# DEPRESSION CONE MIS-SHAPENNING DUE TO VARIABLE PERMEABILITY OF A DOLOMITE EXCAVATION AQUIFER IN LATVIA

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## ABSTRACT

If the place hydrogeological conditions are uniform (invariable aquifer transmissivity, no impact of hydrogeological network) then the quarry depression cone and the pumping rate for the quarry draining can be obtained by using analytical methods.

The dolomite aquifer at the Iecava district in Latvia included large impervious areas. Due to this fact, appliance of analytical methods cannot give the right depression cone. The local hydrogeological model (HM) was applied for obtaining the depression cone of the dolomite excavation quarry. The Groundwater Vistas (GV) system was used for running HM.

For obtaining the depression cone, the original method was applied. To carry out the method, the fixed head boundary conditions on the HM area borderline were changed to the zero value. The only non-zero boundary condition for obtaining the depression cone was the quarry drawdown.

It was found out that because of the dolomite aquifer irregular permeability, the cone depression isoline contours, including the borderline, were considerably deformed in comparison with the circles for the related uniform aquifer. The quarry drainage flow was considerably smaller than the one for the uniform aquifer.

The results reported in the paper may be useful for specialists dealing with obtaining of depression cones for heterogeneous aquifers.

**Keywords:** draining of mineral excavation quarries, obtaining of depression cone, hydrogeological model

## INTRODUCTION

The case is considered when at the Iecava district in Latvia (see Fig. 1) the depression cone of dolomite excavation quarry have to be obtained for the aquifer that include impermeable areas. Due to this fact, it was not possible to obtain the correct cone by using analytical methods. The HM was applied for computing the depression cone. The commercial GV program [1] was used for running HM. The model was created in the MODFLOW environment [2] that was part of GV. The program SURFER [3] was applied for preparing initial data for HM and for visualization of simulation results. The place topographical map (see Fig. 2) of the scale 1:50000, was obtained from the Latvian Geospatial Information Agency [4].

Fig. 1. The study area location

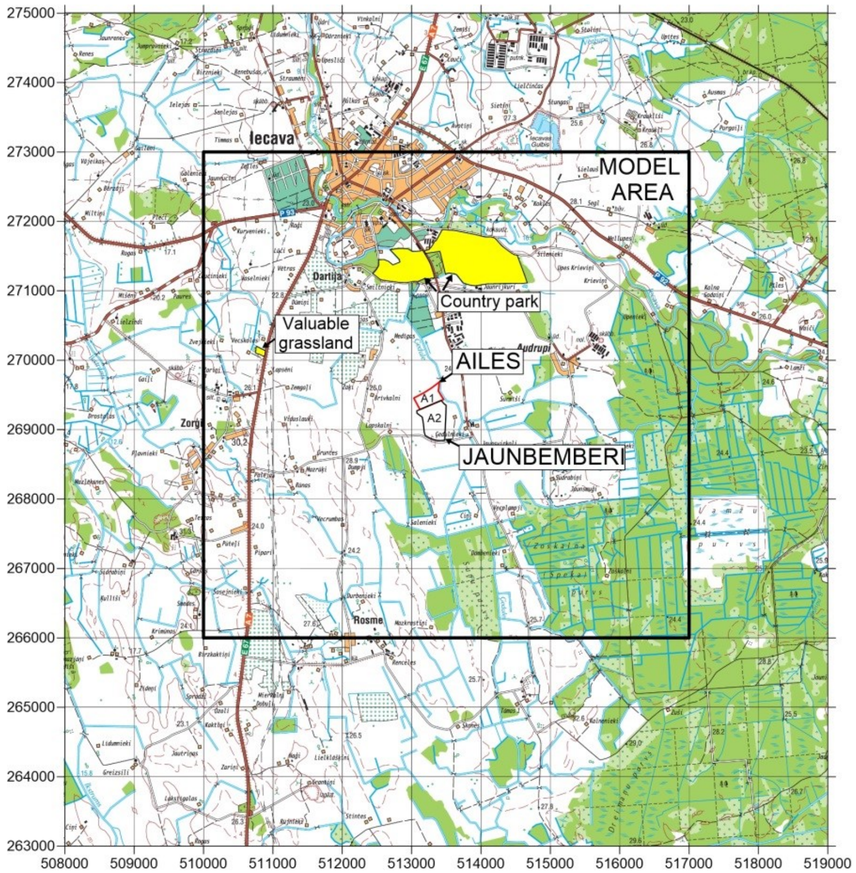

Fig. 2. The HM area and its surroundings

It was necessary to estimate the effect of establishing the new quarry “Ailes” (A1) that must adjoin the existing quarry “Jaunbemberi” (A2). The model included the valuable grassland and the country park areas (see Fig. 2) that may be harmed due to the depression cone of the united quarry (A1+A2).

It was found out that presence of the impermeable areas in the dolomite aquifer considerably deformed the depression cones in comparison with the ones of the related uniform aquifer.

Because the both quarries were situated close to the large impermeable area (see Fig. 3), their drainage flow was much smaller than the flow for the uniform aquifer.

## DESCRIPTION OF HM

The model contained one layer of the thickness $\delta$=5.0m. The layer permeability of its uniform part $k$=220m/day. Therefore, the transmissivity $T=5\times220=1100\text{m}^2/\text{day}$. For the “impermeable” areas, $k$=0.1m/day. The drawdown for both quarries $S$=4.8m. The piezometric conductivity of the aquifer $a=2\times10^3\text{m}^2/\text{day}$. The above initial data for HM were provided by the material [5].

The HM plane size was 7000m×7000m. The plane approximation step 5.0m insured accuracy of modelling for the quarry areas. Therefore, the HM grid contained $1.96\times10^6$ nodes.

To obtain the depression cone, the original method was applied when no data on the place groundwater head distributions were accounted for. To carry out the method, the zero $S_0$=0 value was fixed on the HM plane border and on the Iecava river. The only non zero condition was the drawdown $S$=4.8m for the quarry areas (see Fig. 3). The computed steady state depression cones represented the worst case situation when the quarries operated without interruptions for the full quarry area and depth.

## RESULTS OF MODELLING

The results of modelling are described by using information of the report [6].

The place geological build and the depression cones for the united quarry (A1+A2) of the heterogeneous and uniform aquifers are shown in Fig. 3.

Due to presence of the impermeable areas, the depression cone for the united quarry (A1+A2) is considerably deformed. The form of its border line $S$=0.5m is far from the circle shape.

In Fig. 4, the depression cone isolines in the cross section A-B are shown for the heterogeneous and for the related uniform aquifer.

In Fig. 5, Fig. 6 and Fig 7 the depression cone isolines are shown for the quarries A1, A2 and A1+A2.

In Fig. 8, the isolines are shown of the depression cone change that is caused by the adjoined quarry “Ailes”A1. It is obvious that the change that does not exceed 0.3m cannot harm the valuable grassland and the country park areas.

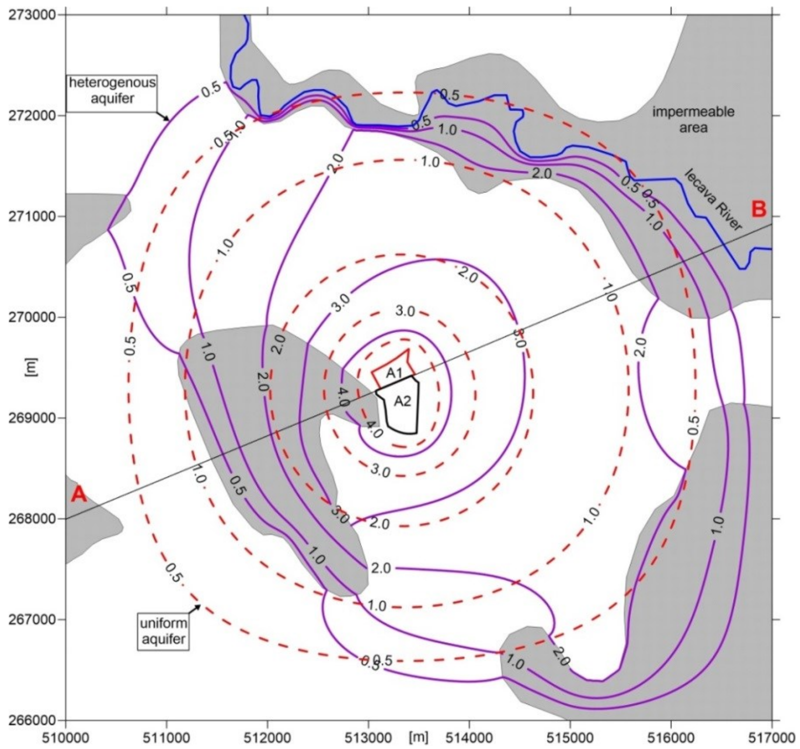

Fig. 3. The HM area geological map. Depression cone isolines [m] of the united quarry (A1+A2) are shown for the heterogeneous and uniform aquifer. The cross section A-B location is shown

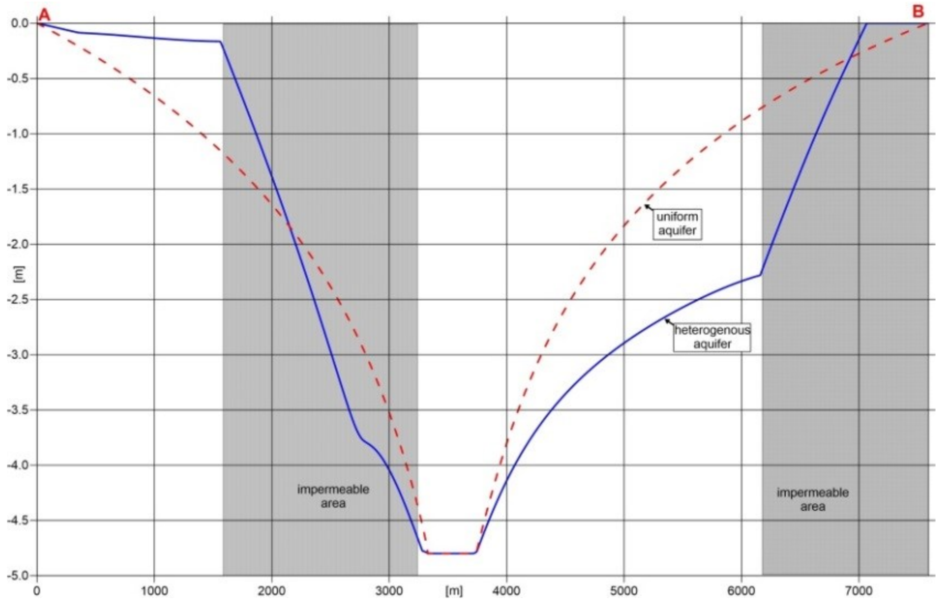

Fig. 4. The groundwater head lowering [m] in the cross – section A-B of the united quarriy (A1+A2) for the heterogeneous and uniform aquifer

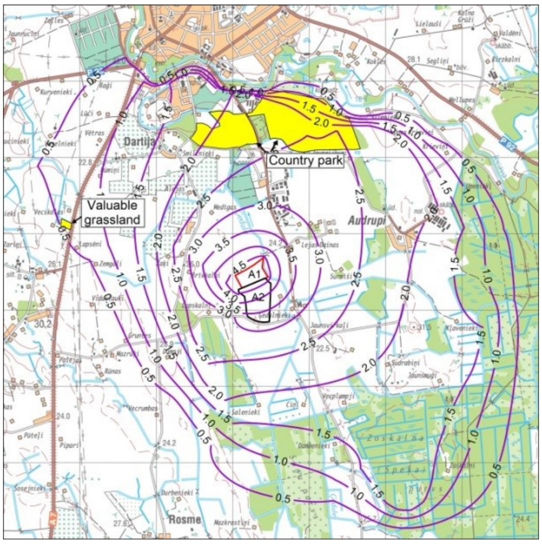

Fig. 5. The depression cone $s_{A1}$ isolines [m] of the quarry ”Ailes”

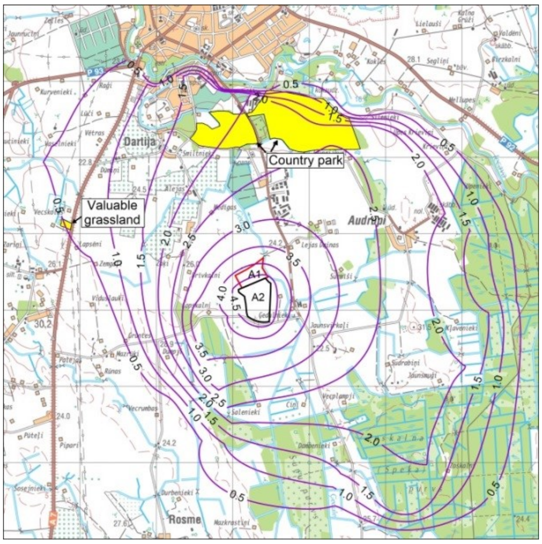

Fig. 6. The depression cone $s_{A2}$ isolines [m] of the quarry ”Jaunbemberi”

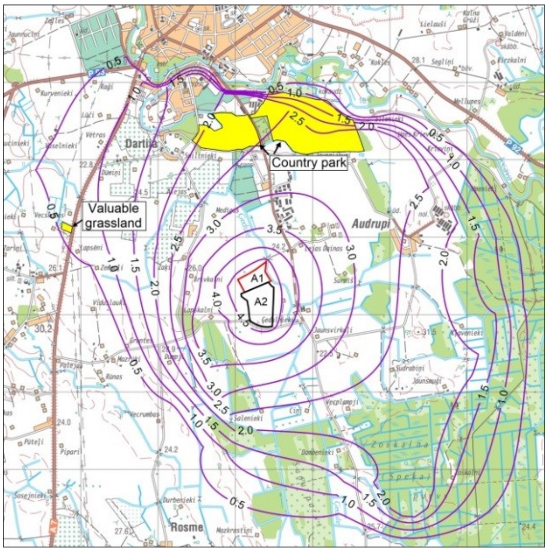

Fig. 7. The depression cone $s_{A1,A2}$ isolines [m] of the united quarry ”Ailes” and “Jaunbemberi”

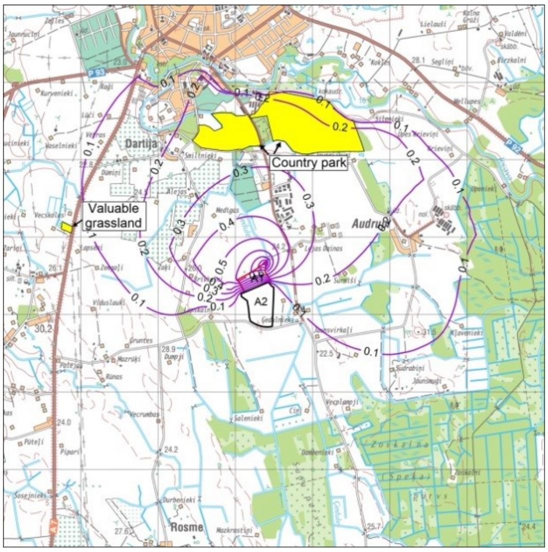

Fig. 8. Isolines [m] of the depression change $\Delta s = s_{A1,A2} - s_{A2}$ when the quarry “Ailes” adjoins the quarry “Jaunbemberi”

The numerical data on the quarries “Ailes” – A1, “Jaunbemberi”.- A2 and the united quarry – (A1+A2) are provided in Table 1. It contains variables that describe the quarry: $L$– area; $r_0$ - radius; $l$ - distance up to impermeable area; $C_h$ – coefficient that relates the drawdown $S$ and the drainage flow $q_h$.

Table 1

Data on quarries for the heterogeneous aquifer

| No | Quarry | Area [$m^2$] | $r_0$ [m] | $2l$ [m] | $C_h$ | $q_h$ [$m^3$/day] |
|---|---|---|---|---|---|---|
| 1 | A1 | 86400 | 165.9 | 118.8 | 6.70 | 4949 |
| 2 | A2 | 170000 | 232.7 | 30.1 | 7.73 | 4287 |
| 3 | A1+A2 | 256400 | 285.7 | 122.2 | 6.13 | 5411 |

Thee data of Table 1 are obtained as follows:

$$r_0 = (L/\pi)^{0.5}; \qquad 2l = R^2/(\, r_0 \exp(C_h)); \qquad C_h = 2\pi TS/\, q_h. \tag{1}$$

where $R=(7000^2/\pi)^{0.5}$~4000m is the radius of the HM area; $T$=1100m$^2$/day; $S$=4.8m.The modelled quarry flow $q_n$ can be approximated by using the formula for a well that is situated close to the impermeable border:

$$q_h \sim \pi TS/\ln(R/(2l\, r_0)^{0.5}). \tag{2}$$

The formula (2) explains why the flow 4949m$^3$/day of the quarry A1 is larger than the one 4287m$^3$/day of the quarry A2 in spite of $L_{A1}<L_{A1}$. This discrepancy is due to the different locations of the quarries A1 and A2 towards the closest impermeable area (see Fig. 3).

The drainage flows $q_u$ for the related uniform aquifer are given in Table 2. The ratio $q_h/q_u$ confirms that the drainage flow of the uniform aquifer is considerably larger than the one of the heterogeneous aquifer. The drainage flow $q_n$ for the uniform aquifer can be predicted, as follows:

$$q_u = 2\pi TS / C_u , \quad C_u = \ln(4000/r_0). \tag{3}$$

Table 2

Drainage flow for the uniform aquifer

| No | Quarry | $C_u$ | $q_u$ [$m^3$/day] | $q_h/q_u$ |
|---|---|---|---|---|
| 1. | A1 | 3.18 | 10426 | 0.47 |
| 2. | A2 | 2.84 | 11674 | 0.38 |
| 3. | A1+A2 | 2.64 | 12558 | 0.43 |

The ratio $P_N= q_N/q_1$ represents decrease of the quarry flow, if the quarry area reduces N times ($N$<1):

$$P_N=C_1/(C_1 - 0.5\ln N); \qquad C_1 = C_h \text{ or } C_u. \tag{4}$$

For the united quarry (A1+A2), the data on $P_N$ are presented in Table 3. They confirm that reducing of the quarry area has small effect on the quarry flow, especially, for the heterogeneous aquifer.

Table 3

Decrease $P_N$ of the drainage flow, if the united quarry (A1+A2) area reduces $N$ times

| $L_N/L=N$ | | 0.50 | 0,10 | 0.01 | 0.001 | 0.0001 | $r_0$=0.2m |
|---|---|---|---|---|---|---|---|
| Heterogeneous | $P_N$ | 0.94 | 0.84 | 0.73 | 0.64 | 0.57 | 0.45 |
| Uniform | $P_N$ | 0.88 | 0.70 | 0.53 | 0.43 | 0.36 | 0.27 |

The case $r_0$=0.2m represents a single well instead of the reduced quarry area

The results that were obtained by using HM, represent the steady state depression cones. They expose the worst effect that may be caused by the cone. In reality, the depression cone in the quarry area has its steady state and transitive parts, as follows [7]:

$$S(t) = q\ [\ln(R/\ r_0\ )) - 0.5\ W(at/R^2)]\ /\ (2\pi T) \qquad (5)$$

where $W(at/R^2) = W(u)$ is the well function for the time dependent part of the depression cone. In Fig. 9, the graph of the function $W(u)$ is shown.

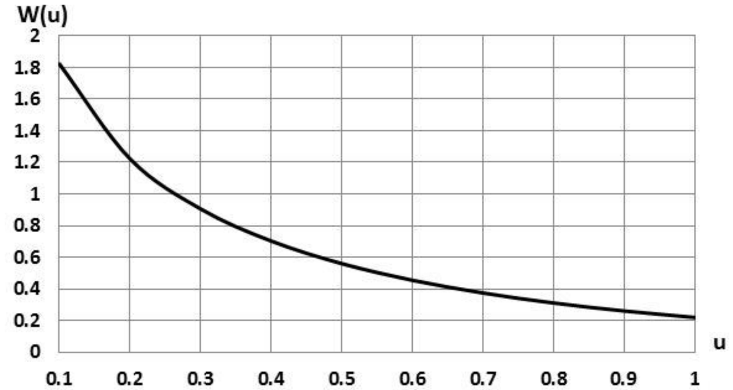

Fig. 9. The graph of the well function $W(u)$

For the united quarry (A1+A2) in the uniform aquifer, $R$=4000m, $r_0$ = 285.7m, $T$=1100m$^2$/day, $a$=2×10$^3$m$^2$/day $q$=12558m$^3$/day.
The steady state part ln(4000/285.7)=2.64. At time $t$ =0, $W(u)$ = 5.28. If it decreases ten times then $u \sim 0.5 = 2\times10^3\ t\ /(4000^2)$ and $t$ = 4000 days ~11 years. Therefore, for the reported case, the transient process is slow.
This fact is also confirmed by the following relationships:

$$U_t = q_t/q_{10} = C/(C\text{-}0.5\ln\ (10/t); \qquad R_t = 1.5\ (at)^{0.5} = 1280\ t^{\ 0.5} \qquad (6)$$

where $C$ = 2.64; $t$ [year].

Data on the time dependent variables $U_t$, $R_t$ for the united aquifer (A1+A2) are presented in Table 4.

Table 4

Time dependent variables $U_t$, $R_t$ for the united quarry (A1+A2)

| $U_t$ | 2.31 | 1.77 | 1.44 | 1.29 | 1.15 | 1.00 |
|---|---|---|---|---|---|---|
| $R_t$ [m] | 905 | 1280 | 2217 | 2317 | 2862 | 4048 |
| $t$ [year] | 0.5 | 1.0 | 2.0 | 3.0 | 5.0 | 10.0 |

The estimates on the transient depression part that were obtained by applying the expressions (5) and (6) practically coincide. If, in reality, the united quarry (A1+A2) operates seasonally, then the depression cone borderline will never reach the country park area.

## CONCLUSIONS

The dolomite aquifer at Iecava district in Latvia included impervious areas. For this reason, the local HM was used for obtaining depression cones of the dolomite excavation quarries. It was found out that because of the aquifer irregular permeability, the depression cones isoline contours were considerably deformed in comparison with the circles for the related uniform aquifer. The quarry drainage flows were considerably smaller than the ones of the uniform aquifer.

The depression cones have rather slow transient part. The quarry drainage flows were considerably smaller than the ones of the uniform aquifer.

If the quarries operate seasonally, then the real depression cone area will be considerably smaller than obtained by HM for the steady state case.

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