Grundwater Flow Balance of the Gauja River Basin District

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***Abstract* – In 2010–2012, the hydrogeological model of Latvia (LAMO) was developed by scientists of Riga Technical University. The commercial program "Groundwater Vistas" is used for running LAMO. In 2013, data provided by LAMO have been used for the mapping of the Gauja/Koiva River basin district. The materials on the mapping have also included information about groundwater flow balances of the district. The flow balances of Latvia and the Gauja district have been considered. The flow balances of groundwater bodies of the district have been analysed. The flow balances provide new knowledge on the complex interaction between surface water (rivers, lakes, sea, precipitation) and groundwater.**

***Keywords* – Groundwater flow balance, hydrogeological models, infiltration distributions.**

I. Introduction

In 2010–2012, the hydrogeological model of Latvia (LAMO) was established. LAMO can provide information necessary for improving plans on the management of drinking groundwater resources of Latvia. In 2013, data provided by LAMO have been used for the mapping of the Gauja/Koiva River basin district [1]. In the current publication, results on groundwater flow balances are considered that have been obtained by using the upgraded LAMO version.

The "Groundwater Vistas" (GV) system provides ample data about groundwater flow balance of LAMO. Three cases of the flow balances will be considered:

- for the whole territory of Latvia;
- for the Gauja district;
- for groundwater bodies of the Gauja district.

The location of the Gauja basin district and the vertical schematization of LAMO are available in [2]. The survey of methods used to develop LAMO is given in [3-13].

II. Groundwater Flow Balance of Latvia

By using information of LAMO, the preliminary version (Table I) of the groundwater flow balance of Latvia was obtained. Table I is taken from [1] and its graphical interpretation gives the scheme of Fig. 1.

Columns 2, 3, 5, 6, 11, 12, 13, 14 of Table I contain LAMO data. Information for final filling of Table I is obtained by performing three sequential steps a), b), c). The step a) serves for computing the flows (columns 4 and 7):

$$q_{toprez}=q_{topin}+q_{topout}\ ;\quad q_{botrez}=q_{botin}+q_{botout} \tag{1}$$

The graphical interpretation of the step is given in Fig.1 a) where descending and ascending groundwater flows of vertical transit (taken from LAMO) are shown. The origin of the descending flow is infiltration caused by precipitation (aquifer Q2). The summing of these two flows gives the resulting descending flow. However, the flow does not provide data about the local balance for each aquifer.

By performing step b), the local inflow (column 10):

$$q_{toprezl}=q_{toprez}+q_{botrez} \tag{2}$$

is obtained for each aquifer. Step c) gives the local balance that shows how the inflow is spent by rivers, lakes, wells and borders of aquifers.

The flows q_{topinl} and $q_{topoutl}$ (columns 8 and 9) allow discovering how the flow

$$q_{toprezl}=q_{topinl}+q_{topoutl} \tag{3}$$

gets formed by accounting for the sign of $q_{topoutl}$. In most cases, $q_{topoutl}$<0. However, sometimes $q_{botin}>q_{topout}$. Then there is the resulting inflow through the aquifer bottom:

$$q_{topoutl}=q_{botin}-q_{topout}\ . \tag{4}$$

Table I contains data on the total flow balance of Latvia and balances for the Quaternary system Q1+Q2 and the primary aquifers. The rough value of total outflow of rivers (~6000 thous. m^3/day) was taken from the book [4] and was accounted for in the course of the LAMO calibration.

It follows from Table I that the inflow [thous m^3/day] of the (Q1+Q2) system is slightly larger than the one of the primary strata (3913>3286). Mean resulting infiltration [mm/year] on the land territory of Latvia (64.5 thous km^2): (7419×0.365)/64.5=42[mm/year].

This recharge of groundwater resources composes 6% of the mean precipitation (700mm/year) for Latvia.

III. Groundwater Flow Balance of Gauja District

The flow balance of the Gauja district is presented in Table II that is explained by the scheme of Fig. 2. In the district, aquifers D3ktl#, D3zg#, D3krs# do not exist. The area of the district is 13 thous. km^2 .

For the Gauja district, aquifers Q2, D3gj2, D3gj1 have the resulting inflow from below ($q_{topoutl}$ >0). These inflows may be caused by rivers that are joined with these aquifers.

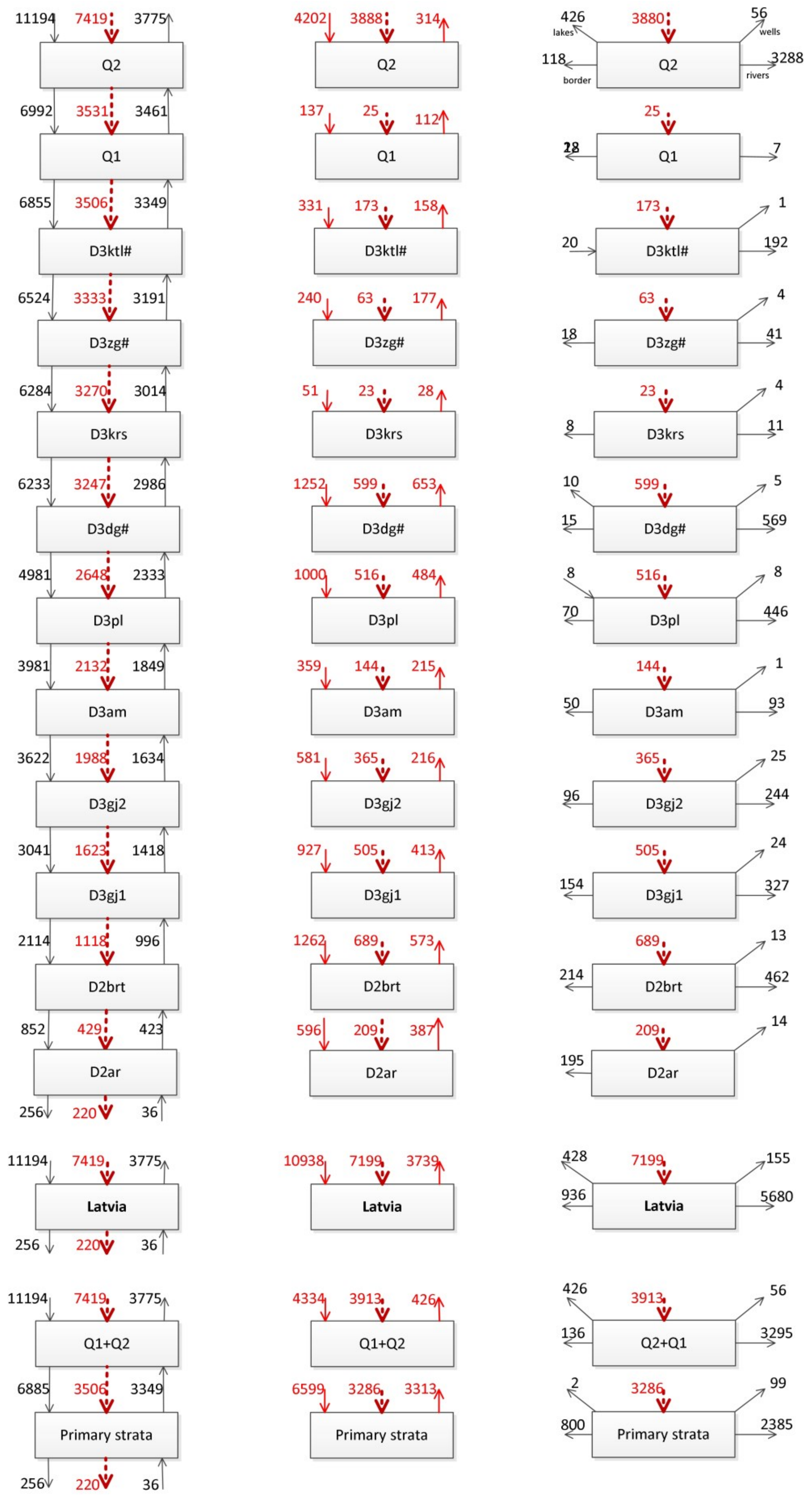
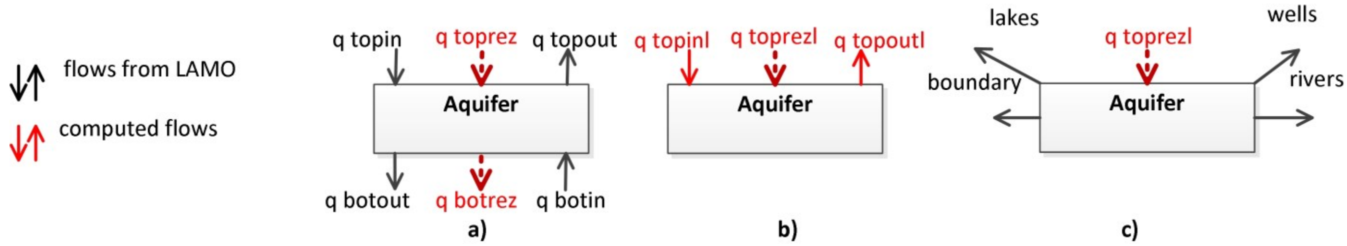


Fig. 1. Scheme of groundwater flow balance of Latvia (Table I).

TABLE I

LAMO GROUNDWATER FLOW BALANCE [THOUS M3/DAY] OF LATVIA (PRELIMINARY 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 Table I:

a) the computing of resulting flows: q_{toprez}, q_{botrez};

b) the computing of local flows q_{topinl}, $q_{topoutl}$, $q_{toprezl}$;

c) local balance of aquifer

TABLE II

LAMO GROUNDWATER FLOW BALANCE OF [THOUS M3/DAY] THE GAUJA RIVER DISTRICT (PRELIMINARY 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	2699	-672	2027	-1926	685	-1241	773	13	786	-675	-76	-27	-8
Q1#	1926	-685	1241	-1915	678	-1237	11	7	4	0	0	-4	0
D3dg#	1915	-678	1237	-1725	609	-1116	190	-69	121	-97	0	-24	0
D3pl	1725	-609	1116	-1597	536	-1061	128	-73	55	-31	0	-24	0
D3am	1597	-536	1061	-1517	510	-1007	80	-26	54	-51	0	-3	0
D3gj2	1517	-510	1007	-1342	514	-828	175	4	179	-190	0	11	0
D3gj1	1342	-514	828	-1069	518	-551	273	4	277	-279	0	3	-1
D2brt	1069	-518	551	-322	215	-107	747	-303	444	-378	0	-61	-5
D2ar	322	-215	107	-45	6	-39	277	-209	68	0	0	-64	-4
Model	2699	-672	2027	-45	6	-39	2654	-666	1988	-1701	-76	-193	-18
Q1+Q2	2699	-672	2027	-1915	678	-1237	784	6	790	-675	-76	-31	-8
Primary	1915	-678	1237	-45	6	-39	1870	-672	1198	-1026	0	-162	-10

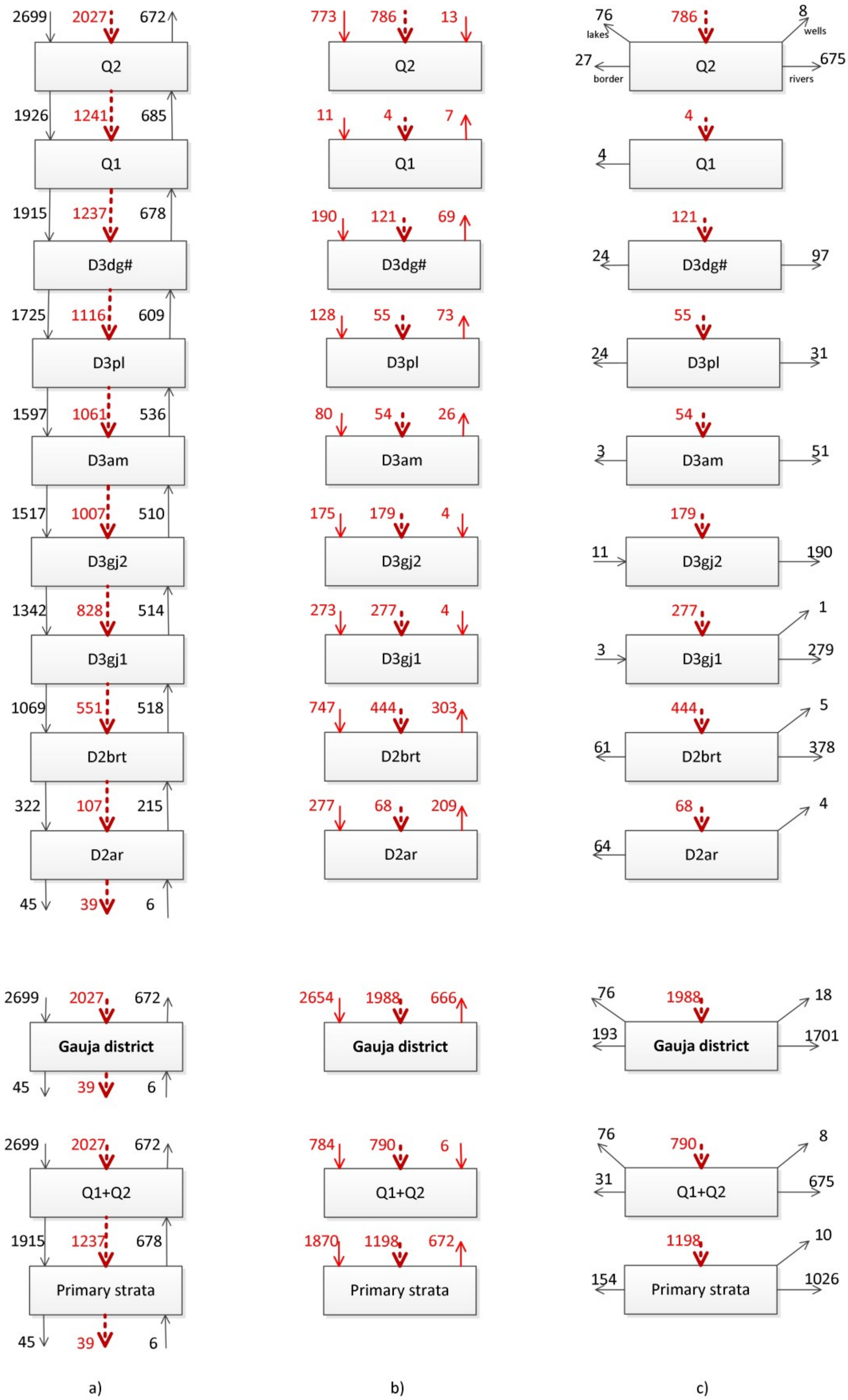


Fig. 2. Scheme of groundwater flow balance of the Gauja district (Table II).

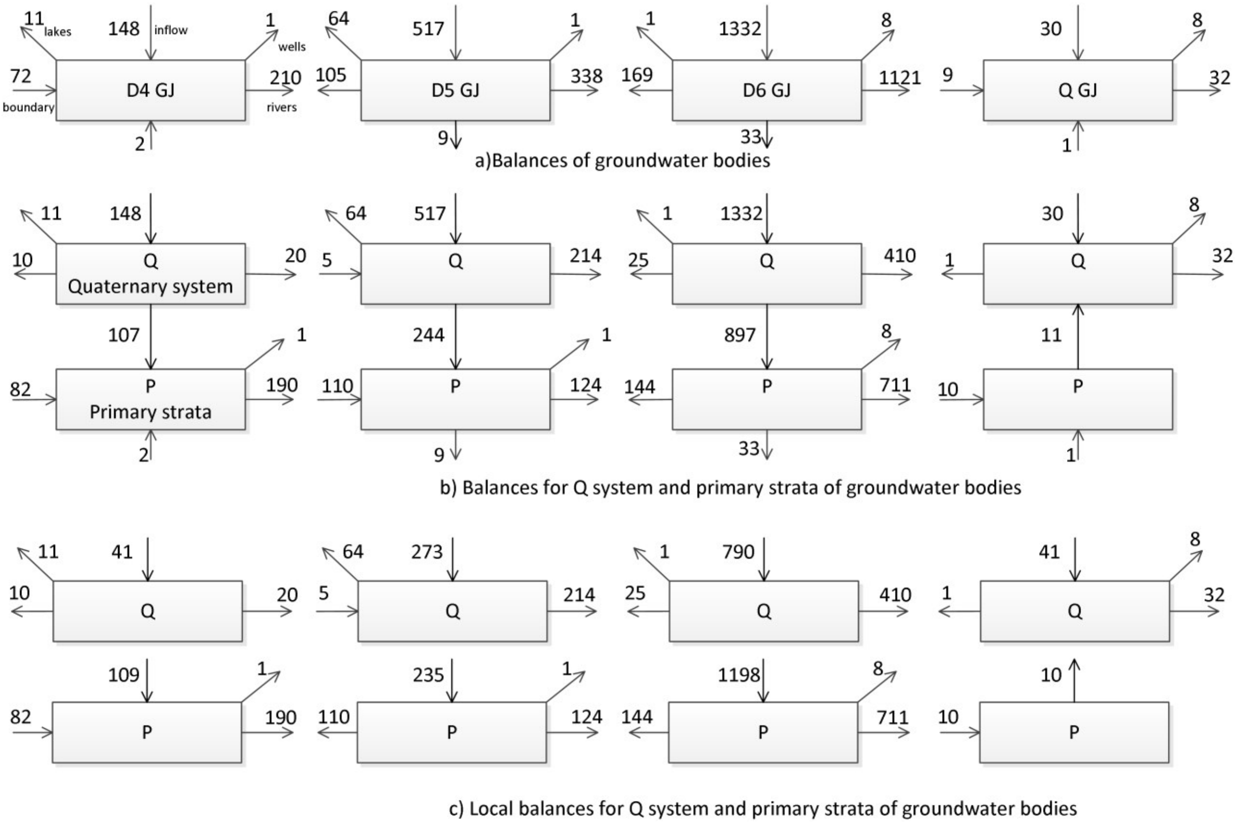


Fig. 3. Scheme of groundwater flow balance for groundwater bodies of the Gauja river basin district (Table III).

TABLE III

LAMO GROUNDWATER FLOW BALANCE [THOUS M^3/DAY] FOR GROUNDWATER BODIES OF THE GAUJA RIVER DISTRICT (PRELIMINARY DATA)

Code of groundwater body	Parts of bilance	Distribution of groundwater flow [thous. m^3/day]						
		q_{toprez}	q_{botrez}	(3+4) $q_{toprezl}$	rivers	lakes	boundary	wells
1	2	3	4	5	6	7	8	9
D4-GJ	Total	148	2	150	-210	-11	72	-1
	Q system	148	-107	41	-20	-11	-10	0
	Primary strata	107	2	109	-130	0	82	-1
D5-GJ	Total	517	-9	508	-338	-64	-105	-1
	Q system	517	-244	273	-214	-64	5	0
	Primary strata	244	-9	235	-124	0	-110	-1
D6-GJ	Total	1332	-33	1299	-1121	-1	-169	-8
	Q system	1332	-897	435	-409	-1	-25	0
	Primary strata	901	-33	864	-712	0	-144	-8
Q-GJ	Total	30	1	31	-32	0	9	-8
	Q system	30	11	41	-32	0	-1	-8
	Primary strata	-11	1	-10	0	0	10	0
Total for Gauja district	Total	2027	-39	1988	-1701	-76	-193	-18
	Q system	2027	-1237	790	-675	-76	-31	-8
	Primary strata	1237	-39	1198	-1026	0	-162	-10

Theoretically, the flow through the border of aquifer D3dg# must be zero, if the border between the Gauja and Daugava districts is a water divide for these aquifers. It follows from Table II and Fig. 2 that it is not true, because for aquifer D3dg#, the border outflow is 24 thous. m^3/day. Therefore, the balance data confirm the shifting of locations of water divides for deeper aquifers. This phenomenon has been considered in [1].

It follows from Table II that the inflow [thous. m^3/day] of the (Q1+Q2) system is considerably smaller than the one of the primary strata (790<1198).

The mean infiltration [mm/year] for the Gauja district area (13 thous. km^2): (2027×0.365)/13=57 [mm/year] is larger than the one for Latvia (57>42).

IV. Flow Balances of Groundwater Bodies for the Gauja District

The flow balance for groundwater bodies D4_GJ, D5_GJ, D6_GJ, Q_GJ is presented in Table III. The scheme of Fig. 3 graphically explains results of Table III. For a groundwater body, its total balance and the balances of the Quaternary system Q and of the Primary strata are found. The summary of the balances for groundwater bodies of Table III coincides with the summary of Table II. In Fig. 3 a), the total balances for bodies are shown. In Fig. 3 b), groundwater flows of Q system and of the primary strata are presented. The local balances are shown in Fig. 3 c).

Balances of small groundwater bodies D4_GJ and Q_GJ are rather unusual. For the body D4_GJ, there is a large inflow of 82 thous. m^3/day for the border of primary strata. This inflow is caused by the Gauja River that is joined with aquifers D3gj2 and D3gj1. For the body Q_GJ, relatively large inflow of 11 thous. m^3/day through the bottom of Q system is caused by the water discharge of wells (8 thous. m^3/day).

V. Comparison of Groundwater Flow Balances of Latvia and the Gauja District

To compare groundwater flow balances, the following standards were used:

- mean resulting infiltration [mm/year];
- outflows for rivers q_{rivrel} [%];
- ratio B of flows for aquifers of Latvia and the Gauja district [%].

The mean resulting infiltration q_{infrel} was computed by using formula

$$q_{infrel} = 0.365\ q / L \qquad (5)$$

where q is the resulting infiltration q_{toprez} [thous. m^3/day] of aquifer Q2 and L represents areas of Latvia and the Gauja district: 64.5 and 13 thous. km^2, respectively.

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

$$q_{rivrel} = 100\ q_{riv} / q_{toprezl} \qquad (6)$$

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

The ratio B [%] gives the proportion:

$$B=100\ (q_{toprezl})_G / (q_{toprezl})_L \qquad (7)$$

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

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

$$N=B/20 \text{ (times)} \qquad (8)$$

where the number 20 shows that the area of the Gauja district covers 20% of the land territory of Latvia.

TABLE IV

Comparison of Balances for Latvia and the Gauja District

Unit	Infiltration[mm/year]		River outflow [%]		B [%]	N [times]
	Gauja district	Latvia	Gauja district	Latvia	Gauja district	Gauja district
Totals	57	42	85	79	27	1.3
Q1+Q2	57	42	85	84	22	1.1
Primary strata	35	20	86	72	36	1.8
D2brt	15	6	85	67	64	3.2

Criterion N shows that groundwater processes of the Gauja district are more intensive than for Latvia. Processes of aquifer D2brt (N=3.2) are especially active, because the large area of the aquifer is covered only by strata Q2 and gQ2z.

VI. Conclusions

By using data provided by the hydrogeological model of Latvia LAMO, preliminary results of the groundwater flow balances for Latvia, for the Gauja river basin district and its groundwater bodies have been obtained. The balances provide new knowledge on the 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 have not been adjusted properly yet. 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.

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