Contamination Migration in the Area of the Sulphur-Tar Sludge Waste Pools in Incukalns, Latvia / Proceedings of XXIX International Association of Hydrogeologists Congress on "Hydrogeology and Land Use Management". 6-10 September 1999, Bratislava, Slovak Republic, 1999 pp.253-258

[15] Spalvins, A., Slangens, J., Janbickis, R., Lace, I. 2008a. Hydrogeological model of the Baltezers, Rembergi and Zakumuiza water supply complex, Latvia / International Interdisciplinary Conference on Predictions for Hydrology, Ecology and Water Resources Management: Using Data and Models to Benefit Society" HydroPredict'2008,15-18 September 2008, Prague, Czech Republic, 9 Pages CD

[16] Spalvins, A., Slangens, J., Lace, I., 2008b. Modelling of groundwater regime changes that may be caused by building of transportation tunnel in Riga, / Scientific Proc. of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation, vol. 5, 37. (50) –th issue. Riga: RTU, 2008, pp. 7-17. (ISSN 1407-7493)

[17] Spalvins, A., Slangens, J., Lace, I., Krauklis, K., 2009a Hydrogeological model of water supply system for the prospective factory of Coca-Cola company, Latvia // Scientific Journal of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation, vol. 5, 41. (51) –th issue. Riga: RTU, 2009, pp. 21-28. (ISSN 1407-7493)

[18] Spalvins, A., Slangens, J. & Lace, I. 2009b. Modelling of remedy process for the hazardous liquid waste deposit area at the Jelgava town, Latvia / Proceedings of HydroEco 2009 2nd international Multidisciplinary Conference on Hydrology and Ecologie20-23 April 2009,Wienna, Austria, 10 pages CD

[19] Spalvins, A., Slangens,J., O., Aleksans, Krauklis, K., Lace, I. (2012). Regional hydrogeological model of Latvia for management of its groundwater resources, In 5-th International scientific conference Applied information and communication technologies, 24.-26. april 2012, Jelgava, Latvia, p. 135-155 (CD) (ISBN (78-9984-48-065-7)2.

[20] Environmental Simulations, Inc. Groundwater Vistas. Version 6, 2011. Guide to using.

[21] Spalvins, A., Slangens,J., Krauklis, K., Lace, I., 2011a Methods and tools to be applied for creating of regional hydrogeological model of Latvia In:25th European Conference on Modelling and Simulation, June 7-10, 2011, Krakow, Poland, pp. 132-141, (ISBN: 978-0-9564944-2-9)

[22] Spalvins, A., Slangens,J., Krauklis, K., Lace, I., V. Skibelis, 2011b. Creating of initial data maps for regional hydrogeological model of Latvia / Scientific Journal of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation , vol. 5, 50–th issue. Riga: RTU, p. 14-22

[23] Slangens, J., Krauklis, K., Eglite, I. 2010. Incorporation of the Hydrographical Network into the Digital Map of the Ground Relief // Scientific Journal of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation , vol. 5, 45. (52) –th issue. Riga: RTU, 2010, p. 45-53 (ISSN 1407-7493)

[24] Slangens, J. and K. Krauklis. 2011. Creating of digital relief map for regional hydrogeological model of Latvia, *Scientific Journal of Riga Technical University in series "Computer Science". Boundary Field Problems and Computer Simulation* , vol. 5, 49. (53) –th issue. Riga: RTU 21-25 lpp

[25] SURFER-9 for Windows. Users Manual. Golden Software .2010.

[26] A. Spalvins, J. Slangens, I. Lace, K. Krauklis, O. Aleksans, N. Levina, / Methods and software tools used to designate geometry for regional hydrogeological model of Latvia, In this Journal, 13-19

[27] A. Spalvins, J. Slangens, I. Lace, K. Krauklis / Arrangement of boundary conditions for hydrogeological model of Latvia, In this Journal, 20-24

Aivars Spalvins was born in 1940, Latvia. In 1963, he graduated from Riga Polytechnic Institute (since 1990, Riga Technical University) as a computer science engineer. In 1967, A. Spalvins received the degree of Cand. Sc. (Dr. sc.).
A. Spalvins has been with the university since 1958 (as a student) until now. His present scientific interests are computer modeling of groundwater flows and migration of contaminants. He is the author of about 300 scientific papers. His present position is Director of the Environment Modelling centre of Riga Technical University.
He is a member of the International Association of Hydrogeologists.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: emc@cs.rtu.lv

Janis Slangens was born in 1940, Latvia. In 1969, he graduated from Riga Polytechnic Institute (since 1990, Riga Technical University) as a science engineer. In 1985, J. Slangens received the degree of Cand. Sc. (Dr. sc.).
Since 1969, he was an assistant, senior lecturer of the Department of Computer Engineering of the Faculty of Computer Science and Information Technology of the university. Since 1993, he is a senior researcher of the Environment Modelling Centre. His present scientific interests are computer modeling of groundwater flows. He is the author of about 200 scientific papers.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: emc@cs.rtu.lv

Inta Lace was born in Latvia. In 1971, she graduated from Riga Polytechnic Institute (since 1990, Riga Technical University) as a computer science engineer. In 1995, I. Lace received degree of M.sc. (applied computer science).
I. Lace has been with the university since 1965 (as a student) until now. Since 1991, she is a researcher of the Environment Modelling Centre, Faculty of Computer Science and Information Technology, Riga Technical University. She took part in projects of Latvian Science Council on informatics for hydrogeology and other projects. Her present scientific interests are computer modeling of groundwater flows. She is the author and co-author of about 100 scientific papers on software used for solving boundary field problems.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: emc@cs.rtu.lv

Olgerts Aleksans was born in 1956, Latvia. In 1979, he graduated from Vilnius State University (since 1988, The University of Vilnius) as a hydro geologist & engineering geologist. In 2011, O. Aleksans received Doctoral Degree in Geology at the University of Latvia. From 1979 till 1991 he worked in the Geological Survey of Latvia as a senior hydrogeologist. In 1991 – 1993 he continued to work in the Ministry of the Environment and Regional Development as an Environmental Specialist. From 1993 till 1997 he worked as a Senior Environmental Specialist in the Latvian – American joint company Baltec Associates, Ltd. In the time period from 1997 till 2011 he was one of the company's VenEko Ltd founders and its Technical and Scientific Director. Currently, from 2011 he works as a researcher in the Environment Modeling Centre which is the part of the Faculty of Computer Science and Information Technology of Riga Technical University. He is the author of more than 65 scientific papers.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: olgerts.aleksans@gmail.com

Kaspars Krauklis holds M.Sc. degree of engineering science in computer systems from Riga Technical University (2007) and the certificate in Teaching of Engineering Sciences from RTU Institute of Humanities (2005). Since 2005, he participated in several projects of ESF, ERDF and Latvian Council of Science.
Currently he works as a researcher in the Environment Modelling Centre which is the part of the Faculty of Computer Science and Information Technology of Riga Technical University and as a lecturer in the Division of Applied Systems Software of RTU. His main scientific interests are groundwater modelling and technologies of e-learning. He is the author and co-author of 17 publications in both above-mentioned fields.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: emc@cs.rtu.lv

Natalija Levina was born in Novosibirsk, Russia. In 1961 she graduated from Leningrad State University (now St. Petersburg), majoring in hydrogeology and engineering geology. In 1961-1963 she worked in Novosibirsk, from 1964 to 2009 - at the Geology Department of the Latvian SSR, the State Geological Survey of Latvia, the Latvian Environmental, Geological and Meteorological Agency. She is the author and co-author of more than 90 reports on the monitoring of groundwater regime in natural conditions and disturbed groundwater regime on drainaged areas, around the well-fields and water reservoirs, hydro-geological conditions of subway construction, prospecting of groundwater resources and reserves, analysis of the balance of groundwater.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67265313
E-mail: nnnlevina@gmail.com

Viesturs Skibelis was born in 1945, Germany. In 1967, he graduated from Riga Polytechnic Institute (since 1990, Riga Technical University) as a computer science engineer. In 2001, V. Skibelis received degree of M.sc. (applied computer science).
V. Skibelis has been with the university science 1965 (as a student) until now. Since 1971, he is a researcher of the Environment Modelling Centre, Faculty of Computer Science and Information Technology, Riga Technical University. Since 1991, he took part in projects of Latvian Science Council on informatics for hydrogeology and other projects. His present scientific interests are computer modeling of groundwater flows and diagnostic of electrical circuits. He is the author and co-author of about 30 scientific papers.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
Phone: +371 67089511
E-mail: Viesturs.Skibelis@cs.rtu.lv

Antons Macans was born in 1938, Latvia. In 1963, he graduated from Polytechnic Institute (since 1990, Riga Technical University) as a computer science engineer. Antons Macans has been with the university science 1965 (as a student) until now. Since 1960 he took part in research and technical service of hybrid computing systems for boundary field problems. Since 1991 he is an assistant of the Environment Modelling Centre, Faculty of Computer Science and Information Technology, Riga Technical University. He took part in projects of Latvian Science Council on informatics for hydrogeology and other projects.
His present scientific interests are computer modeling of groundwater flows and migration of contaminants. He is the author and co-author of about 20 scientific papers on software problems of solving boundary field problems.
Address: 1/4 Meza Str., Riga, LV-1007, Latvia
E-mail: emc@cs.rtu.lv