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Section: Water Engineering

Survey of the first results provided by hydrogeological model of Latvia

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Abstract

In 2010–2012, scientists of Riga technical University have developed the hydrogeological model of Latvia (LAMO). In 2013, LAMO has been applied as a tool to implement in Latvia aims laid down by the European Union Water Framework Directive for sustainable use of water resources. The set of hydrogeological maps was prepared for updating of the water management plans for the river basin districts of Gauja, Daugava, Lielupe and Venta. For aquifers, distributions of groundwater heads and infiltration flows were mapped. In the maps of heads, directions of groundwater flows and contacts of aquifers with rivers were shown. By joining information, carried by the distributions for heads and infiltration flows, the special maps were created where isolines of heads and areas of groundwater discharge, recharge and transit were shown. Numerous geological profiles were provided. The profile represents the geological stratigraphy, isolines of groundwater head and directions of groundwater flows. Groundwater flow balances were obtained for the whole Latvia and for the river basin districts.

Keywords: hydrogeological models; infiltration distributions; groundwater flow balance.

1. Introduction

The countries of the world and of the European Union are developing hydrogeological models (HM), where by means of computer modelling, the information necessary for the groundwater management planning is obtained. In 2012, scientists of Riga Technical University have worked out the regional HM of Latvia (LAMO) [1]. It simulates the steady state average groundwater regimes for the zone of active water exchange that is used in Latvia for drinking water supply. LAMO covers the area of 475km×300km; the plane approximation step is 500 metres; the spatial grid contains 27 planes; therefore, the HM grid consists of $951\times601\times27=15.43\times10^6$ nodes. The commercial program "Groundwater Vistas" is used for running LAMO. In 2013, the first practical application of LAMO has taken place and its results are described in this publication. The results were used for improving of the water management plans of the Gauja, Daugava, Lielupe and Venta river basin districts [2–5]. Locations of the four districts and of the geological profiles are shown in Fig. 1. The set of profiles includes six W−E and eight S−N type regional profiles, accordingly.

The reports on mapping have been prepared by using a common scheme of representing results for all river basin districts as the parts of the united hydrogeological model of Latvia. The report contains the main section where the data related to the district are included and Appendix (equal for all districts) which provides important hydrogeological information for the whole Latvia. Appendix contains 16 maps, 2 tables and 5 text pages. The number of maps to be prepared for the main section depends on the number of aquifers presented by the district and on the arrangement of its geological profiles. LAMO contains 14 aquifers and for each of them the distributions of groundwater heads and infiltration flows have been mapped. However, the Gauja and Daugava river basin districts contain only 11 aquifers, because three upper primary aquifers are not present there [1–3], [9].

In the paper, the Appendices A, B, C are included. They present data taken from the district report Appendix. To illustrate the common results of mapping, the Daugava river basin data are used. Figures and Tables included in the paper are taken from the report [3].

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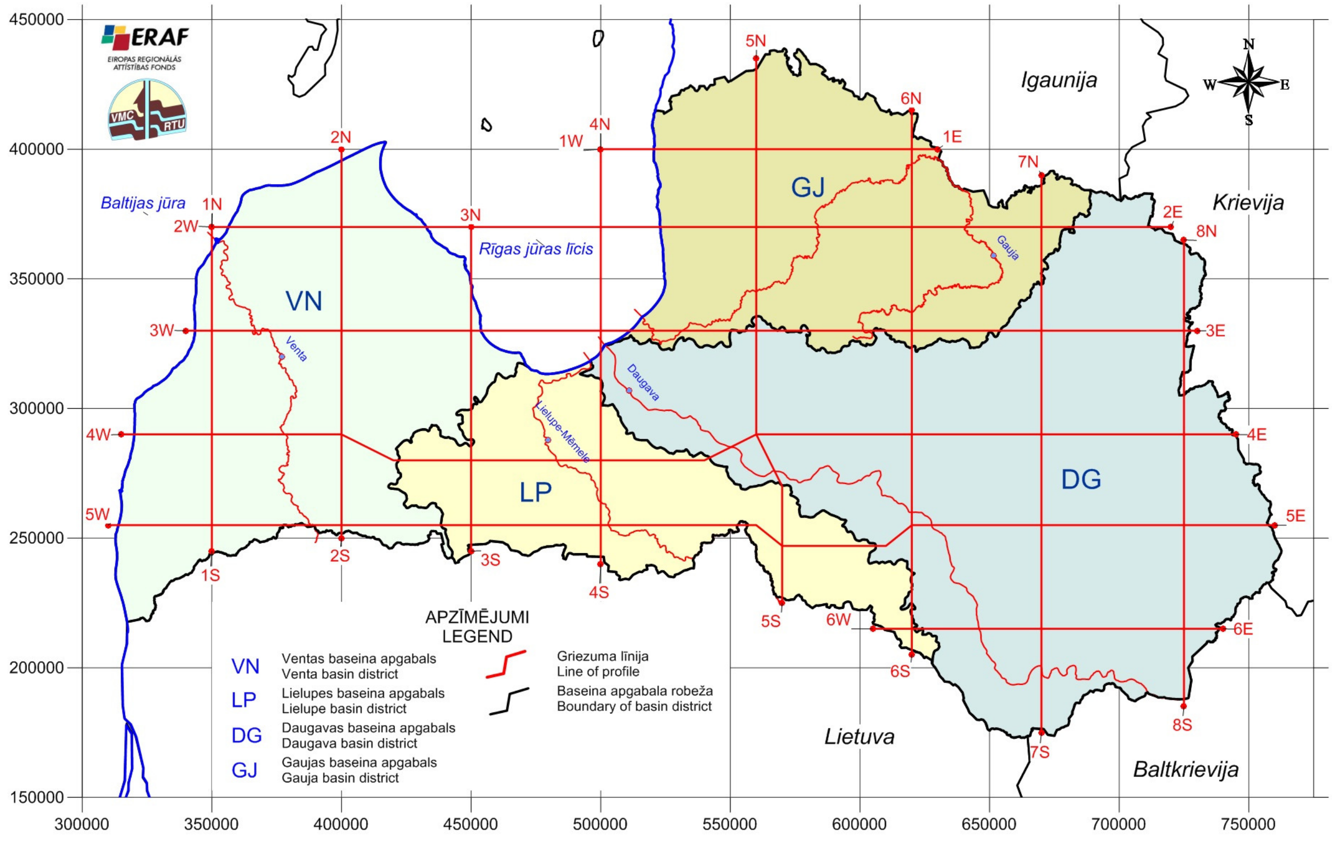

Fig. 1. Location of river basin districts and geological profiles

The groundwater flow balances provided by the current version of LAMO are preliminarily, because links of rivers with the HM body are yet not adjusted properly. In the course of the LAMO calibration, as the calibration target, the total flow of rivers has been used for adjusting these links. Its rough value (6000 thous. m^3/day) was obtained from the book [14]. Presently, a river link correctly accounts only for the river width. The other elements of the link (permeability and thickness of a river bed have been adjusted empirically, not accounting for measured in nature river flows. Making use of these measurements is a part of LAMO upgrading that will result in more exact estimates of the interaction between groundwater and rivers and of the groundwater flow balances for Latvia and its river basin districts.

Methods and software tools that have been used to develop LAMO are presented in the publications [1], [6–8] and [9–12], accordingly. Important regional data were provided by the books [13], [14].

2. Results of mapping

In the Daugava district, the geological strata D3ktl#, D3ktlz, D3zg#, D3akz, D3krs#, D3el#z (Appendix A, LAMO planes 7–12) do not exist and no maps are provided for these strata. For the Daugava district, 32 maps were prepared. The maps represented four types of hydrogeological information:

- the digital relief and distributions of groundwater heads for aquifers (11 maps);
- the infiltration distributions (10 maps);
- the maps where areas of inflow, outflow and transit areas of groundwater flows were shown (3 maps);
- geological profiles (8 maps).

In the maps of the groundwater head distributions, the parts of rivers are marked that are joined with aquifers. These connections may be very complex. For example, the Daugava River (Fig. 5), on its run, is joined with aquifers Q2, D3pl, D3dg#, D3pl, Q2. Information regarding connections of rivers with aquifers is used when rivers are immersed into LAMO. Directions of groundwater flows are also shown. No isolines of groundwater heads are given for a nonexistent part of an aquifer. An exception is the groundwater head distribution map of the prequaternary aquifers preQ (Fig. 2). The distribution is superposition of visible head distributions of the primary aquifers that can be observed from the bird's eye view.

The distributions of infiltration flows were computed for aquifers by using the groundwater head distributions, the maps of permeability and thickness of geological strata. As an example, the distribution for the aquifer preQ (Fig. 3) is presented. The distribution of Fig. 3 is very complex. The infiltration intensity there depends on the flow through the aeration zone aer. The flow is controlled by the digital relief relh (boundary conditions) and by the variable conductivity of the aeration zone aer (see Appendix A). Maximal recharges coincide with hilly areas, but outflows are in the areas of lowlands, lakes and rivers.

Like the map of Fig. 2, the infiltration map of Fig. 3 also presents the superposition of visible infiltration areas of primary aquifers. For the deep aquifers, the intensity of infiltration decreases. However, the areas of maximal infiltration coincide with uplands simulated by the digital relief [3].

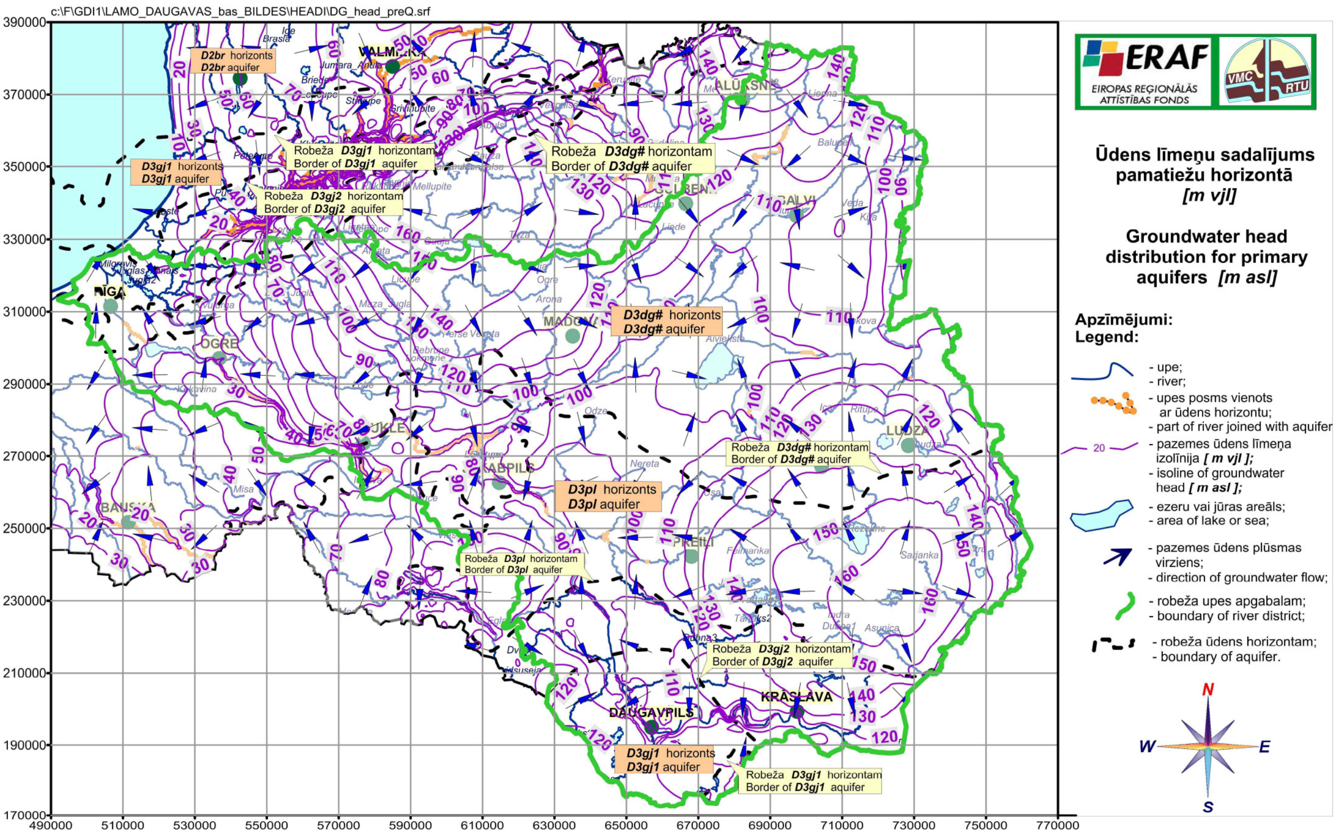

Fig. 2. Groundwater head distribution of primary preQ aquifers [m asl]

For aquifers Q2, preQ, D2ar, special maps were prepared. In these maps, areas of inflow, outflow and transit areas of groundwater flows are shown (see Fig. 4 for preQ). The map of Fig. 4 was obtained by joining data carried by distributions of groundwater heads and of the infiltration (Figs 2 and 3). To mark the areas, the simplified color scale of infiltration was applied. The width of transit zone was decreased for D2ar aquifer. For aquifers Q2, preQ, the zone (0–60) mm/year was used, but the transit zone (0-10)mm/year was used for the aquifer D2ar. Otherwise, it was not possible to mark the inflow areas of the aquifer D2ar, where the infiltration intensity was much smaller [3].

Hence the groundwater body is uninterrupted , the hydrogeological data are provided for the whole map of a district. For example, in Fig.2–4, the data are not blanked, for the bordering areas of the Gauja and Lielupe districts. Due to full exposition of the data, it is possible to investigate processes happening in the border zones of the districts (influence of existing and new well fields, contamination / sanitation of groundwater bodies, etc.). For deeper aquifers, one can observe deviation of the water divide location in relation to the district borderline. For example, in Fig. 2, such deviation has taken place in the D3dg# aquifer where some parts of the water divide do not coincide with the borderline of the Gauja and Daugava districts, because the borderline there is not orthogonal to the isolines.

The geological profiles provide valuable information about hydrogeological processes. As an example, the profile for the Daugava River is presented (Fig. 5). It gives the geological stratification, the set of isolines for groundwater head, directions of groundwater flows. To graph the isolines of head, it was taken into consideration that in aquifers the isolines had to have vertical orientation, because there the vertical hydraulic gradient was very small. Special methods were used to obtain right results where different behavior of isolines within aquifers and aquitards was accounted for.

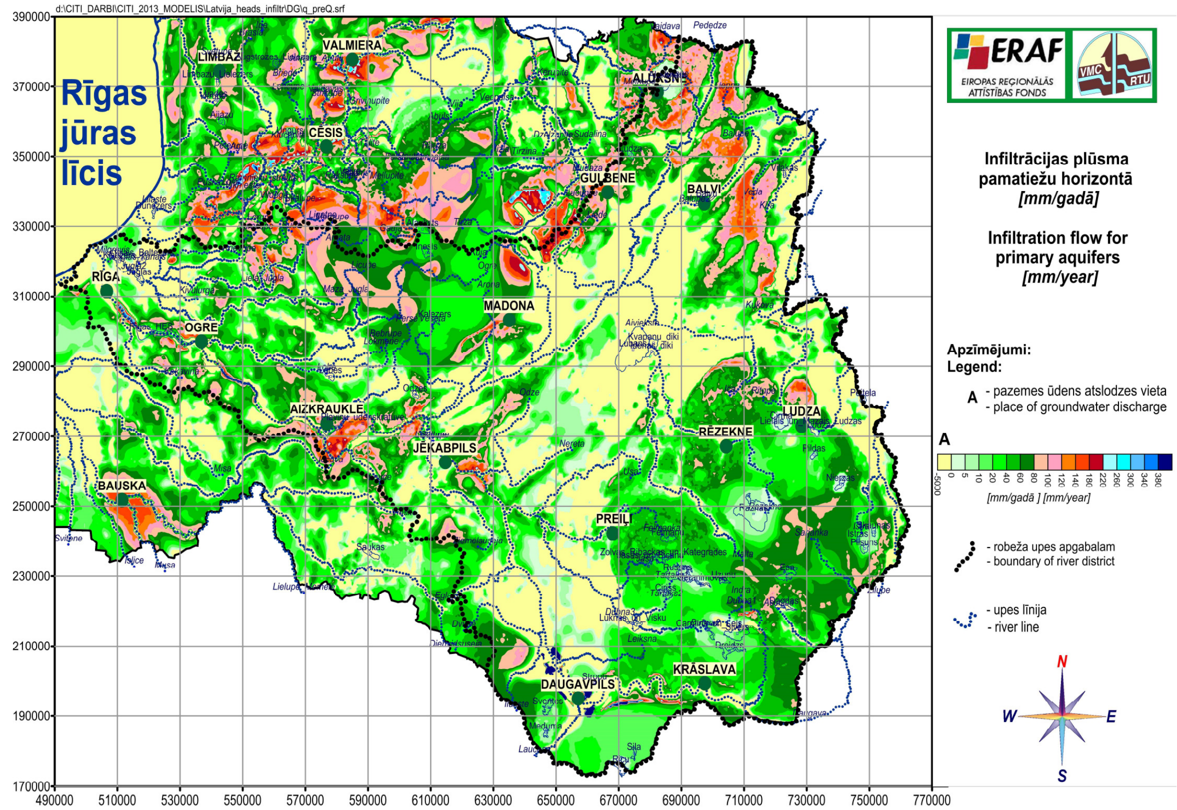

Fig. 3. Infiltration flow for primary preQ aquifers [mm/year]

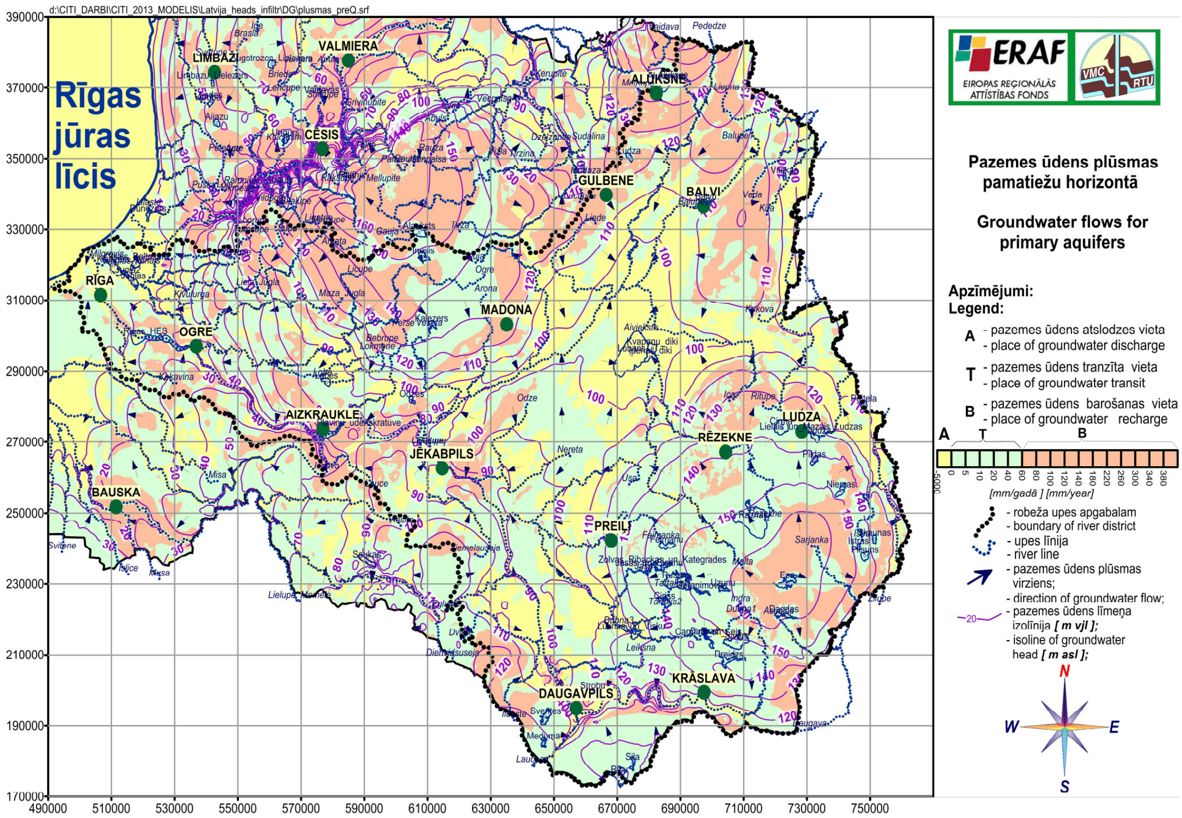

Fig. 4. Groundwater flows for preQ aquifers [mm/year]

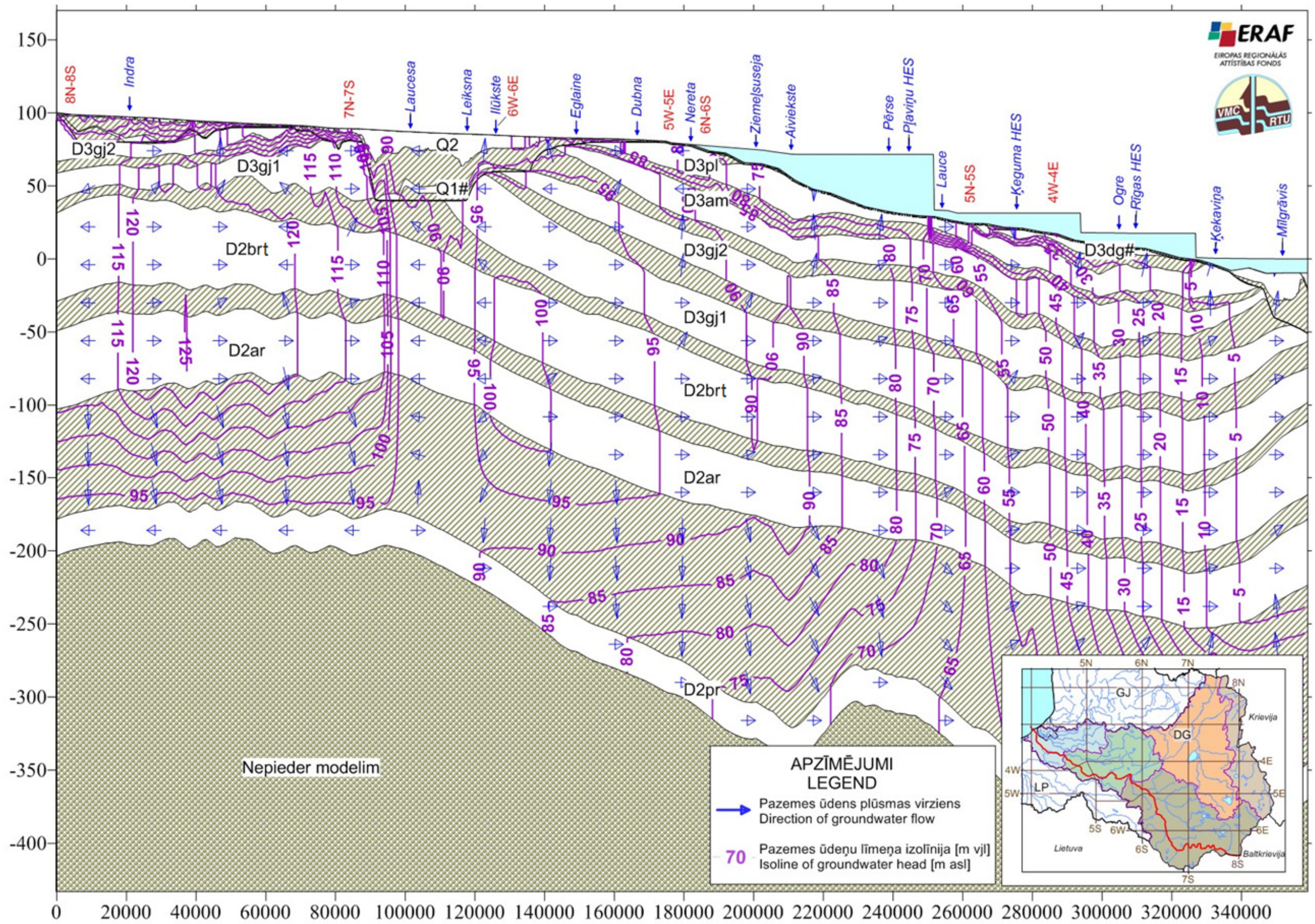

Fig. 5. Geological profile along the Daugava River

3. Groundwater flow balance

By using results of LAMO, the preliminarily groundwater flow balances of Latvia and its river basin districts were prepared. In Appendix B1, the groundwater flow balance of Latvia is presented. The columns Nr. 2, 3, 5, 6, 11, 12, 13, 14 of Table for Appendix B1 contain LAMO data. Information for final filling of Table is obtained by performing three sequential steps a), b), c). The step a) serves for computing the resulting flows qtoprez and qbotrez (columns 4 and 7): by summing descending and ascending groundwater flows of vertical transit (taken from LAMO). The origin of the descending flow is infiltration caused by precipitation (aquifer Q2). The summing of these two flows gives the resulting descending flows qtoprez, qbotrez. However, the flows do not provide data about the local balance for each aquifer.

By performing the step b), the local inflow qtoprezl (column 10) is obtained for each aquifer. The step c) gives the local balance that shows how the inflow is spent by rivers, lakes, wells and borders of aquifers. The local inflow qtoprezl can be obtained without performing the steps a), b), because all other elements of the local balance are given by LAMO. However, then no information is exposed related to the spatial transfer of groundwater flows. The graphical interpretation of the Appendix B1 data is given by the scheme of Appendix C.

The flow balance of the Daugava district is presented by Appendix B2.

To compare groundwater flow balances of Latvia and the Daugava district, the following standards were used:

- mean resulting infiltration [mm/year];
- relative outflows for rivers q_{rivrel} [%];
- ratio B of flows for aquifers of Latvia and the Daugava district [%];
- deviation N from the value of B [times].

The mean resulting infiltration q_{infrel} [mm/year] was computed by using formula

$$q_{infrel} = 0.365\ q / L \tag{1}$$

where q is the resulting infiltration q_{toprez} [thous. m^3/day] of the aquifer Q2 (7419 and 2960 from Appendices B1, B2) and L represent areas of Latvia and the Daugava district: 64.5 and 27.04 thous. km^2, accordingly.

The relative outflows for rivers q_{rivrel} [%] are computed, as follows:

$$q_{rivrel} = 100\ q_{riv} / q_{toprezl}, \tag{2}$$

where q_{riv} and $q_{toprezl}$ are taken from the local balance data of Latvia and the Daugava district.

The ratio B [%] gives the proportion:

$$B = 100\ (q_{toprezl})_D \ /\ (q_{toprezl})_L, \tag{3}$$

where the local inflows of the Daugava district and Latvia are applied.

Deviation N from the mean value of B is computed as the ratio:

$$N = B/42 \text{ [times]}, \tag{4}$$

where the number 42 shows that the area of the Daugava district covers 42% of the land territory of Latvia.

The values of the above standards are presented by Table1. In Table 2, the standards for balance of Latvia and its river basin districts are compared.

Table 1. Comparison of balances for Latvia and the Daugava district

Unit	Infiltration[mm/year]		River outflow [%]		*B* [%]	*N* [times]
	Daugava district	Latvia	Daugava district	Latvia	Daugava district	Daugava district
Totals	40	42	74	79	38	0.91
Q1+Q2	40	42	88	84	45	1.08
Primary strata	16	20	49	72	31	0.74
D2brt	5	6	0	67	14	0.33

Table 2. Comparison of balances for Latvia and its river basin districts

District	Infiltration[mm/year]	*B* [%]	*N* [times]
Gauja	57	27.17	1.30
Daugava	40	38.14	0.91
Lielupe	25	8.43	0.61
Venta	43	26.26	1.08
Latvia	42	100	1.0

In Table 1, the criterion N shows that groundwater processes only for the quaternary system (Q1 + Q2) of the Daugava district are slightly more active (N = 1.07) than for Latvia. This may be caused by the larger river outflow (88>84) for the (Q1 + Q2) system. For the whole district, N = 0.91. Values of N are small 0.74 and 0.33, for the primary strata system and for the D2brt aquifer, respectively. This may be caused by the small river outflows of these objects (49<72, for primary strata) and (0<67), for the D2brt aquifer.

It follows from Table 2 that the groundwater processes are very active for the Gauja district (N = 1.30), but they are slow for the Lielupe district (N = 0.61).

The groundwater flow balances will improve if the links of rivers and lakes with the HM body will be adjusted more accurately accounting for river flow measurements and the real regimes of lakes. To carry out this task, the set of rivers and lakes for LAMO have to be increased. The plane approximation step must be changed from 500 metres to 250 metres.

4. Conclusions

In 2010–2012, scientists of Riga Technical University have developed the hydrogeological model of Latvia (LAMO). In 2013, the first results were provided by LAMO. The set of hydrogeological maps and geological profiles have been prepared for improving the water management plans for the river basin districts of Gauja, Daugava, Lielupe, Venta.

Preliminarily results of the groundwater flow balances for Latvia and for its river basin districts have been obtained. The balances provide new knowledge on interaction between groundwater and surface water bodies for the active groundwater zone of Latvia. However, the present version of LAMO does not account for the flows measured in rivers. Regimes of lakes are yet not adjusted properly. The above mentioned field data will be used by the upgraded version of LAMO when its plane approximation step will be decreased from 500 meters to 250 meters.

Acknowledgements

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Appendix A. Vertical schematization of LAMO

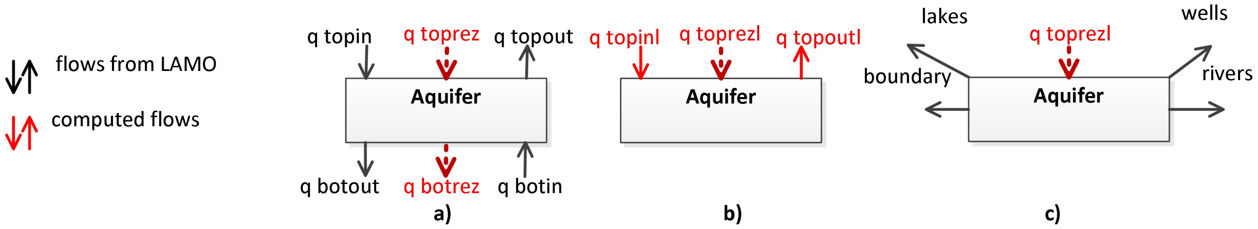
No of HM plane		Name of layer	Geological code	HM plane code
1.		Relief	relh	relh
2.	▤	Aeration zone	aer	aer
3.		Unconfined Quaternary	Q4-3	Q2
4.	▤	Upper moraine	gQ3	gQ2z
5.		Confined Quaternary or Jura	Q1-3 J	Q1#
6.	▤	Lower moraine or Triass	gQ1-3 T	gQ1#z
7.		Perma Karbons Skerveles Ketleru	P2 C1 D3šķ D3ktl	D3ktl#
8.	▤	Ketleru	D3ktl	D3ktlz
9.		Zagares Svetes Tervetes Muru	D3žg D3sv D3tr D3mr	D3zg#
10.	▤	Akmenes	D3ak	D3akz
11.		Akmenes Kursas Jonisku	D3ak D3krs D3jn	D3krs#
12.	▤	Elejas Amulas	D3el D3aml	D3el#z
13.		Stipinu Katlesu Ogres Daugavas	D3stp D3ktl D3og D3dg	D3dg#
14.	▤	Daugavas Salaspils	D3dg D3slp	D3slp#z
15.		Plavinu	D3pl	D3pl
16.	▤	Plavinu Amatas	D3pl D3am	D3am#z
17.		Amatas	D3am	D3am
18.	▤	Upper Gauja	D3gj2	D3gj2z
19.		Upper Gauja	D3gj2	D3gj2
20.	▤	Lower Gauja	D3gj1	D3gj1z
21.		Lower Gauja	D3gj1	D3gj1
22.	▤	Burtnieku	D2brt	D2brtz
23.		Burtnieku	D2brt	D2brt
24.	▤	Arikula	D2ar	D2arz
25.		Arikula	D2ar	D2ar
26.	▤	Narvas Narvas	D2nr2 D2nr1	D2nr#z
27.		Pernavas	D2prn	D2pr

▤ - aquitard

\# -united aquifer; #z – united aquitard

Appendix B1. Groundwater flow balance of LAMO [thous. m^3/day] of Latvia (preliminarily data)

Name of aquifer	q_{topin}	q_{topout}	q_{toprez} (2+3)	q_{botout}	q_{botin}	q_{botrez} (5+6)	q_{topinl} (2+5)	$q_{topoutl}$ (3+6)	$q_{toprezl}$ (4+7) (8+9)	rivers	lakes	boundary	wells
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Q2	11194	–3775	7419	–6992	3461	–3531	4202	–314	3888	–3288	–426	–118	–56
Q1	6992	–3461	3531	–6855	3349	–3506	137	–112	25	–7	0	–18	0
D3ktl#	6855	–3349	3506	–6524	3191	–3333	331	–158	173	–192	0	20	–1
D3zg#	6524	–3191	3333	–6284	3014	–3270	240	–177	63	–41	0	–18	–4
D3krs	6284	–3014	3270	–6333	2986	–3247	51	–28	23	–11	0	–8	–4
D3dg#	6233	–2986	3247	–4981	2333	–2648	1252	–653	599	–569	–10	–15	–5
D3pl	4981	–2333	2648	–3981	1849	–2132	1000	–484	516	–446	8	–70	–8
D3am	3981	–1894	2132	–3622	1634	–1988	359	–212	144	–93	0	–50	–1
D3gj2	3622	–1634	1988	–3041	1418	–1623	581	–216	365	–244	0	–96	–25
D3gj1	3041	–1418	1623	–2114	996	–1118	927	–412	505	–327	0	–154	–24
D2brt	2114	–996	1118	–852	423	–429	1262	–573	689	–462	0	–214	–13
D2ar	652	–423	429	–256	36	–220	596	–387	209	0	0	–195	–14
Model	11194	–3775	7419	–256	36	–220	10938	–3739	7199	–5680	–428	–936	–155
Q1+Q2	11194	–3775	7419	–6855	3349	–3506	4339	–426	3913	–3295	–426	–136	–56
Primary	6855	–3349	3506	–256	36	–220	6599	–3313	3286	–2385	–2	–800	–99



Legend of stages (a), (b), (c) for obtaining flows of Appendices B1, B2: a) computing of resulting flows: qtoprez, qbotrez; b) computing of local flows qtopinl, qtopoutl, qtoprezl; c) local balance of aquifer

Appendix B2. Groundwater flow balance of LAMO [thous m3/day] for Daugava river basin district (preliminarily data)

Name of aquifer	q_{topin}	q_{topout}	q_{toprez} (2+3)	q_{botout}	q_{botin}	q_{botrez} (5+6)	q_{topinl} (2+5)	$q_{topoutl}$ (3+6)	$q_{toprezl}$ (4+7) (8+9)	rivers	lakes	boundary	wells
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Q2	4804	–1844	2960	–2893	1713	–1180	1911	–131	1780	–1565	–186	19	–48
Q1#	2893	–1713	1180	–2819	1633	–1186	74	–80	–6	0	0	6	0
D3dg#	2819	–1633	1186	–2153	1156	–997	666	–477	189	–157	–10	–18	–4
D3pl	2153	–1156	997	–1478	853	–625	675	–303	372	–349	8	–23	–8
D3am	1478	–853	625	–1309	720	–589	169	–133	36	0	0	–36	0
D3gj2	1309	–720	589	–1056	569	–487	253	–151	102	0	0	–81	–21
D3gj1	1056	–569	487	–632	275	–357	424	–294	130	0	0	–123	–7
D2brt	632	–275	357	–369	110	–259	263	–165	98	0	0	–96	–2
D2ar	369	–110	259	–180	7	–173	189	–103	86	0	0	–85	–1
Model	4804	–1844	2960	–180	7	–173	4624	–1838	2787	–2061	–188	–447	–91
Q1+Q2	4804	–1844	2960	–2819	1633	–1186	1985	–211	1774	–1565	–186	25	–48
Primary	2819	–1633	1186	–180	7	–173	2639	–1628	1013	–496	–2	–472	–43

Appendix C. Scheme of groundwater flow balance of Latvia (explanation of Appendix B1)