HYDROGEOLOGICAL MODELLING OF THE INTERACTION BETWEEN DOLOMITE EXCAVATION QUARRIES AT LATVIA

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ABSTRACT

In the Ropazu district at Latvia, a set of dolomite excavation quarries is located. Because the quarries must by drained by pumping out groundwater, depression cones appear in the quarry areas and around them. The research targets were investigation of the interaction between the quarries, evaluation of adverse changes caused by them in the groundwater regimes of the nature reserve wetland area «Lielie Kangari» and in flows of hydrographical network. The research was carried out by applying the hydrogeological model (HM) that was run by the system Groundwater Vistas 6. The quarries were simulated by using their toughest working conditions (maximal areas and depths for a long time excavation without interruptions). It was found out that due to appearance of artificial lakes in flooded areas of abandoned quarries, the interaction between the working quarries has considerably decreased. The quarries which are situated near the reserved wetland area and a small river can worsen their natural regimes. The methodology and results reported in the paper may be useful for specialists dealing with estimation of adverse effects that can be caused by mineral excavation quarries.

Keywords: drawdown, groundwater pumping rate, hydrographical network

INTRODUCTION

The study area is located in the Ropazu district at Latvia (Fig. 1) where a set of dolomite excavation quarries is situated. In Fig. 2, the area base map is shown. Its size is $12km \times 14km = 168km^2$. In the area middle, between the Liela Jugla and Maza Jugla rivers, the six working quarries named Dutkas, Jaundutkas, Sienazi, Lejasnoras, Kalnagravisi and Areni are located. The abandoned flooded quarries Remine and Turkalne have become lakes.

To excavate dolomite from a quarry, it must be drained by pumping groundwater out of it. Because of pumping, a depression cone (drawdown of a groundwater head) forms in the quarry area and around it. The cones of nearby quarries merge.

The research objective was investigation of the interaction between quarries and estimation of adverse changes caused by them on the natural hydrogeological conditions of the study area.

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Fig. 1. The study area location

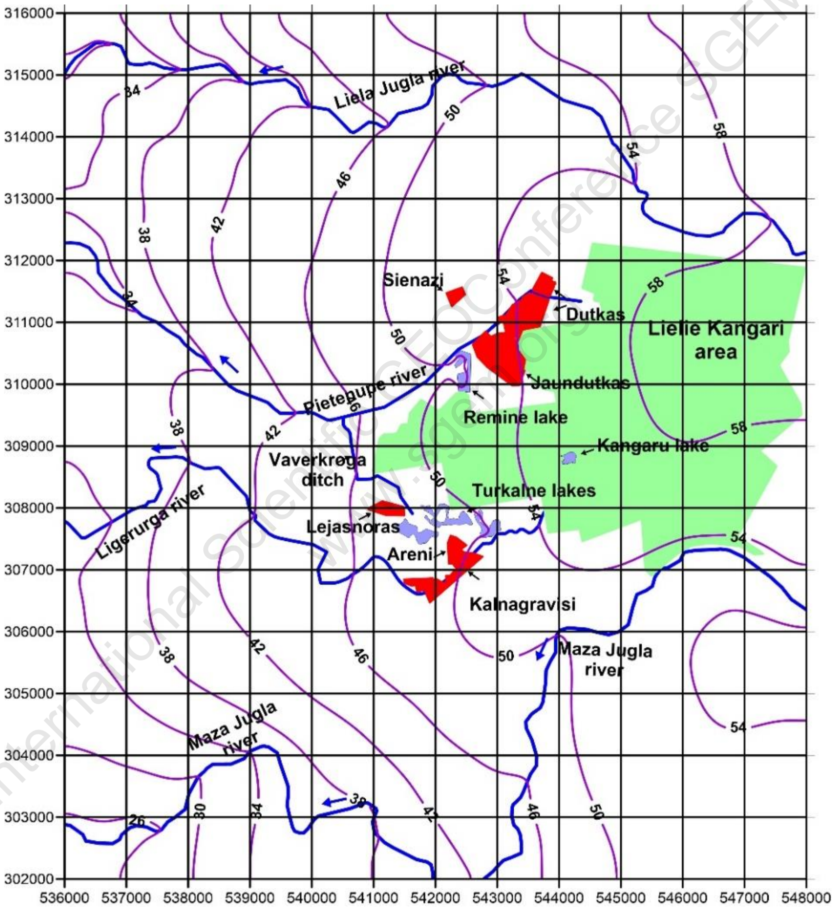

Fig. 2. The study area base map. The undisturbed groundwater head φ_{D3dg} isolines [m asl] are shown for the dolomite excavation aquifer D3dg

The research was carried out by using the local HM of the study area. The model was run by the system Groundwater Vistas 6 (GV) [1]. The graphical program SURFER 12 [2] was used for presenting the research results graphically and for preparing the HM initial data.

DESCRIPTION OF HM

The model simulated the steady long time hydrogeological regime at the study area. The model contained seven layers (Table 1). Five of them (layers No. 2-6) modelled the Quaternary (aeration zone, sand aquifer Q2, moraine gQ2z) and the Primary (dolomite aquifer D3dg, aquitard D3slpz) geological structures.

Table 1: 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	0.1-11.3	10^{-4}-10^{-5}	k_{aer} calibration
3.	Quaternary sand aquifer	Q2	0.7-9.7	5.0	Hydrographical network as boundary conditions
4.	Aquitard	gQ2z	0.3-9.0	10^{-2}	
5.	Aquifer	D3dg	0.6-15.3	15.0	Dolomite excavation
6.	Aquitard	D3slpz	0.5-9.2	3×10^{-5}	
7.	Conditions ψ_{D3pl}	D3pl	0.02	10.0	ψ_{D3pl}–map used

The ground relief ψ_{rel} (Fig.3) and the aquifer D3pl head ψ_{D3pl} (Fig. 4) maps were used as the fixed head boundary conditions in the layers No.1 and 7, accordingly.

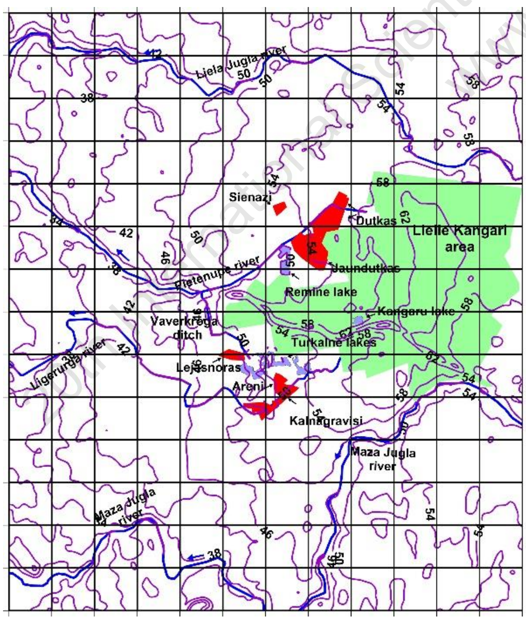

Fig. 3. The ψ_{rel} isoline [m asl] map [3]

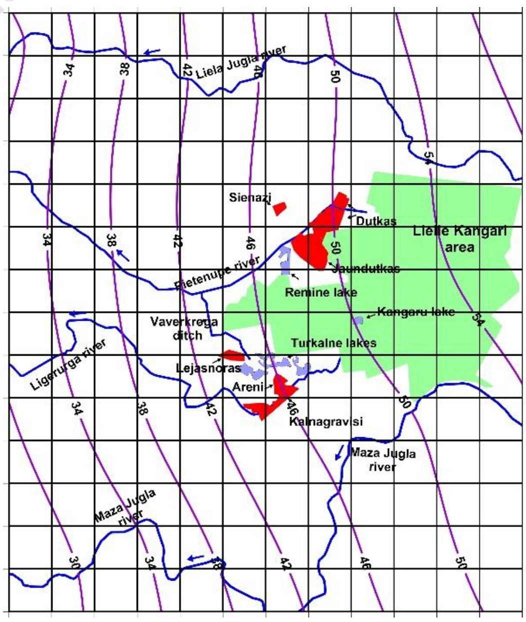

Fig. 4. The ψ_{D3pl} isoline [m asl] map [4]

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The hydrographical network elements (rivers and lakes) were applied as boundary conditions in the layer No. 3. Modelling of quarries in the aquifer D3dg (layer No. 4) was carried out by applying the quarry pit bottom area elevation z [m asl] for simulation of the toughest dolomite excavation regime.

The plane approximation step of the HM 3D-grid was 10m. Therefore, the grid contained $11.76\times10^6=7\times1.68\times10^6$ nodes. In the nodes, the GV system computed the groundwater head distribution φ [m asl] as the solution of the algebraic system [1]:

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

where A is the matrix of geological space hydraulic conductivity [m^2/day]; A_{xy} and A_z are the matrices of horizontal and vertical conductivity; ψ and β are vectors of fixed head [m asl] and flow [m^3/day] boundary conditions, accordingly; G is the matrix of links that connect the condition ψ with the HM grid. For the quarry, $z = \psi_z$. The conditions β were not used in HM.

The relief map (Fig. 3) was obtained from the Latvian geospatial information agency [3]. The data of the Primary geological structures on the layers No.5, 6, 7 were provided by the HM of Latvia LAMO4 [4]. Data on rivers were found in [5]. Information on the Quaternary layers No. 3 and 4 and on the quarries (locations, excavation areas and depths) were extracted from their hydrogeological investigation summaries.

In Table 2, the groundwater flow balance is presented when quarries do not work.

Table 2: Undisturbed groundwater flow [thous.m^3/day] balance

q_{aer}	q_{rivers}	q_{lakes}	q_{D3slpz}	$q_{boundary}$
33.62	-28.60	-3.34	-2.05	0.37

About 85% of the infiltration flow q_{aer} is discharged by the river baseflow q_{rivers}. In the study area, the river stream flow ~5.5 q_{rivers} [6]. Changes that can be caused by quarries in the flows q_{aer} and q_{D3slpz} were estimated (Table 6).

The depression cone S [m] for the study area is the following difference:

$$S = \varphi_{D3dgu} - \varphi_{D3dgd} \tag{2}$$

where φ_{D3dgu} and φ_{D3dgd} are the computed heads of the aquifer D3dg for its undisturbed and disturbed states, accordingly. The mean drawdown S_m is obtained in the quarry area centre. In Fig. 2, the undisturbed state head map (no quarry works) is shown.

In [6], the detailed description of the HM building and calibration is presented.

RESULTS OF MODELLING

In Fig. 5, the depression cone S isoline map for the aquifer D3dg is shown when all quarries work simultaneously. To investigate the interaction between the quarries, the virtual monitoring posts A1, A2, …A6 were marked in their area centres.

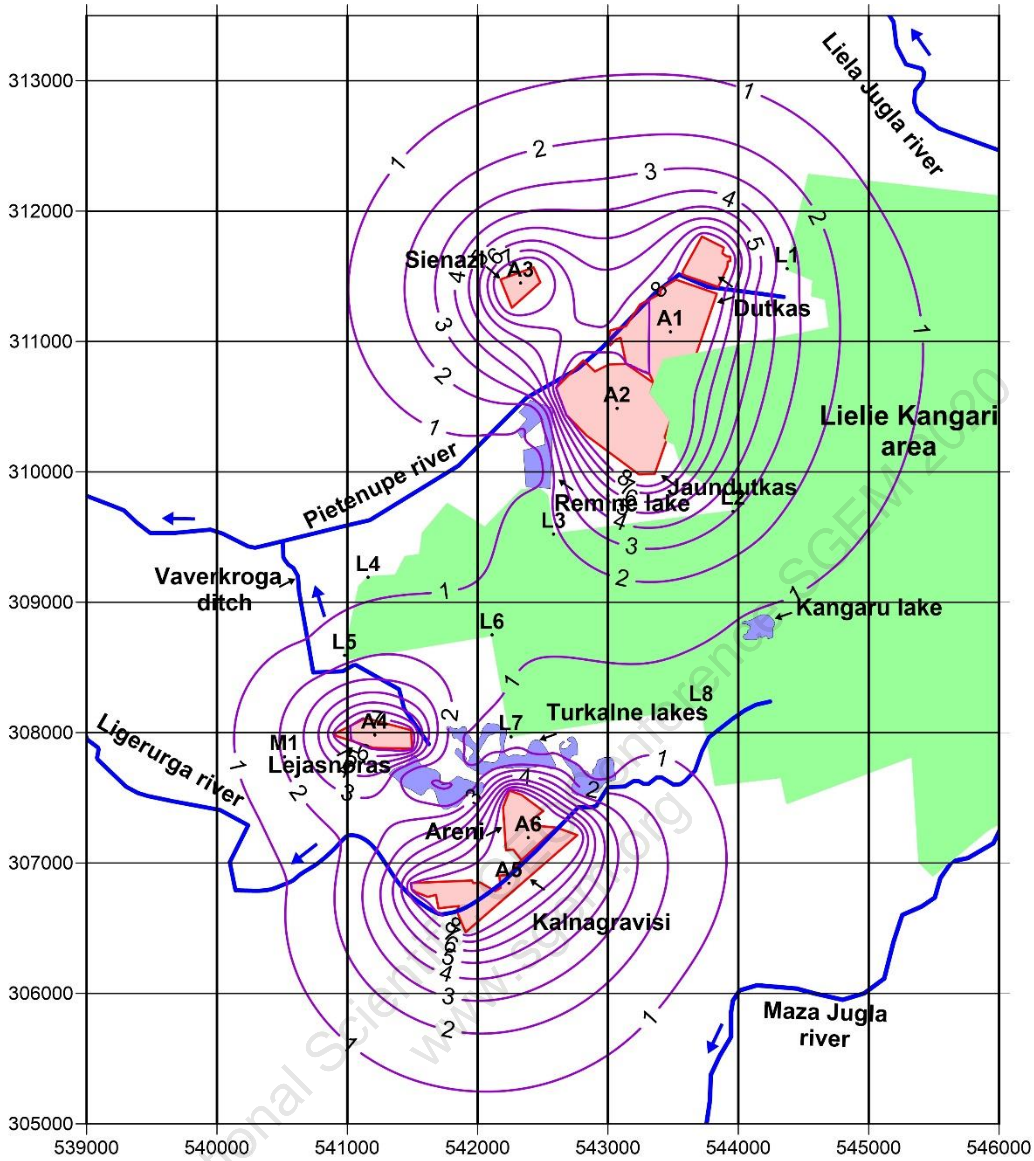

Fig. 5. The depression cone *S* isoline [m] map of the aquifer D3dg when quarries work simultaneously

Table 3: Groundwater drawdowns [%] in centres of quarry areas

No.	Name of quarry and its HM code		Groundwater drawdown [%]						Quarry data		
			A1	A2	A3	A4	A5	A6	*z* [m asl]	S_m [m]	*q* [m^3/day]
1.	Dutkas	a1	100	**44.1**	**17.3**	0.0	0.0	0.0	46.0	8.5	10522
2.	Jaundutkas	a2	**41.7**	100	**15.6**	0.2	0.1	0.1	43.0	10.0	11981
3.	Sienazi	a3	5.7	4.7	100	0.0	0.0	0.0	42.0	10.3	4947
4.	Lejasnoras	a4	0.0	0.1	0.0	100	1.3	1.1	40.0	7.4	5748
5.	Kalngravisi	a5	0.0	0.1	0.0	2.4	100	**83.8**	40.0	9.7	9927
6.	Areni	a6	0.0	0.0	0.0	1.1	**51.5**	100	40.0	9.8	7459

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In Table 3, the mean drawdowns S_m [%] in the monitoring posts A1, A2, …A6 are presented, if the quarries a1, a2, …a6 work separately. It follows from these results, that mainly due to appearance of the new Remine and Turkalne lakes, the interaction exists no more between the groups of quarries (a1, a2, a3) and (a4, a5, a6).

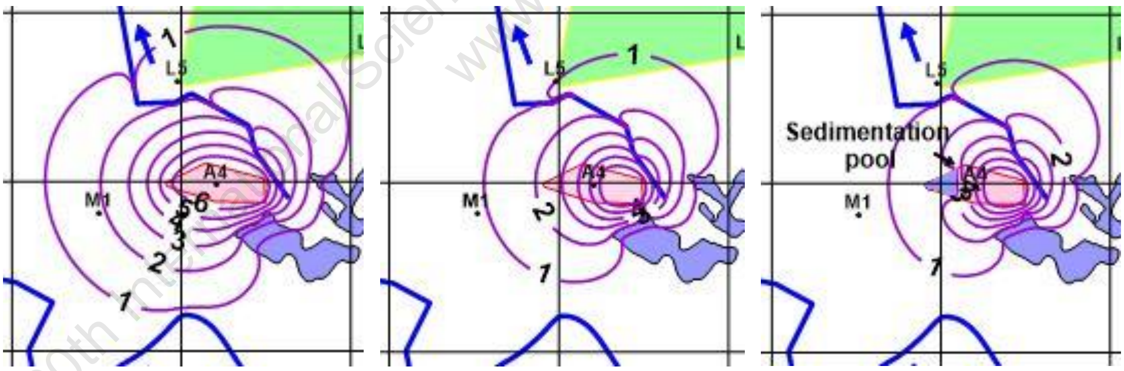
It follows from data of Table 3 that the interaction between the nearby quarries Dutkas, Jaundutkas (a1-a2) and Kalnagravisi, Areni (a5-a6) is strong, hence for them S_m>40% and S_m>50%, respectively. Due to existence of the Turkalne lakes, the quarry Lejasnoras interacts no more with the quarries Kalnagravisi and Areni.

Due to the quarry interaction, the groundwater pumping rates considerably decrease, if the nearby quarries work simultaneously (Table 4).

Table 4: Groundwater pumping rates

No.	Codes of quarries	Pumping rate [m^3/day]		
		Simultaneously	Separately	Decrease
1.	a1+a2+a3	19866	27450	7584 (27%)
2.	a4+a5+a6	17587	23134	5547 (24%)
	Total	37453	50584	13131 (26%)

As an example, it is shown in Fig. 6, how the drawdown caused by a quarry can be reduced by decreasing its excavation area and by applying a pool for sedimentation of the suspension that contains soil and dolomite particles in groundwater that is pumped out of the quarry.



Full area, drawdowns [m]: S_{M1}=1.85; S_{L5}=1.59 | 0.5 area, drawdowns [m]: S_{M1}=0.9; S_{L5}=1.0 | 0.5 area, drawdowns [m]: S_{M1}=0.5; S_{L5}=0.9

Fig. 6. Depression cones for of the quarry «Lejasnoras» working versions.
The mean excavation depth is 7.4m for all versions.

In the virtual monitoring posts L1, L2, …L8 (Fig. 5), the drawdown was computed on the borderline of the nature reserve area «Lielie Kangari» (Table 5). The allowable drawdown S_{min}= 1.0m, because the groundwater head seasonal change at the study area is 1.5-2.5m.

The quarries Dutkas and Jaundutkas can notably worsen natural conditions of the reserved area "Lielie Kangari" (Table 5), because the quarries are situated nearby the area.

Table 5: Groundwater drawdowns [m] along boundary of the «Lielie Kangari» area

No.	Name of quarry and its HM code		Groundwater drawdown [m]								S_m [m]
			L1	L2	L3	L4	L5	L6	L7	L8	
1.	Dutkas	a1	**3.24**	**1.17**	0.36	0.03	0.01	0.10	0.01	0.12	8.5
2.	Jaundutkas	a2	0.63	**2.68**	**1.60**	0.11	0.04	0.39	0.05	0.34	10.0
3.	Sienazi	a3	0.13	0.07	0.07	0.04	0.01	0.03	0.00	0.01	10.3
4.	Lejasnoras	a4	0.00	0.01	0.12	0.57	**1.59**	0.60	0.17	0.03	7.4
5.	Kalngravisi	a5	0.00	0.03	0.04	0.03	0.06	0.09	0.22	0.32	9.7
6.	Areni	a6	0.00	0.02	0.04	0.02	0.03	0.11	0.49	0.23	9.8
7.	Expected drawdown		4.00	3.98	2.23	0.80	1.74	1.32	0.94	1.05	
8.	Real drawdown		3.35	2.97	1.80	0.74	1.67	1.11	0.73	0.74	

Rows No. 7 and No. 8 of Table 5 represent, accordingly, the sum of separate drawdowns of quarries a1-a6, and the drawdown if the quarries work simultaneously. Due to the quarry interaction, the real drawdown (row No. 8) is always smaller the expected one (row No. 7).

Table 6: Changes of water flows [%] caused by separate quarries

No.	Name of quarry and its HM code		Changes in flows [%]			
			U1	U2	q_{D3slpz}	q_{aer}
1.	Dutkas	a1	0.01	**9.93**	**5.13**	**19.50**
2.	Jaundutkas	a2	0.03	**8.42**	**4.90**	**18.46**
3.	Sienazi	a3	0.01	3.51	2.54	9.82
4.	Lejasnoras	a4	2.28	0.62	1.58	5/91
5.	Kalngravisi	a5	3.48	0/05	**4.08**	**15.91**
6.	Areni	a6	0.99	0.04	2.12	8.16

U1 and U2 represent, accordingly, changes in the stream flows 12.8 thous.m^3/day and 22.0 thous.m^3/day of the Legerurga and Pietenupe rivers [6].

Because the quarries Dutkas and Jaundutkas are located nearby the Pietenupe river, they can considerably reduce its stream flow (Table 6). The quarries Dutkas, Jaundutkas and Kalnagravisi (due to their rather large areas (see Fig. 5)), can cause notable changes in the flows q_{D3slpz} and q_{aer} (Table 2).

In practice, the adverse effects caused by quarries are considerable smaller than the ones predicted in Tables 5 and 6, because the quarries were simulated by using their toughest working conditions.

In [6], the results of modelling are described more thoroughly by considering full amount of information on the dolomite excavation quarries and on the study area hydrogeological conditions.

CONCLUSION

In the Ropazi district at Latvia, dolomite excavation quarries are located. Exploration of the study area hydrogeological situation resulted in establishing local HM that was founded on information provided by the regional HM of Latvia LAMO4. By applying HM, the interaction between the quarries was investigated, changes caused by them in the groundwater regimes of the nature reserve wetland area «Lielie Kangari» and in flows of hydrographical network were evaluated.

In practice, the adverse effects caused by quarries on the natural hydrogeological conditions of the study area are much smaller than the predicted ones, because the quarries were simulated by using their maximal excavation areas and depths.

It was found out that the new lakes existing in flooded areas of abandoned quarries considerably reduced the interaction between the working quarries. The quarries Dutkas and Jaundutkas can worsen natural conditions of the reserved wetland area "Lielie Kangari" and of the Pietenupe river, because the quarries are situated nearby the area and the river.

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