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Examination of a geothermal system from a porous geothermal reservoir in the Pannonian Basin in Hungary

Aniko N. Toth[1], Tamas Kerekgyarto[2], Gyorgy Toth[2], Gabor Szita[3], Daniella Tolmacs[2] and David K. Fenerty[4]

[1]University of Miskolc 3515 Miskolc-Egyetemvaros, Hungary

[2]Geological and Geophysical Institute of Hungary, 1143 Budapest, XIV. Stefánia út 14.

[3]Porcio Ltd., 1021 Budapest, Ötvös Janos u.3. Hungary

[4]Fenerty Bros Co. 348 Owl, Louisville CO 80027, USA

toth.aniko@uni-miskolc.hu

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ABSTRACT

Natural conditions in Hungary are very favorable for geothermal energy production and utilization. The anomalously high terrestrial heat flow (~0.09 W/m^2), the high geothermal gradient (~0.05 ^{o}C/m), and the vast expanses of deep aquifers form an important geothermal resource. The Pannonian Basin is encircled by the Carpathian Mountains. The Earth's crust here is relatively thin (~25 km) due to sub-crustal erosion. There are two types of geothermal reservoir in Hungary. One type of geothermal reservoir can be found in the carbonate rocks from the Triassic age, characterized by secondary porosity. These can be fractured or karstified rock masses with continuous recharge and significant convection. About 20% of the Hungarian geothermal wells produce from such carbonate rock formations, mainly in the western part of the country (Toth, A., 2012). The other type of geothermal reservoir is the Pannonian sedimentary reservoir, which is multilayered, composed of sand and shale. Lower Pannonian sediments are mostly impermeable; the Upper Pannonian and Quaternary formations contain vast, porous, permeable sand and sandstone beds. The latter forms the Upper Pannonian aquifer, which is the most important thermal water resource in Hungary. About 80% of Hungarian geothermal wells produce from sedimentary reservoirs.

In 2004 a geothermal well was drilled in the Orosháza-Gyopárosfürdő region in the southeast part of Hungary. The depth of the production well was 1560 m. The flow rate was 15-30 m^3/h and the well produced 90 ^{o}C water. In 2010 and 2011 two injection wells were drilled into the same reservoir. The injected water temperature was about 45-50 ^{o}C. Our study aims to examine this geothermal system. Based on what happened in this operating geothermal system, we analyzed the interaction of the region's natural geothermal environment with other wells which have modified flow systems. The flow between and around the three wells was investigated using a hydrodynamic model. Scenario models are based on Visual Modflow programs, and show how the system would be affected if operated without reinjection, thus demonstrating injection's importance.

1. INTRODUCTION

Natural conditions in Hungary are very favorable for geothermal energy production and utilization. The anomalously high terrestrial heat flow (~0.09 W/m^2), the high geothermal gradient (~0.05 ^{o}C/m), and the vast expanses of deep aquifers form an important geothermal resource. The Pannonian Basin is encircled by the Carpathian Mountains. The Earth's crust here is relatively thin (~25 km) due to sub-crustal erosion. There are two types of geothermal reservoir in Hungary. One type of geothermal reservoir can be found in the carbonate rocks from the Triassic age, characterized by secondary porosity. These can be fractured or karstified rock masses with continuous recharge and significant convection. About 20% of the Hungarian geothermal wells produce from such carbonate rock formations, mainly in the western part of the country (Toth, A., 2012). The other type of geothermal reservoir is the Pannonian sedimentary reservoir, which is multilayered, composed of sand and shale. Lower Pannonian sediments are mostly impermeable; the Upper Pannonian and Quaternary formations contain vast, porous, permeable sand and sandstone beds. The latter forms the Upper Pannonian aquifer, which is the most important thermal water resource in Hungary. About 80% of the Hungarian geothermal wells produce from sedimentary reservoirs. More and more settlements are willing to use these geothermal resources mainly for wellness and nowadays for heating purposes. But the quantity (recharge) of the thermal waters is limited, so strong efforts are made to reinject of the used and cooled waters maintaining the pressures of the reservoirs.

A geothermal system was put into operation in Orosháza-Gyopárosfürdő, in the southeastern part of Hungary (Fig. 1). In 2004 a geothermal well was drilled here. The depth of the production well was 1560 m. The flow rate was 15-30 m^3/h; the temperature of the produced water was 90 ^{o}C. In 2010 and 2011 two injection wells were drilled into the same reservoir. The temperature of the injected water was about 45-50 ^{o}C. This system heats 5 consumer sites, and the energy savings is approximately 16 557 GJ/year. Luckily, one of the wells requires only gravity and no extra pressure for reinjection.. That's unusual for intergranular aquifers.

Our study aims to examine this geothermal system. Based on what happened in this operating geothermal system, we analyzed the interaction of the region's natural geothermal environment with other wells which have modified the original, natural, pre-exploited flow systems. The flow between and around the three wells was investigated using a hydrodynamic model. Scenario models are based on Visual Modflow programs, and show how the system would be affected if operated without reinjection, thus demonstrating its importance. The first part of this report will give information about the construction and operation of these well systems, followed by some model scenarios using different production variations. Finally, we will examine the hypothetical effect of doubling the present production rate.

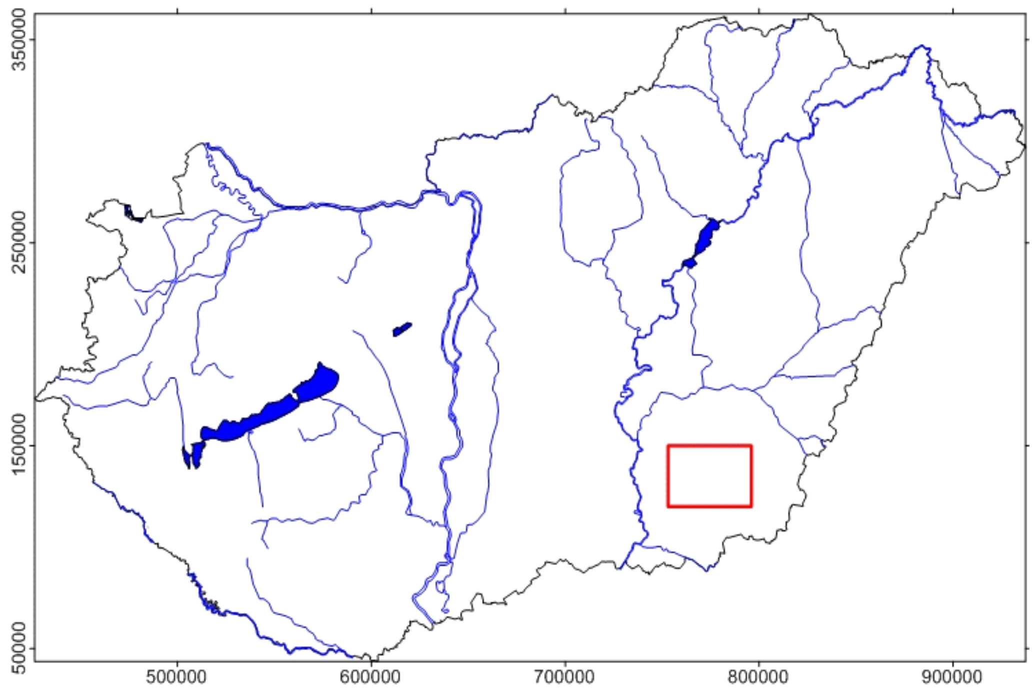

Figure 1: Location of the Orosháza-Gyopárosfürdő model area in Hungary

2. THE GEOTHERMAL SYSTEM

In the following we would like to present the technical details of the Orosháza-Gyopárosfürdő geothermal system and compare the production and injection wells based on their physical and chemical properties, such as technical parameters, water- and gas-composition, pressure, temperature, etc.

2.1 Technical parameters of the wells

Basic data for the relevant wells is shown in Table 1. The depths of the screened intervals are roughly the same, but the diameter of the screened cases are different. Differences in the static water levels are caused by well T-4 and/or measurement conditions. Well V-2 has worse hydraulic properties.

2.2 Physical and chemical properties of the thermal water

The thermal water is of the Na-HCO_3 type. The total organic carbon content (250–350 mg/l) is relatively high. The amount of free gas is approximately 200–500 l/m^3, in which the proportion of the methane is 30–40%, that of the carbon-dioxide 40–50%. Fig. 2 shows the measured temperature in the T–4 production and the V–1 reinjection well. It can be seen that the geothermal gradient is high, even compared to the Hungarian average (~50 °C/km).

2.3 The system

Construction of the geothermal system:

- Production well (T–4)
- Reinjection wells (V–1, V–2)
- Gas separator
- Hydrocyclone
- Filters (10 and 6 μm)

- Heat exchanger (1100 kW)
- KO pipes

Operation data (wellhead pressure and reinjection yield) of the two reinjection wells (V-1, V-2) is shown on Fig. 3. Wellhead pressure of well V-1 decreased from approximately 5 bar to 0 bar between November 30 and December 3. This situation remains the same. One reason for this might be an excessively good hydraulic connection between the production well and the V-1 injection well. This is a rare phenomenon in porous systems.

Table 1: Technical parameters of the geothermal wells

	Orosháza T-4	Orosháza V-1	Orosháza V-2
True vertical depth [subsurface depth in meters]	-1560	-1558	-1565
Screened section [subsurface depth in meters]	-1415 to –1513	-1415 to –1513	-1415 to –1513
Screen number [db]	8	5	4
Size of screen case (out/in) [mm]	101.6/90	102/93.5	114.3/104
Size of screen mesh [mm]	0.4	0.4	0.4
Screen type	Johnson	Johnson	Johnson
Static water level [maBsl]	90.28	61.01	79.42
Yield [l/min]	1700	1000	700
Production water level [subsurface depth in meters]	-11.1	-12.7	-21.3
Borehole temperature [°C]	at -1485 m: 101.2	in -1527 m: 101.4	in -1561,5 m: 100.5
Outflow temperature [°C]	88.2	84.5	88

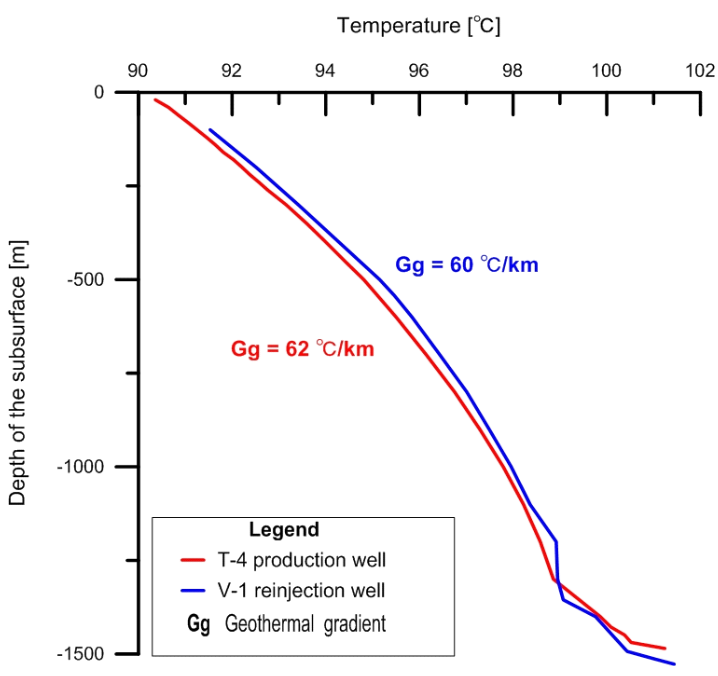

Figure 2: Measured temperature in the T–4 production and the V–1 reinjection well

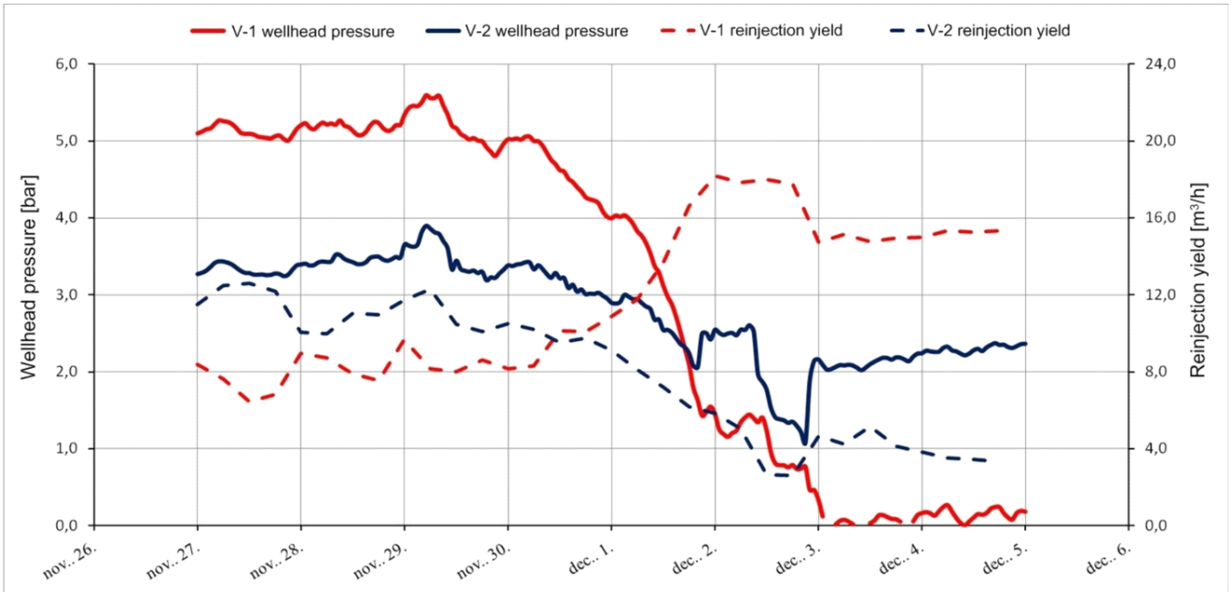

Figure 3: Measured wellhead pressure and reinjection yields in the V–1 and V–2 reinjection wells

3. HYDROGEOLOGICAL NUMERICAL MODEL

The regional hydrogeological modeling of the Orosháza region was performed by Visual MODFLOW (VMOD), a graphical interface of the worldwide standard modelling software MODFLOW. The software is a three-dimensional finite-difference groundwater model, a computer code that solves the groundwater flow equation. It can simulate a wide range of different systems.

3.1 The system General concepts

The construction of the model was based on a simplified model, which only investigated the porous system, the lower boundary of which is represented by the overlying formation of the Pre-Tertiary basement.

3.1.1 Model Grid

The horizontal extent of the model is a rectangular area, the corner points of which in EOV projection are the following:

Easting (X): 753 000 and 796 000

Northing(Y): 120 000 and 150 000

Size of the model area: 43 × 50 km

Horizontal resolution (grid size) of the model is 250 × 250 m, near to the geothermal wells the size is 50 × 50 m.

The depth of the model is determined by the base of the regional flow system. Since the software computes only at the center of a cell, it is recommended to increase the vertical partition of the hydrostatigraphic units. Quaternary was divided into 2, the Upper Pannonian into 10, while the Lower Pannonian into 5 units.

3.1.2 Hydrostratigraphic (HS) units in 3D

The geological build-up of the model area is quite simple. As such, and due to the regional illustration, three HS units have been distinguished:

- Quaternary formations (model layers 2, 3)
- Upper Pannonian sediments (model layers 4, 5, 6, 7, 8, 9, 10, **11**, 12, 13)
- Lower Pannonian / Post-Sarmatian Miocene sediments (model layers 14, 15, 16, 17, 18)

The screened sections of the geothermal wells are located in model layer 11

3.1.3 Hydraulic properties and boundary conditions of the HS units

Conductivity

Fig. 4 shows the conductivities of the defined HS units. The lowermost, moss green layer indicates the basement that was treated as an inactive part.

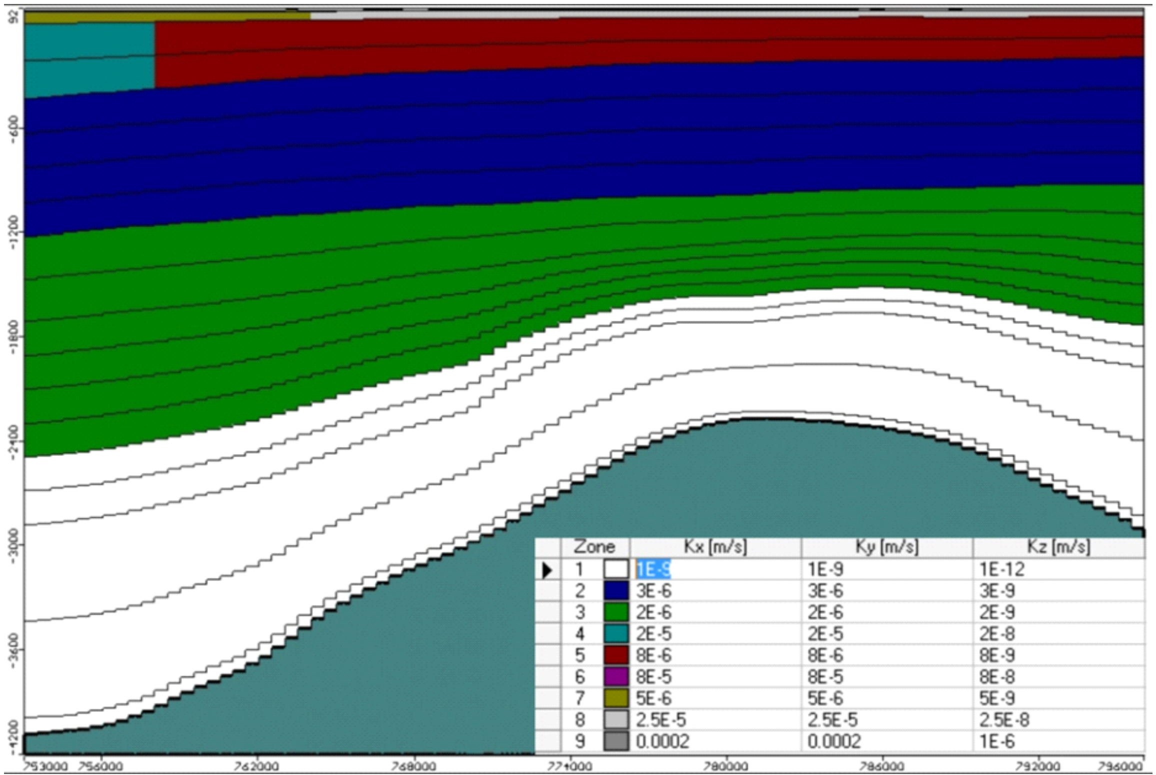

Figure 4: Conductivities Used in the Model

Porosity

0.15 effective and 0.3 total porosity values have been used in the model layers, with the exception of those (Újfalu Formation) into which the wells have been drilled. The porosity maps of the literature data (L.,Zilahi-Sebess, P., Lendvay, 2009) were used, according to which the effective porosity varied between 0.125 and 0.17, the total porosity between 0.18 and 0.24.

Boundary conditions

- Drainage: the drainage package of the model helped to generate groundwater table with sufficient accuracy, since with the conductance values of the bottom of the drain we can influence the degree of the downward and upward flow. The modeling term 'drain' basically indicates a height (asl). When the groundwater level exceeds this height, drainage occurs in the given cell. The above mentioned vertical hydraulic conductance controls the degree of drainage.
- Recharge: to calculate infiltration it is important to know the conditions of precipitation and evaporation, as well as the morphology of the surface. Since the model primarily focuses on the Upper Pannonian aquifers (those that provide hot water), the drainage was not computed. The value of the infiltration was chosen to be 40 mm/year, which was confirmed both by literature data and the regional modeling experiences of György Tóth.
- General Head Boundary: the GHB helps place the modelled area within the regional flow systems. It also helps in calculating the water flow along the boundaries. The determination of this parameter required literature data and maps, as well as the results of hydrodynamic models from the Pannonian Basin.
- Constant Head: in the modelled area, in the formations of the Lower Pannonian Premartonian Formation Group, there is overpressure (pressure higher than hydrostatic) that could affect the flow system of the thermal water to a small degree. This was demonstrated by a 10 m thick overpressure (40-90 Pa) zone at the bottom of the Szolnok Formation, for the generation of which the numeric model results of the Southern Great Plain was used.
- Inactive: the basement was treated as an inactive (no flow) zone, since it does not influence the active thermal water flow system.

Production

For the model, annual production data was used, obtained from NeKI (National Institute for Environment) Because the geothermal system has been in operation since 2011, we used annual production data from that year.

3.2 Model results

We have presented the results of the steady state model focusing on the Upper Pannonian aquifer system in the region. Successively, to better understand the geothermal system, we have modeled a multiplet well setup in the study area and evaluated its effects. In the case of the given multiplet the model indicates the three-dimensional hydraulic head distribution in the relevant aquifer layers. Finally, the scenario models demonstrate the positive effect of reinjection and also the possibilities of an increased production.

Different model variants have been made to examine the effects of the wells of the geothermal system on each other and on their environment. In the first case we examined how much water level change is induced by the operation of the reinjection wells. For this, we made a model variant in which only the production well was in operation, than a second model variant for which the reinjection wells were put into operation as well. After that, the depression difference between the two model types was illustrated (Fig 5). It can be seen that in the production well there is a water level rise of 3 m, while in the 2-2.5 m environment of the wells there is a rise of 2 m. The software is capable of computing path lines and flow time. The red lines indicate the direction of the flow, while the arrows show the access time of 20 years. As can be seen, from well V-1 water reaches the T-4 production faster (~150 years) than it does from well V-2 (~200 years).

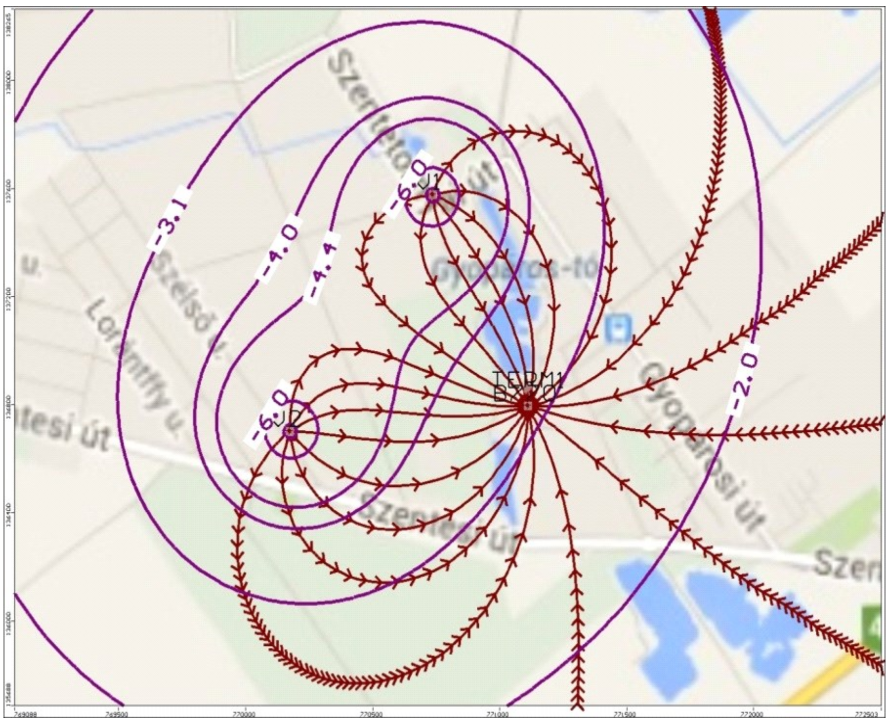

Figure 5: The calculated depressions (lilac), path lines (red) and 20 year time intervals (red arrowheads) in the 11th model layer, after the reinjection wells have been started (V1=200 m³/day, V2=200m³/day)

Next, we examined what kinds of changes occur with different yields in the reinjection wells. The reinjected water quantity was changed to 300 m^3/day in the case of well V-1 and 100 m^3/day in the case of well V-2. In well V-1 water level increased by 3.7 m, in well V-2, it decreased by 3.2 m. In Fig. 6 it can be seen that the time required to reach the production well changed as follows: it decreased to 120 years for well V-1 and increased to 260 years for V-2 (Fig. 6).

Then we increased water yields to 300 m^3/day in well V-2 and decreased it to 100 m^3/day in well V-1. In this case, the time required for the water to reach the production well changed as follows: to 200 years for well V-1, and to 150 years for well V-2 (Fig. 7)

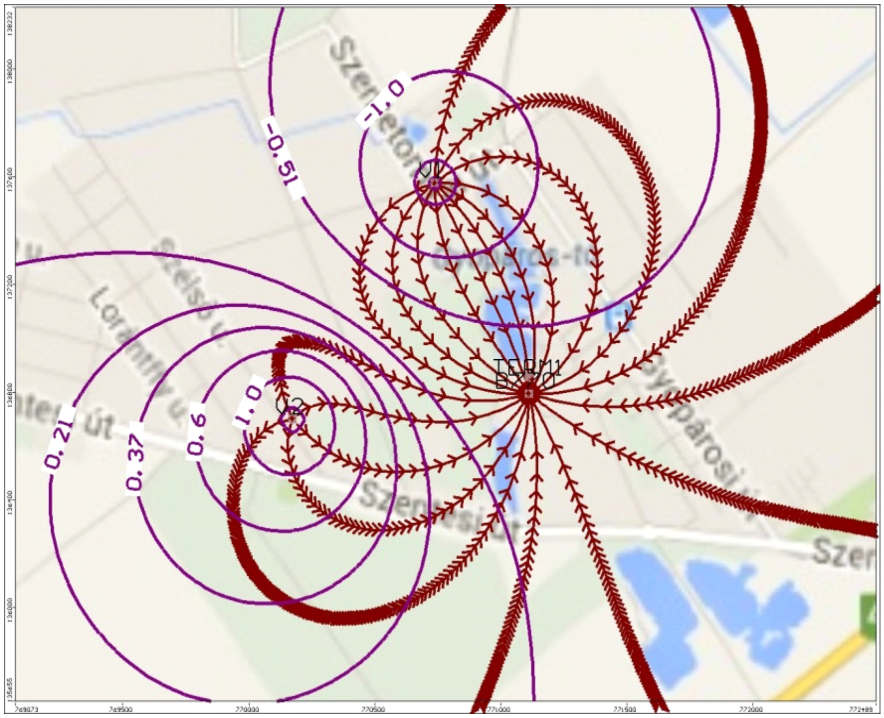

Figure 6: The calculated depressions (lilac), path lines (red) and 20 year time intervals (red arrowheads) in the 11th model layer, after reinjection wells were started (V1=300 m^3/day, V2=100m^3/day)

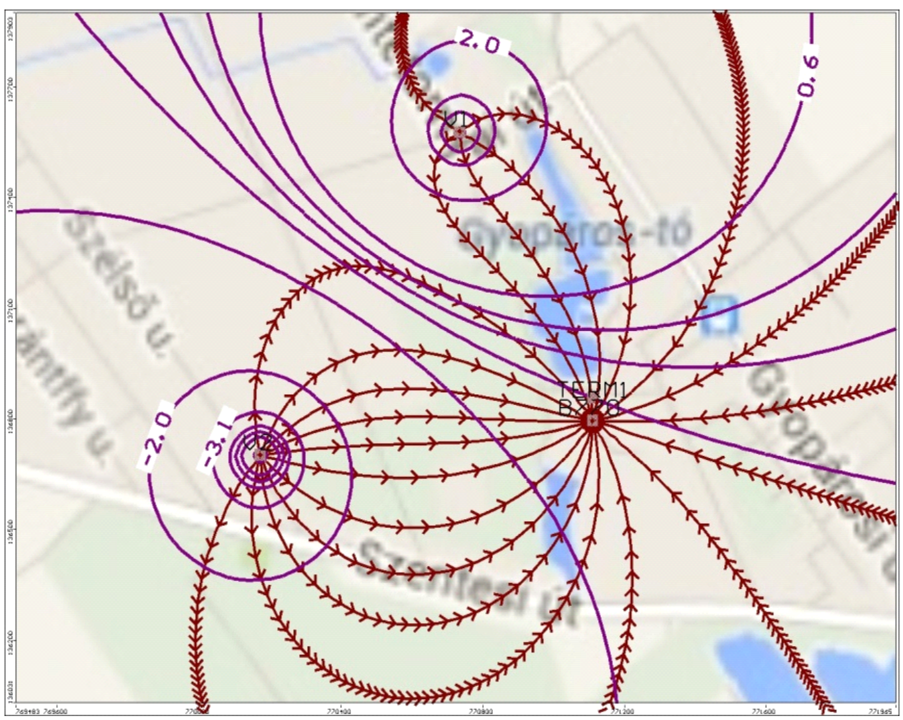

Figure 7: The calculated depressions (lilac), path lines (red) and 20 year time intervals (red arrowheads) in the 11th model layer, after reinjection wells were started (V-1=100 m^3/day, V-2=300m^3/day)

Finally, we investigated an enlargement scenario. For this case, the production and reinjection amounts were doubled (Fig. 8). This meant (given V–1=V–2= 400 m^3/day, T= -800 m^3/day) the drawdown at the production well would be -10 meter, and the dynamic water head at the production wells would raised ~5 meter. The modification of the regional potential heads is minimal.

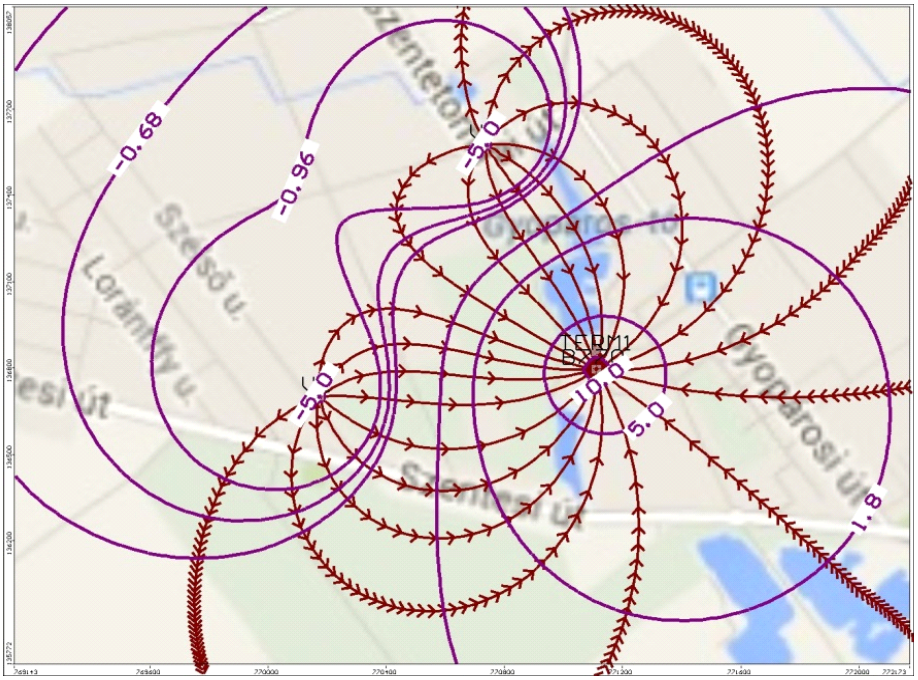

Figure 8: The calculated depressions (lilac), path lines (red) and 20 year time intervals (red arrowheads) in the 11th model layer (T= -800 m^3/day and V-1=V-2=400m^3/day)

3. CONCLUSION

The results discussed in this paper represent 'good practice' utilisation of geothermal energy, using reinjection wells in an intergranular aquifer. Based on our experiences so far, it should be possible to construct well-working, sustainable-operation systems even in this kind of geological environment. Our results and experiences could be helpful iin planning and operating future projects of this kind.

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