MODELLING OF THE FOREST MELIORATION SYSTEM AT LATVIA. A CASE STUDY

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ABSTRACT

The climate in Latvia is moderately warm and humid. To provide optimal groundwater heads (levels) for plant and tree growth, agricultural and forest melioration systems (AMS and FMS) have been set up in many places. Reconstruction of the FMS "Zamelu-Tisu mezs" will be carried out. To assess the reconstruction impact, hydrogeological and hydrological conditions in and around the FMS territory were studied. To accomplish this task, specialists of Riga Technical University for the study area developed and used the local hydrogeological model (HM). HM included natural hydrographic network elements (4 rivers and 2 brooks) and drainage ditches (11 AM and FM ditches and 306 FMS ditches). The aeration zone thickness maps, which characterize FMS performance, were obtained. FMS territory was divided into areas, where the drainage runoff before and after the system reconstruction was calculated. It was found out in which areas reconstruction will provide the best effect. Changes caused by FMS in hydrographical network flows were estimated. The modeling methodology and results explained in this paper may be useful for professionals designing large melioration systems.

Keywords: aeration zone, drainage runoff, hydrogeological model

INTRODUCTION

The FMS "Zamelu-Tisu mezs" reconstruction will take place in the southern part of Latvia near the border with Lithuania (Fig. 1). To assess the reconstruction effect, the current hydrogeological and hydrological situations in the FMS territory and its surroundings were studied. To complete this research, specialists of Riga Technical university developed local HM which was founded on information provided by the regional HM of Latvia LAMO4 [1].

In Fig. 2, the base map of the local HM area is shown. The model area size is 11km×8km =88km^2. In its middle, the FMS territory (11.5 km^2), is situated. The territory is divided into six drainage areas (DA) that replenish streams of three rivers (Vilce, Platone, Sidrabe), the Rezu brook and two ditches (Radzinu, Lielplatone). The FMS territory is surrounded by the Vilce and Eleja rivers, by the Zemdegu brook, by three AM ditches and eight FM contour ditches along the FMS territory boundary.

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Figure 1. The study area location

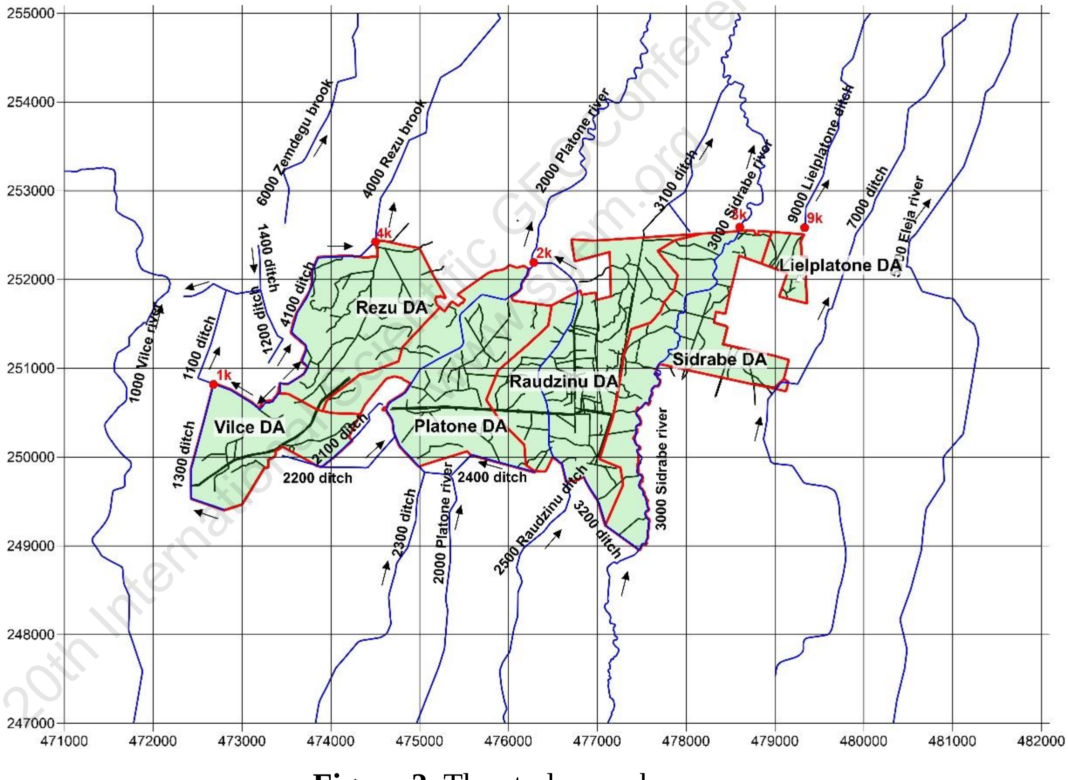

Figure 2. The study area base map

In Table 1, the summary is presented on the above mentioned HM hydrographical network elements. The data on the network were obtained from [2,3]. The information on FMS (306 ditches) were found in [4].

Table 1: The summary on the mean annual flows of the hydrographical network elements that are included in HM

No.	Name of element	HM code	Flow [l/sec]	Point of interest No.
1.	Vilce river	1000	1400.0	
2.	FM ditch	1100	3.7	
3.	AM ditch	1200	4.4	1k
4.	FM ditch	1300	8.8	1k
5.	AM ditch	1400	1.3	
6.	Platone river	2000	1490.0	2k
7.	FM ditch	2100	2.0	
8.	FM ditch	2200	8.7	
9.	AM ditch	2300	85.0	
10.	FM ditch	2400	3.4	
11.	Raudzinu ditch	2500	39.0	2k
12.	Sidrabe river	3000	654.0	3k
13.	FM ditch	3100	1.3	
14	FM ditch	3200	1.9	
15.	Rezu brook	4000	10.0	4k
16.	FM ditch	4100	10.0	4k
17.	Eleja river	5000	110.0	
18.	Zemdegu brook	6000	15.2	
19.	AM ditch	7000	18.0	
20.	Lielplatone ditch	9000	0.0	9k

FM and AM – forest and agricultural melioration

The commercial system Groundwater Vistas 7 (GV) [5] was used to run HM. The graphical system SURFER-12 [6] was applied for presenting the research results and for preparing the HM initial data.

RESULTS OF MODELLING

In Fig. 3, the groundwater head distribution φ_{Q2} map is shown before the FMS reconstruction is carried out. The distribution represents interaction between the relief ψ_{rel} (Fig. 8) and the hydrographical network (Fig. 2).

By using the GV tool MASS BALANCE [5], the DA flows were computed for the six FMS areas before and after the reconstruction. In Table 3, the summary on these results is presented. The proportions A/E and A/B are estimates, accordingly, of the FMS impact on the hydrographical network flows in the points of interest and on the reconstruction effect.

The reconstruction can considerably enlarge the flows at the points of interest 1k, 2k, 4k, 9k, because there A/E>1. FMS will be the most effective for the Lielplatone, Rezu and Raudzinu DA where B/A=21.50, 2.97 and 2.70, accordingly.

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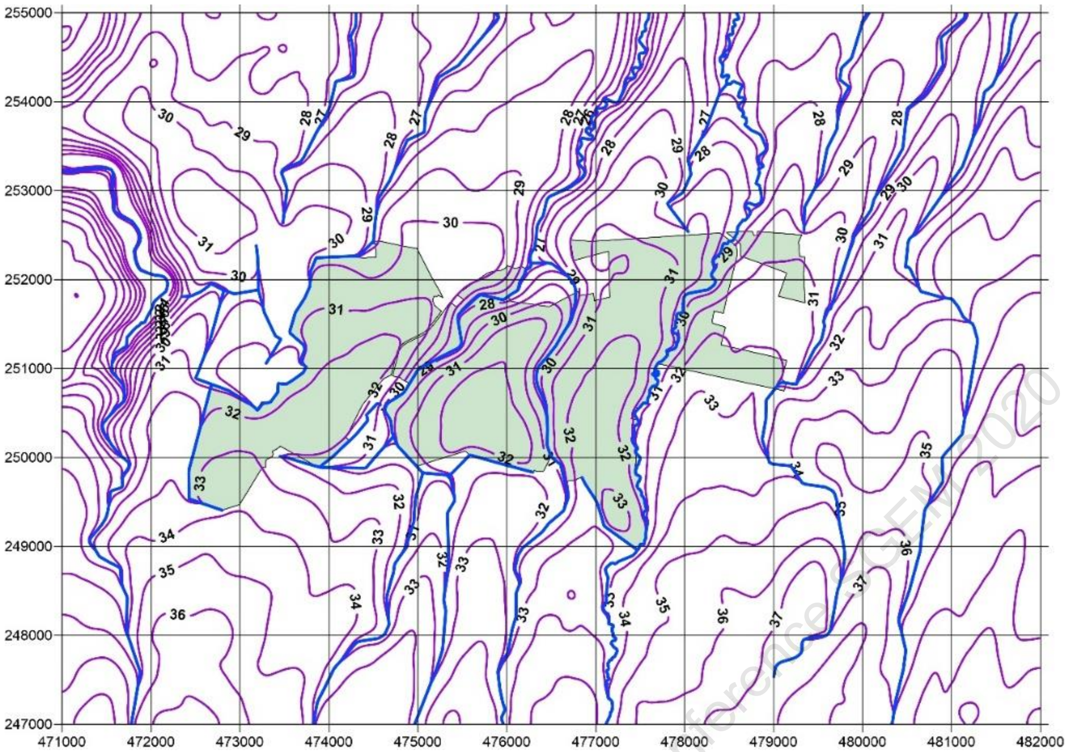

Fig. 3. The groundwater head distribution φ_{Q2} izolines [m asl] for the aquifer Q2 if FMS does not operate

Table 2: Mean annual flows and their changes caused by the FMS reconstruction.

HM code	Point No.	Drainage area name	Area		Flows [l/sec]			Changes caused by FMS	
			[km^2]	[%]	E	B	A	A/E	A/B
1000	1k	Vilce DA	1.42	12.3	3.7	15.5	27.0	>1.00	1.74
2000	2k	Platone DA	2.61	22.6	1490.0	25.6	41.3	0.028	1.61
2500	2k	Raudzinu DA	2.99	26.0	39.0	16.3	44.0	>1.00	2.70
3000	3k	Sidrabe DA	2.25	19.7	654.0	25.1	36.3	0.056	1.44
4000	4k	Rezu DA	1.98	17.2	11.0	8.8	26.1	>1.00	2.97
9000	9k	Lielplatone DA	0.25	2.2	0.0	0.2	4.3	>1.00	21.50
		Total	11.50	100	2197.7	91.5	179.0	0.081	1.96

E – flow of the hydrographical network element in the point of interest;
B and A - drainage area flows before and after FMS reconstruction, accordingly.

In Fig. 4 and Fig. 5, the aeration zone thickness m_{aer} maps of the FMS western side are shown before and after the FMS reconstruction. The maps are obtained as follows:

$$m_{aer} = \psi_{rel} - \varphi_{Q2} \quad (1)$$

where the distributions φ_{Q2} before and after the reconstruction are used. In groundwater discharge areas, $m_{aer} < 0$. To improve conditions of tree growth, there draining is necessary.
Comparison of the both m_{aer} maps confirms effectiveness of FMS, hence in the map of Fig. 5, m_{aer} has increased, only some small $m_{aer} < 0$ areas exist near the Platone river.

The drawdown S_0 and S_{FMS} maps of Fig. 6 and Fig. 7 are obtained, as follows:

$$S_0 = \varphi_{Q2} - \varphi_0 \,, \qquad S_{FMS} = \varphi_{Q2} - \varphi_{FMS} \qquad (2)$$

where φ_0 and φ_{FMS} are φ – distributions , accordingly, when no hydrographical network is used and when FMS operates.

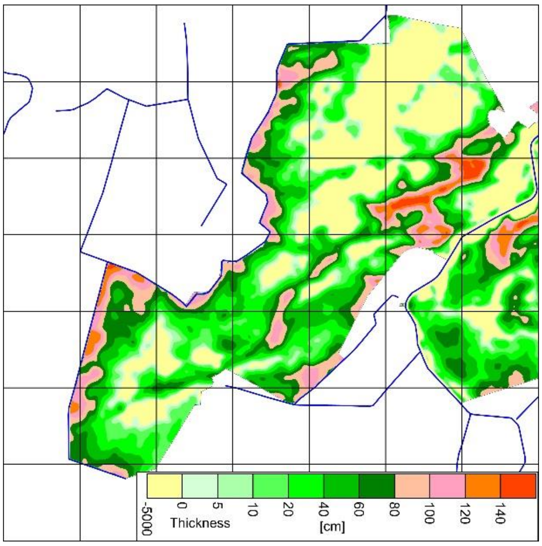

Fig. 4. The aeration zone thickness m_{aer} [cm] map of the FMS western side if FMS does not operate

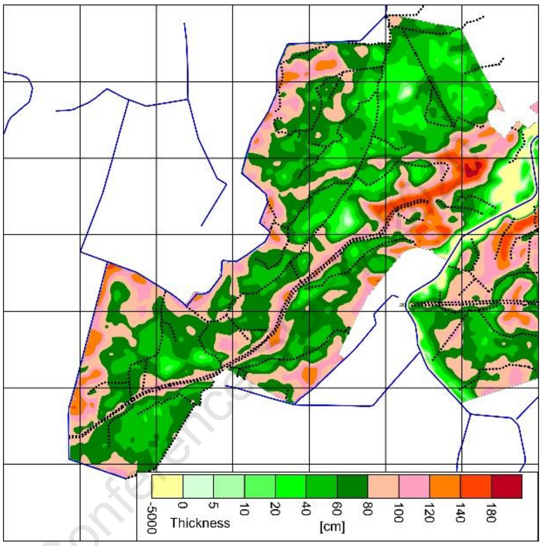

Fig. 5. The aeration zone thickness m_{aer} [cm] map of the FMS western side if FMS operates

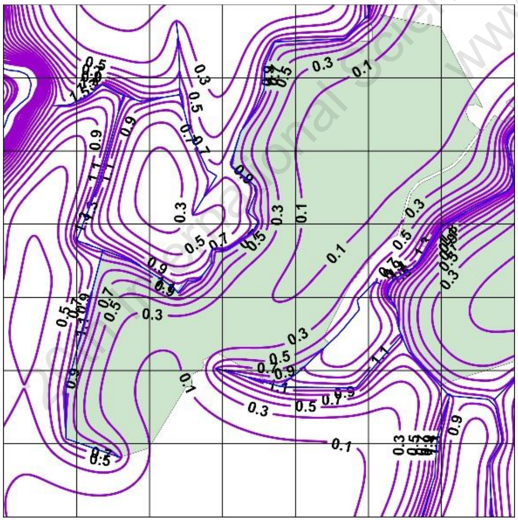

Fig. 6. The drawdown S_0 [m] izoline map of the FMS western side and its surroundings if FMS does not operate

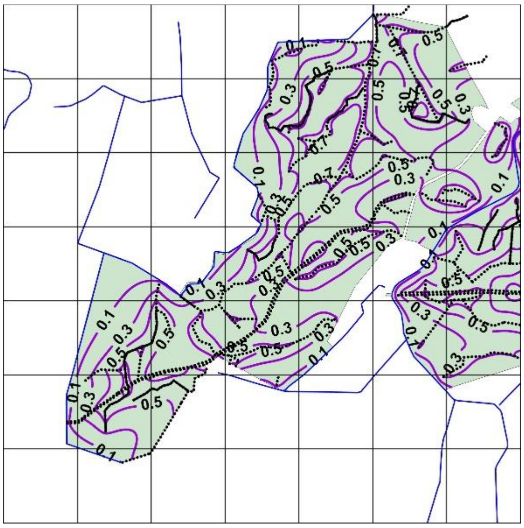

Fig. 7. The drawdown S_{FMS} [m] izoline map of the FMS western side if FMS operates

The flow *B* (Table 2) is caused by the drawdown S_0 (Fig. 6) that is originated by the hydrographical network (Fig. 2). The distribution m_{aer} of Fig. 5 is caused by the resulting drawdown $S = S_0 + S_{FMS}$. It induces the common flow *A* of DA.

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To obtain initial data for creating long line profiles ψ_j of the forest ditches, the following difference:

$$\sigma = m_{aer} - 0.9 \quad (3)$$

was found where 0.9 is the ditch depth in metres.

If $\sigma > 0$, the ditch can only reduce the flood event impact, because it cannot drain the dry area where $m_{aer} > 0.9$. Thick $m_{aer} > 0.9$ exists in upland areas of DA and near the FM contour ditches (Fig. 4). In the $m_{aer} < 0$ areas, FMS is the most effective (Fig. 5 and Fig.7), because there the full depth of ditches takes part in draining. The profiles ψ_j were found by applying sections along the forest ditches for the data $\sigma < 0$ set [8].

DESCRIPTION OF HM

For the geological space, HM provides the steady long term groundwater head distribution φ [m asl] in nodes of the HM spatial (3D) x, y, z – grid. The distribution is obtained by using the GV system to solve the following algebraic equation:

$$A\varphi = \beta - G\psi, \qquad A = A_{xy} + A_z \quad (4)$$

where the matrix A [m^2/day] represents the geological space hydraulic conductivity; A_{xy} and A_z , accordingly, expose the horizontal and vertical conductivity of the space; the vectors ψ [m asl] and β [m^3/day] designate the boundary head and flow conditions; the matrix G [m^2/day] assembles connections between the locations where ψ are fixed with nodes of the HM grid. The conditions β were not used for creating of HM.

The HM grid is built by applying the finite difference approximation of the boundary field problem for the groundwater processes. The grid consists of the ($h\times h\times\delta$) sized blocks where h is the plane approximation step and δ represents the geological layer thickness. For HM of FMS, $h=5m$.

The elements a_{xy}, a_z of A_{xy} , A_z are computed by the GV system:

$$a_{xyi} = k_i\,\delta_i\,,\;\; a_{zi} = h^2\,k_i / \delta_i, \qquad \delta_i = z_{i-1}\text{-}z_i \geq 0, \qquad i=1, 2, \ldots, n, \quad (5)$$

where n is the number of the HM grid layers, for HM of FMS, n=5; z_{i-1} and z_i are the top and bottom surface elevation maps [m asl] of the i-th layer; the z_0 surface is the relief elevation ψ_{rel} map; δ_i and k_i represent the thickness [m] and permeability [m/day] distribution maps of the layer.

Because the permeability of an aquitard is very small (k=10^{-3} – 10^{-6} m/day), its $a_{xy} \sim 0$. For this reason, the elements a_z of aquitards are used for connecting adjacent aquifers of the HM grid.

The local HM area size is 11000m × 8000m. Therefore, the HM grid contains $17.6\times10^6 = 5\times3.52\times10^6$ nodes. The vertical schematization of HM is shown in Table 3.

Table 3: The vertical schematization of HM

No. of HM layer	Name of layer	Code	Thickness [m]	Permeability [m/day]	Notes
1.	Relief	rel	0.02	10.0	ψ_{rel} – map used
2.	Aeration zone	aer	0.1-3.1	10^{-4}-10^{-5}	k_{aer} calibration
3.	Quaternary sand aquifer	Q2	0.5-16.1	0.3-2.0	Surface water bodies and FMS as boundary conditions
4.	Aquitard	gQz	3.4-26.7	10^{-4}-10^{-5}	gQ2z+D3akz
5.	Conditions ψ_{D3krs}	D3krs	0.02	10.0	ψ_{D3krs}–map used

The layers No. 1 and 5 are thin aquifers (δ = 0.02m) that are used for setting the boundary conditions ψ_{rel} and ψ_{D3krs}, accordingly. The aquitards aer and gQz (layers No.2 and No.4) control the top and bottom flows q_{aer} and q_{gQz} of the aquifer Q2 (layer No.3):

$$q_{aer} = G_{aer} (\varphi_{Q2} - \psi_{rel}), \qquad q_{gQz} = G_{gQz} (\varphi_{Q2} - \psi_{D3krs}) \tag{6}$$

where G_{aer} and G_{gQz} assemble the elements a_z of the aquifers aer and gQz, respectively; φ_{Q2} is the computed groundwater head of the aquifer Q2. The aquifer Q2 is also connected with rivers, brooks and ditches of the HM area and with FMS. The groundwater inflow q_j (base flow in the aquifer Q2) caused by the j-th surface water object are computed by the GV system:

$$q_j = G_j (\varphi_{Q2} - \psi_j), \tag{7}$$

where G_j and ψ_j are the conductivity matrix of links with the aquifer Q2 and the long line profiles of the j-th surface water objects and FMS, correspondingly. They were modelled by using the GV option RIVER [5].

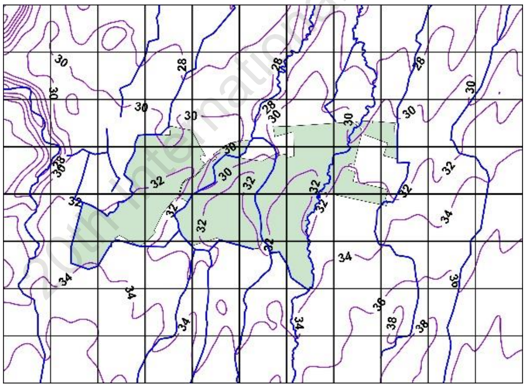

Fig. 8. The ψ_{rel} – izoline [m asl] map

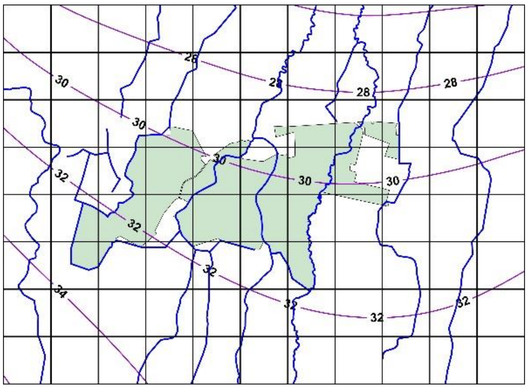

Fig. 9. The ψ_{D3krs} - izoline [m asl] map

The aquitard gQz is formed by the contiguous aquitards gQ2z (Quaternary moraine) and D3akz. The regional data on the layers No. 3, 4 were provided by the hydrogeological model of Latvia LAMO4.

The ψ_{rel} and ψ_{D3krs} - maps (Fig. 8 and Fig. 9) were obtained from the Latvian Geospatial Information Agency [7] and from LAMO4 [1], accordingly. As the main HM calibration

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target, the groundwater runoff q_{gr} module 0.8 m/(sec km^2) for the study area was used. Its long-term value was obtained in the nearby (~6km far from the HM area) hydrological observation station "Uzini" on the Svete river. There the runoff into the river $q_h \sim 7\ q_{gr}$ (q_{gr} – base flow) [8]. The relationship was applied for computing flows in hydrographical network when q_{gr} were obtained by GV.

In HM, q_{gr} =-5069 m^3/day; q_{aer} =5414 m^3/day; q_{gQz} =-536 m^3/day; the inflow through the HM border is 191 m^3/day [8].

CONCLUSION

The FMS "Zamelu-Tisu mezs" reconstruction effect was estimated by using HM. The task of creating and calibrating of HM was rather burdensome, because of the dense study place hydrographical network and of a large number of the FMS ditches. It was found out how the reconstruction will improve the situation in the FMS territory and how the hydrographical network flows will change. The modelling methodology and results reported in this paper may be useful for professionals designing large melioration systems.

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