UNITED NATIONS UNIVERSITY
UNU-GTP
Geothermal Training Programme

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Reports 2016
Number 40

GEOTHERMAL RESERVOIR MODEL OF DOMBÓVÁR AREA, SW-HUNGARY

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ABSTRACT

Dombóvár is a town in the southwestern part of Hungary with a population of 19,000 people. As part of a geothermal development plan, MVM (Hungarian Power Engineering and Consulting Ltd.) is planning to change the existing heating system of Dombóvár's industrial park into a geothermal supplied system, and possibly make the same changes to the district heating system of the entire town in the future. The goal of this study was to perform a feasibility study on the geothermal reservoir at Dombóvár to determine if it has the capacity to support a proposed geothermal well duplet. A conceptual model of the reservoir was created using available data and then a preliminary numerical model was constructed using MODFLOW. Results of the model simulations indicate that the reservoir is capable of supporting the proposed production, and therefore it is recommended to move forward with the development plan.

1. INTRODUCTION

Dombóvár is a town in SW-Hungary with a population of 19,000 people. A detailed geothermal development plan has been created with the goal of fulfilling the heating requirement of 2.1 MWth to an industrial park in Dombóvár. As part of the development plan, a detailed cost-benefit analysis was performed taking into account all physical and economical variables in the system. Estimated ranges of production rates and intake temperatures were analyzed in order to determine usage options for the geothermal fluid. Complementary usage of the geothermal fluid was analyzed, including agricultural usage and electricity generation using an ORC cycle. As geothermal production is a single source supply and heat delivery is mandatory, a backup heating source is required in case of system failure. The most likely backup system is a boiler station operated by oil, gas or wood. Costs associated with infrastructure were also analyzed.

According to preliminary calculations from the development plan, the heating demand for the industrial park can be reached with 17 l/s and 50°C heatsteps. According to the Hungarian legislation, 100% of the produced geothermal fluid must be reinjected back into the reservoir. This requires an injection well, which has to be included in the total investment cost on top of the district heating pipeline system. In order to achieve these goals and requirements, a proposed well duplet with the following dimensions is recommended:

F-1 (injection well):

Depth: 2300 m
Coordinates: EOV: X=112194, Y=580691, Z: 114 m a.s.l. (mBf)
Planned yield: -17 l/s
Casing plan – using steel casings:

0 - 40 m	diameter 550 mm;
0 - 1100 m	diameter 341 mm;
900 - 1400 m	diameter 244 mm;
1200 - 2100 m	diameter 178 mm;
1900 - 2300 m	diameter 114 mm.

F-2 (production well):

Depth: 2500 m
Coordinates: EOV: X=112194, Y=580691, Z: 114 m a.s.l.
Planned yield: 17 l/s
Casing plan – using steel casings:

0 - 40 m	diameter 550 mm;
0 - 1150 m	diameter 341 mm;
950 - 1500 m	diameter 244 mm;
1300 - 2300 m	diameter 178 mm;
2100 - 2500 m	diameter 114 mm.

According to the development plan, the expected lifetime of the proposed geothermal plant is 30 years. The goal of this study was to assess the geothermal reservoir at Dombóvár to determine if it has the capacity to support this proposed geothermal well duplet. A conceptual model of the reservoir was created using available data and a preliminary numerical model was constructed using MODFLOW.

2. CONCEPTUAL MODEL

2.1 Geological setting

The Pannonian basin (Figure 1) in eastern Central Europe is a large sedimentary depression from the Neogene inside the Alpine orogenic belt. It is surrounded by the mostly linear chains of the Eastern Alps and Dinarides and the strongly arcuate belts of the Carpathians. The formation of the basin on the Alpine orogenic edifice occurred during the Pannonian extension and coeval compression in the Outer Carpathian arc (Horváth, 1995).

The Pannonian basin system was formed by rifting during the late Early and Mid-Miocene. Extension was controlled by the retreat and roll-back of the subducted lithospheric slab along the Carpathian arc (Fodor, 1999). Two corners, the Bohemian and Moesian promontories, formed gateways towards this open space. At both the northern and southern corners, broad shear zones developed. The initial northeast directed tension was gradually replaced by a later east- to southeast-directed tension as a consequence of the progressive termination of subduction roll-back along the arc from the western Carpathians towards the southern Carpathians. There is growing evidence that an E-W-oriented short compressional event occurred during the earliest Late Miocene but during most of the Late Miocene extension was renewed. Starting at the end of the Miocene, roll-back terminated and a compressional stress field propagated from the Southern Alps gradually into the Pannonian Basin, followed by tectonic inversion of the entire basin system in the Pliocene and Quaternary (Horváth et al., 2006). A geological cross-section of the Dombóvár area is shown in Figure 2.

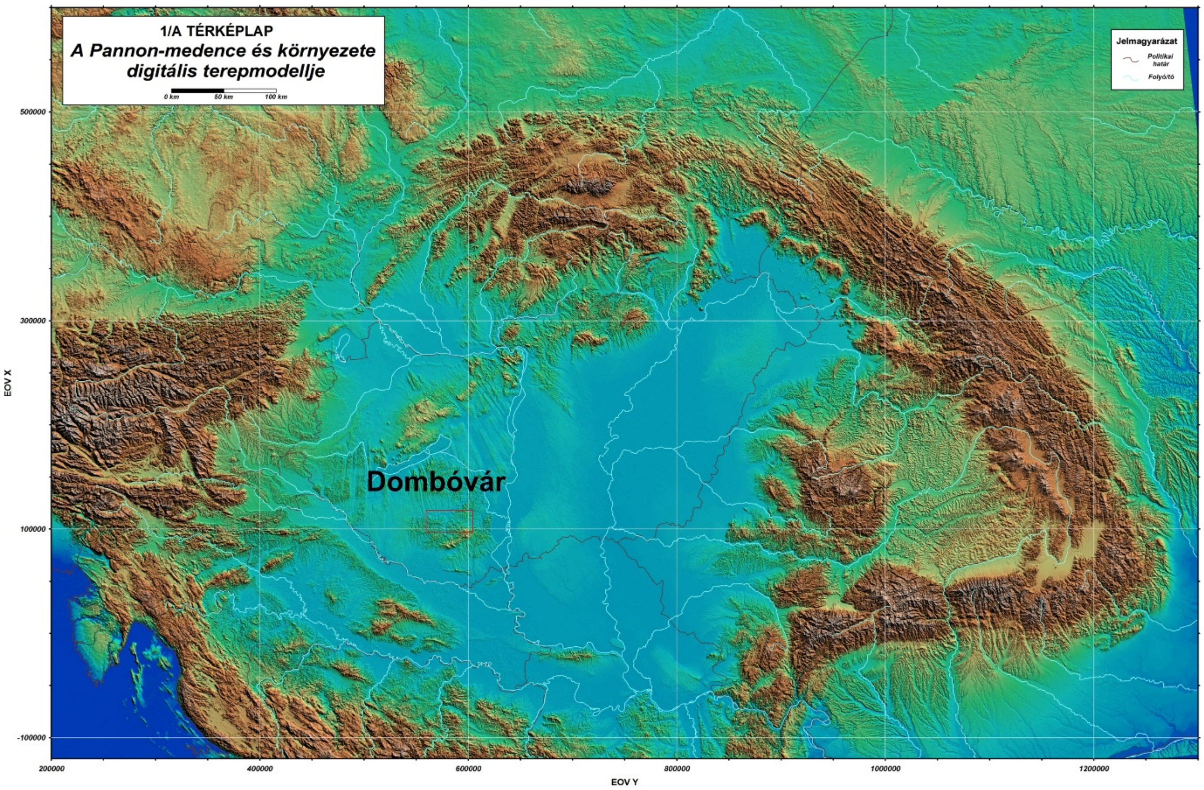

FIGURE 1: Topographical map of the Pannonian basin showing location of Dombóvár area

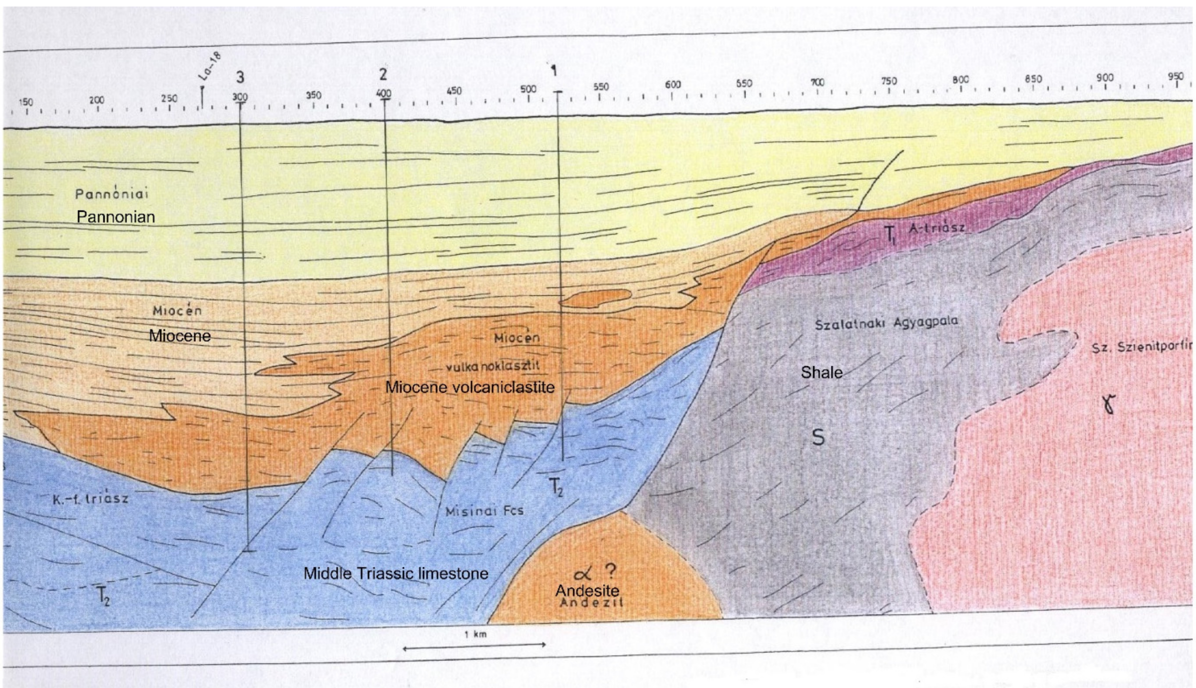

FIGURE 2: Geological cross-section of the Dombóvár area (Waterplan Ltd., 2016)

The area of interest has been analyzed by means of two 2D seismic lines, shown in Figure 3, which along with other geological data provide a general knowledge of the regional underground structure. According to the seismic interpretations, the target area of the reservoir is located at the eastern rim of

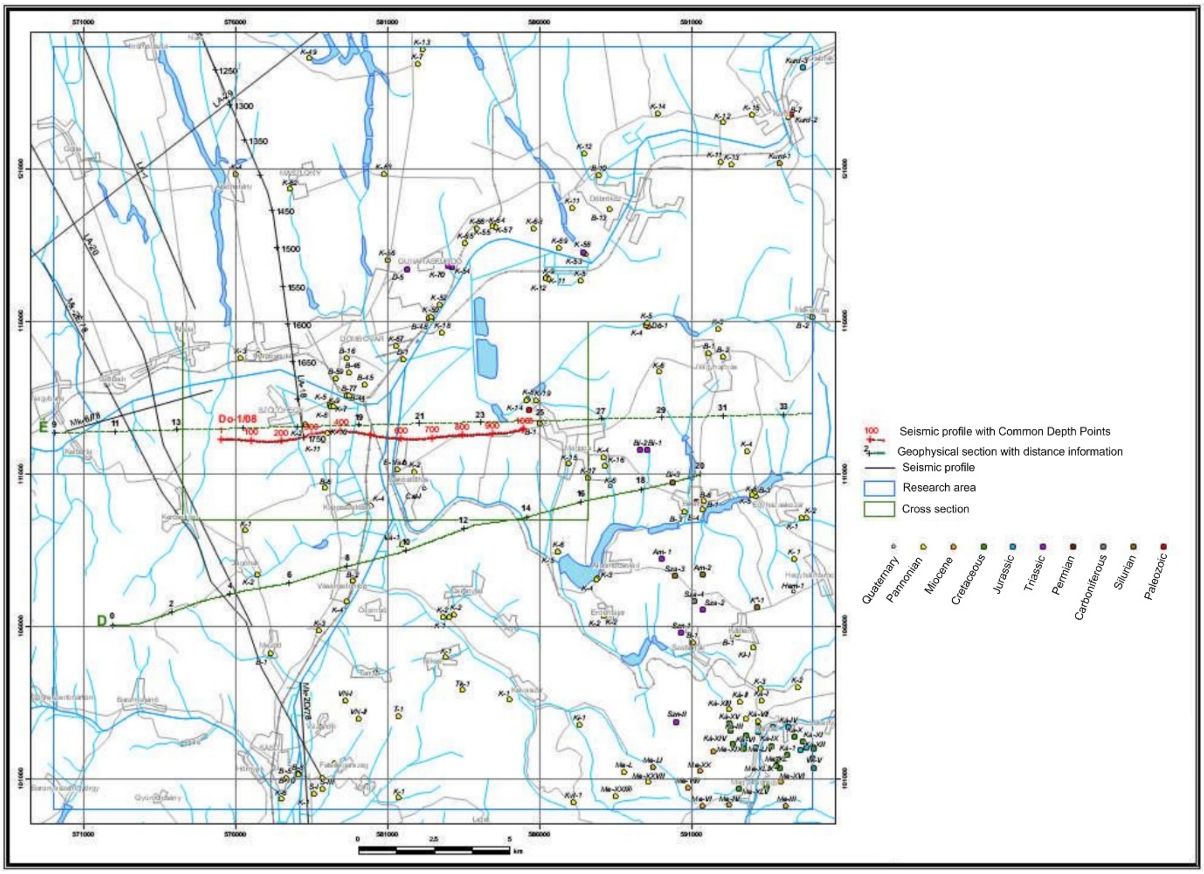

FIGURE 3: Local map showing the east-west trending seismic line Do 108 in red. The town of Dombóvár is located some 3 km north of the slight bend in the seismic line. North-south trending seismic line La – 18 (shown in black) is located just to the west of Dombóvár (Waterplan Ltd., 2016)

a basin, which is assumed to have been highly fractured due to tectonic uplifting. In addition, the basin itself has been confirmed by gravimetric and magnetic measurements carried out in the area.

The west-east cross-sections in Figures 4 and 5 show that the fractures on the eastern side of the basin reach from the basement through the Miocene up to the Pannonian, which indicates that some massive movement took place and leads to the assumption that the fractures should provide a good hydraulic connection into the lower basement.

The target geothermal reservoir is the Triassic limestone formation, which is not well defined in the area because few wells have been drilled into it. It is thought that after a small sedimentary hiatus, the Triassic sedimentary cycle of the Mecsek developed into the so-called German facies with continental Lower and Upper Triassic compression of shallow marine carbonate Middle Triassic rocks (Less, 2009). There are two wells in the area which have been drilled into the Triassic limestone to a depth of 2,250 and 2,450 meters, and both have confirmed a temperature of 120°C at a depth of 2000 m. With reference to these data and the experience from other geothermal projects in the area, the chances of finding hot water bearing fractures with good productivity is considered good.

With reference to the seismic cross-section of line Do-108 (Figure 4), there are two target areas for the establishment of the geothermal project. The first is between CDP (common depth point) 320 and 400 and the other between CDP 430 and 520. Both areas show highly faulted zones stretching from the upper Pannonian down to the lower Miocene and possibly into the basement.

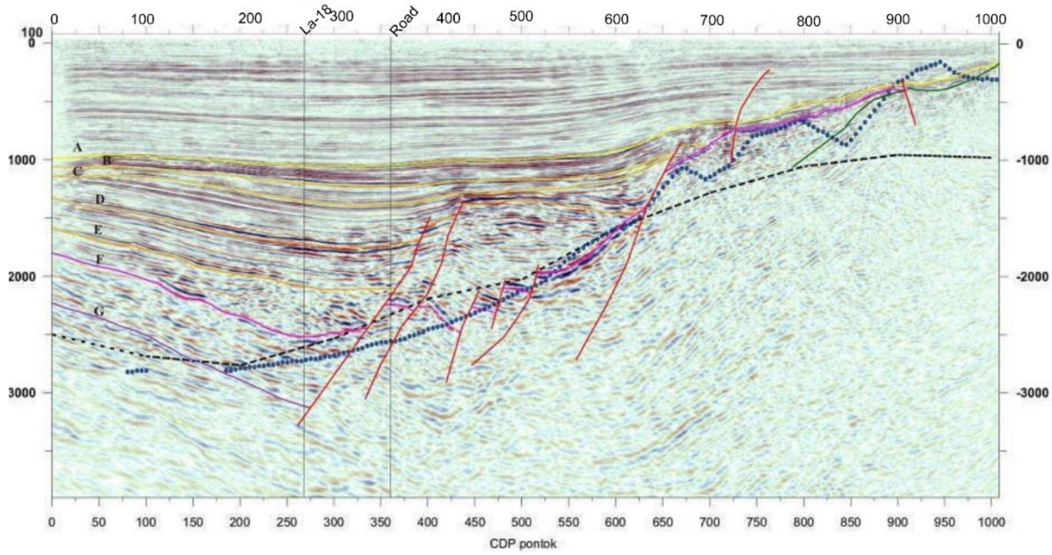

FIGURE 4: Seismic cross-section line Do-108 (west to east) (Waterplan Ltd., 2016)

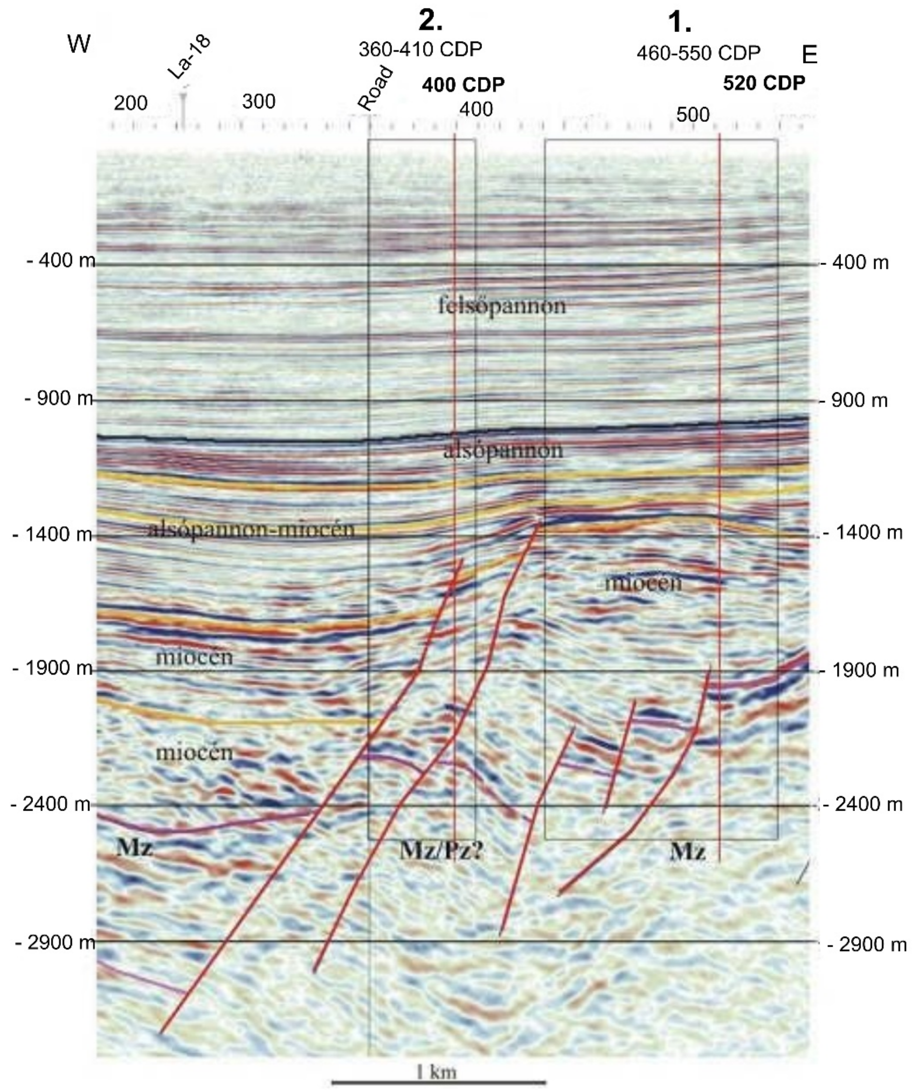

FIGURE 5. Seismic cross-section showing a close-up view of the basin between wells CDP 250 and 550 (Waterplan Ltd., 2016)

In addition to the geological and geophysical information referred to above, there are several shallower wells surrounding Dombóvár, e.g. Dombóvár K-47, K-54, K-60 and K-70, which comprise a depth range from 400 to 1500 m and which confirm a temperature gradient between 45 and 68°C/km with a production rate between 10 and 70 l/s. The regional temperature conditions are shown in Figure 6 and confirm a temperature of 120°C at 2000 m. The general trend of the surrounding wells confirms the assumption of a geothermal gradient of 50°C/km and a reservoir depth of 2300-2600 m, which would be the target depth for a geothermal well in this region according to the seismic cross-section. This would yield a minimum reservoir temperature of 125-140 or 145-160°C, assuming a temperature gradient of 60°C/km.

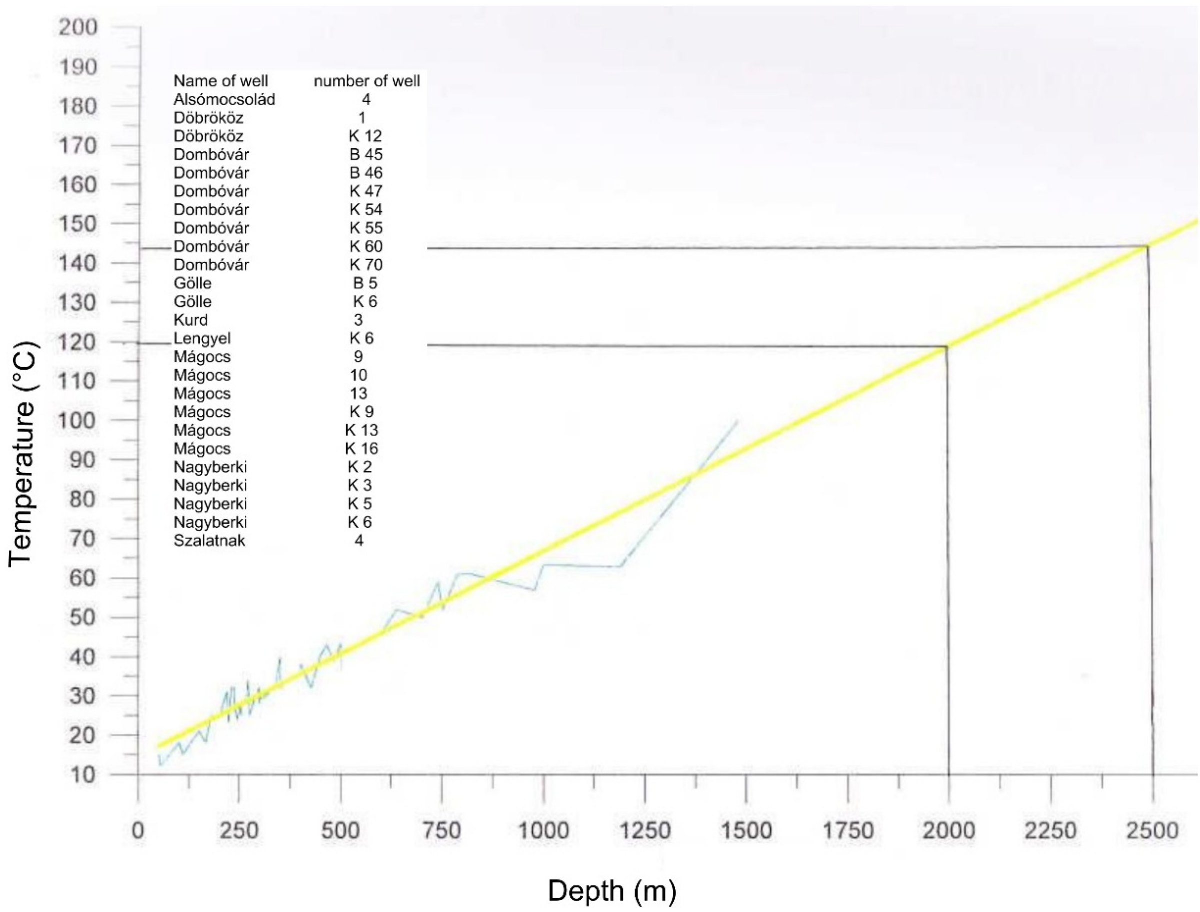

FIGURE 6: Temperature vs. depth measured in the Dombóvár region (Waterplan Ltd., 2016)

Rock temperature and water temperature data collected from wells which extend deeper than 100 m are shown on Figure 6. These wells were very scarce and unevenly distributed across the study area. However, the data do show an approximate straight line correlation between rock temperature and depth, indicating that they are close to equilibrium temperature. Using this relationship, the rock temperature from 0-2500 m depth can be estimated. According to this diagram, in the 2000-2500 m depth range, the temperature will be in the range 120-145°C.

With reference to the overall geological setting at Dombóvár, it can be stated that there is a reasonably big basin containing highly karstified limestone with good hydrological connection to the Miocene rocks, which should allow for relatively high production rates (above 70 l/s) with a reasonably acceptable drawdown.

3. NUMERICAL MODEL

A preliminary numerical reservoir model was created using available data in order to estimate the capacity of the reservoir and determine the next steps forward in the geothermal development plan.

3.1 Modelling software

The modelling software utilized for this study was VISUAL MODFLOW, MODPATH and MT3D for the heat transport. MODFLOW is a modular three-dimensional finite-difference groundwater model from the U.S. Geological Survey, and is used globally to describe and predict the behaviour of groundwater systems. The early versions of MODFLOW, MODFLOW-88 (McDonald and Harbaugh, 1988) and MODFLOW-96 (Harbaugh and McDonald, 1996a, 1996b) simulate groundwater flow including among other things, the effects of wells, rivers, drains, head-dependent boundaries, recharge and evapotranspiration. Since the publication of MODFLOW, various codes have been developed by numerous investigators. These codes are called packages, modules or sometimes simply programs. Packages are integrated with MODFLOW and each package deals with a specific feature of the hydrologic system to be simulated, such as wells, recharge or rivers. Models or programs can be stand-alone codes or can be integrated with MODFLOW. A stand-alone model or program communicates with MODFLOW through data files (Chiang and Kinzelbach, 1998).

3.2 Model construction

The total thickness of the model is 800 m, which represents the Triassic limestone formation in the area. The total thickness was divided into 4 layers with constant thicknesses. The top two model layers are each 200 m thick, layer 3 is 350 m thick, and the bottom layer (layer 4) is 50 m thick. It was assumed that the proposed production well is extracting from the upper layer (layer 1) and the reinjection well is injecting into model layer 2. The bottom layer (layer 4) was used to simulate heat transport from the deep basement formations below the reservoir.

A well duplet was defined in the model, consisting of a production well (well F2) and a reinjection well (well F1). A production rate of 1440 m^3/day was assigned to the production well and the same amount is injected into the reinjection well. Because the proposed wells are both targetting the same reservoir, it can be assumed that there is a good hydrologic connection between the two. The expected temperature of the reservoir at the production depth is between 120 and 145°C and the expected temperature of the produced water at the wellhead is around 110°C. The reinjection fluid temperature was defined as 50°C in the model.

It was decided to model a 10 km × 10 km area around the proposed well duplet. The model area is therefore a square with a total area of 100 km^2. The eastern model boundary corresponds to a lithological boundary with impermeable rock (clay) to the east. Therefore, a no-flow model boundary was defined along this boundary.

It was assumed that lateral recharge enters the reservoir from the north, west and south. Therefore, the north, west and south model boundaries were defined as constant pressure boundary conditions. Impermeable formations lie above and below the geothermal reservoir, so the model assumes no vertical leakage into the reservoir.

All four model layers were given the same hydraulic parameters because they all consist of the same Triassic limestone formation. There is no available data to suggest major differences in the limestone formation with depth. Therefore, average values taken from the literature for fractured, karstified limestone were assigned in the model (Waterplan Ltd., 2016). The hydraulic conductivity defined in each model layer was 5×10^{-7} m/s, which should be a conservative estimate. The porosity was set to 1%

in all model layers. The constant pressure boundaries were difficult to estimate since there is no available data. It was, however, decided that a fixed pressure of 120 m a.s.l. was appropriate.

The model area, numerical grid and boundary conditions are shown in Figure 7, while a vertical cross-section of the model is shown in Figure 8. The green area, the zone around the reinjection well, is where the maximum cooling is expected to take place, and the red lines are the constant pressure boundary conditions. In Figure 8, the yellow area shows the location of the point source for the reinjection well and the grey area the point source for the production well. The blue area in Figure 8 (model layer 4) shows the constant heat source from below the reservoir.

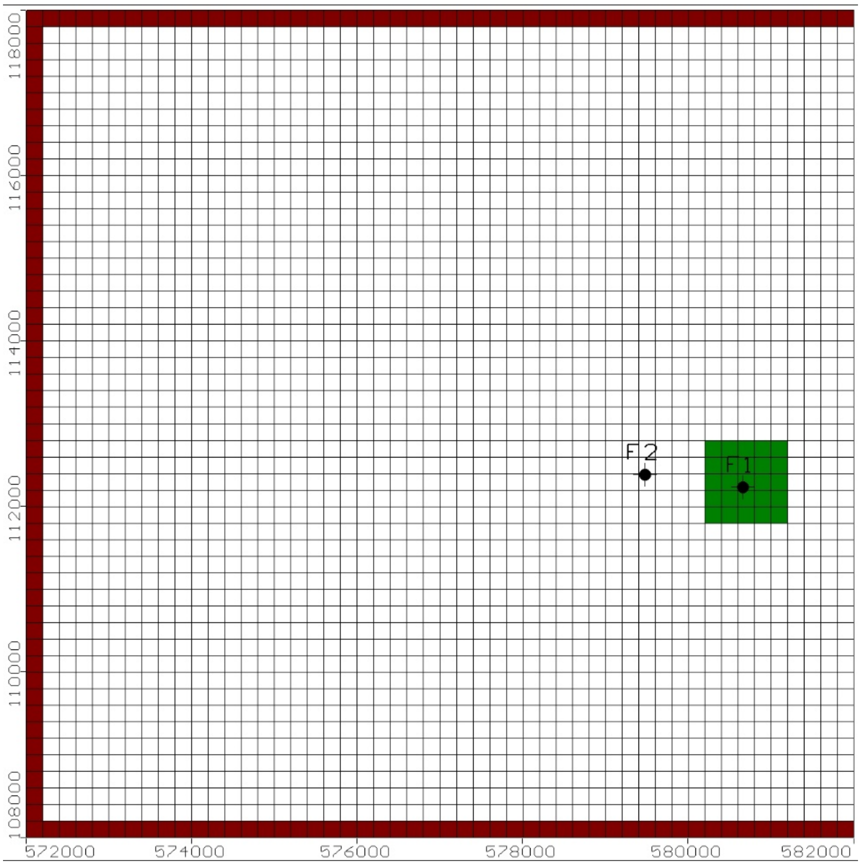

FIGURE 7: Reservoir model area and numerical mesh

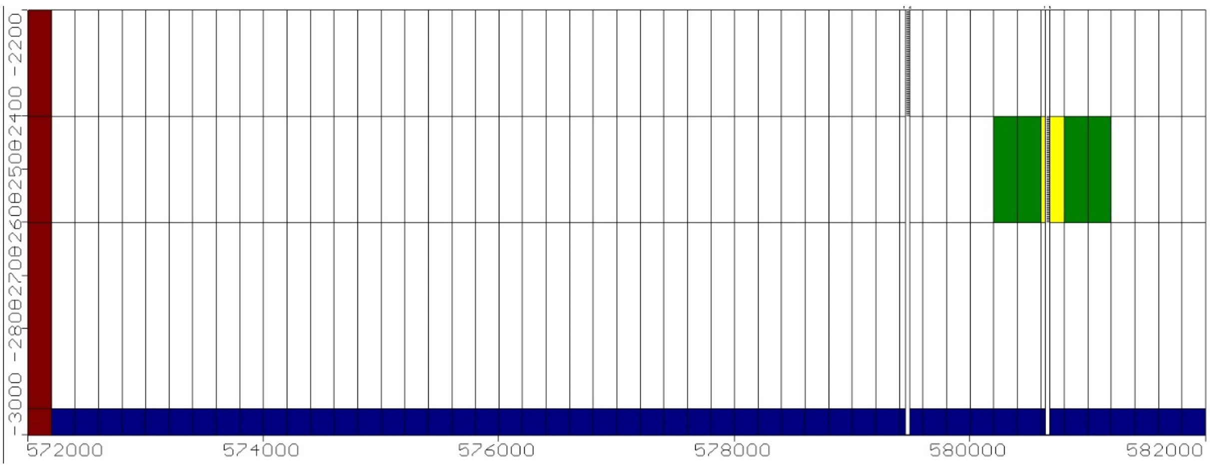

FIGURE 8: Cross-section of the reservoir model

4. RESULTS

4.1 Effects on reservoir pressure

The model was run for a simulation period of 100 years in order to determine the long-term effects of the production and reinjection. The effects of the proposed well duplet on the reservoir pressure in model layer 1 are shown in Figure 9 (groundwater contours are shown in m a.s.l.). The production causes approximately 50-60 m pressure decrease at the production well in the production layer.

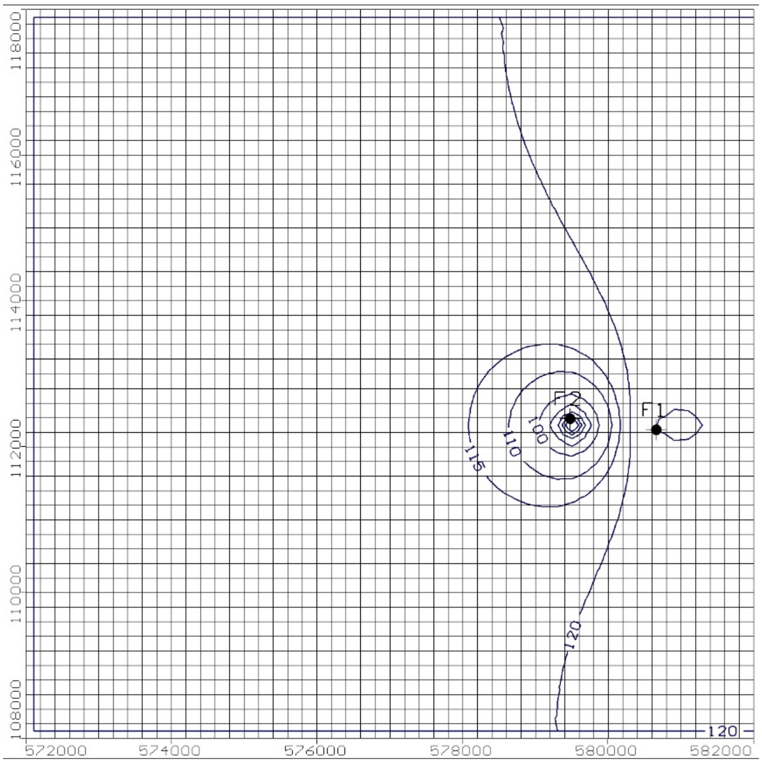

FIGURE 9: Calculated groundwater levels in model layer 1

Figure 10 shows calculated streamlines within layer 1 indicating the direction of groundwater flow in the vicinity of the wells. The red lines indicate flow into the production well and the green lines indicate flow from the injection well. The distance between the arrows on the lines indicate the flow path traveled during a 10-year period.

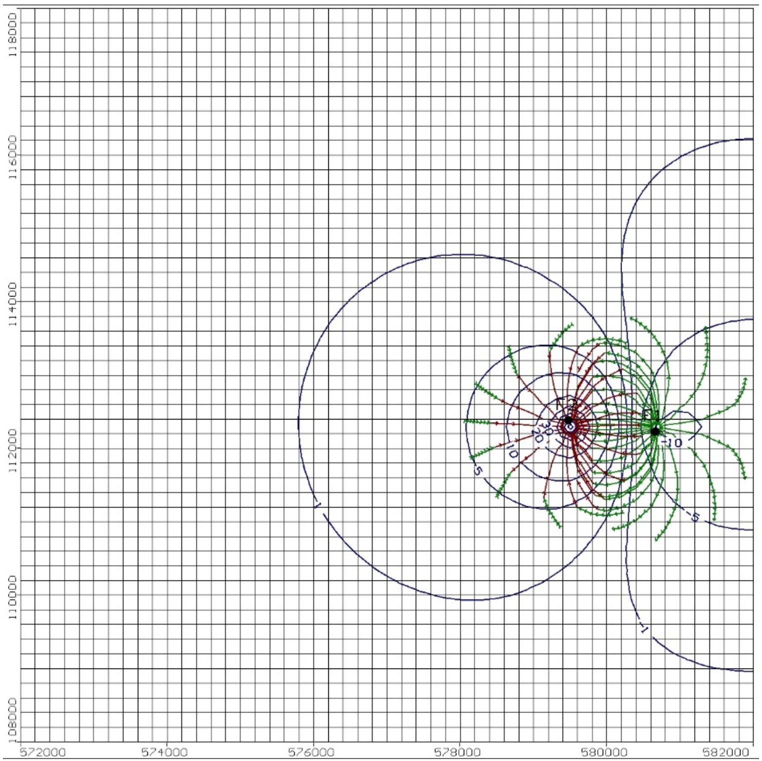

FIGURE 10: Calculated groundwater streamlines in model layer 1

4.2 Effects on reservoir temperature

The MODFLOW software package used for modelling does not include a module for simulating temperature changes in the reservoir. However, the water-soluble contaminant transport program MT3D has been used in previous studies to simulate heat transport in low-temperature geothermal reservoirs and it was decided to use this approach (Hecht-Méndez et al., 2010).

Figures 11-17 show the results of the heat flow simulation at different time increments. Figure 11 shows the calculated reservoir temperature in layer 2 after 10 years. As the figure shows, the reinjection well is cooling the reservoir around it, with the cooling effect reaching out radiallly approximately 0.2 km from the reinjection well. Figure 12 shows the results in cross-section view after 10 years. In addition to lateral spreading of the cooling zone, the cooling also extends vertically from layer 2 into layers 1 and 3 above and below.

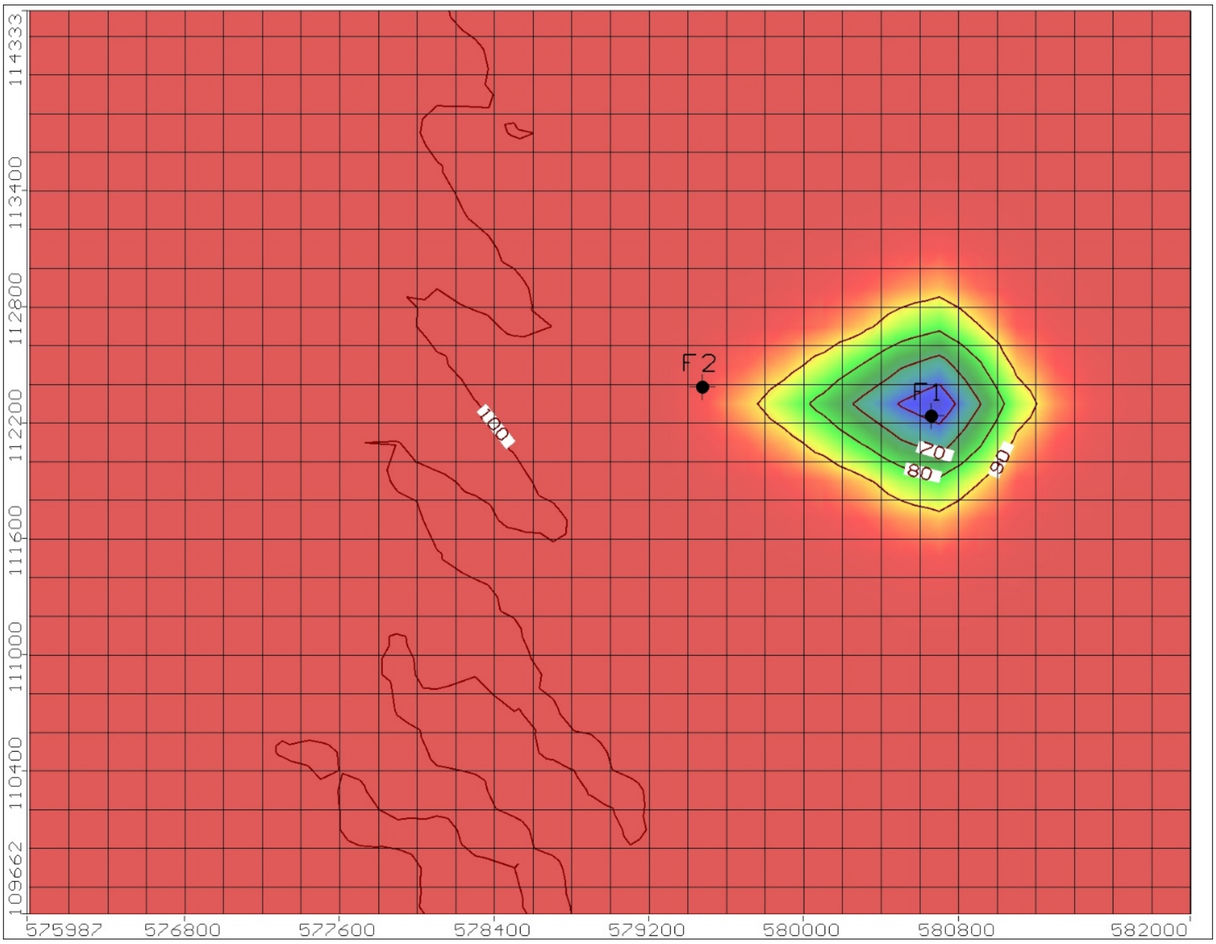

FIGURE 11: Calculated reservoir temperature in layer 2 after 10 years

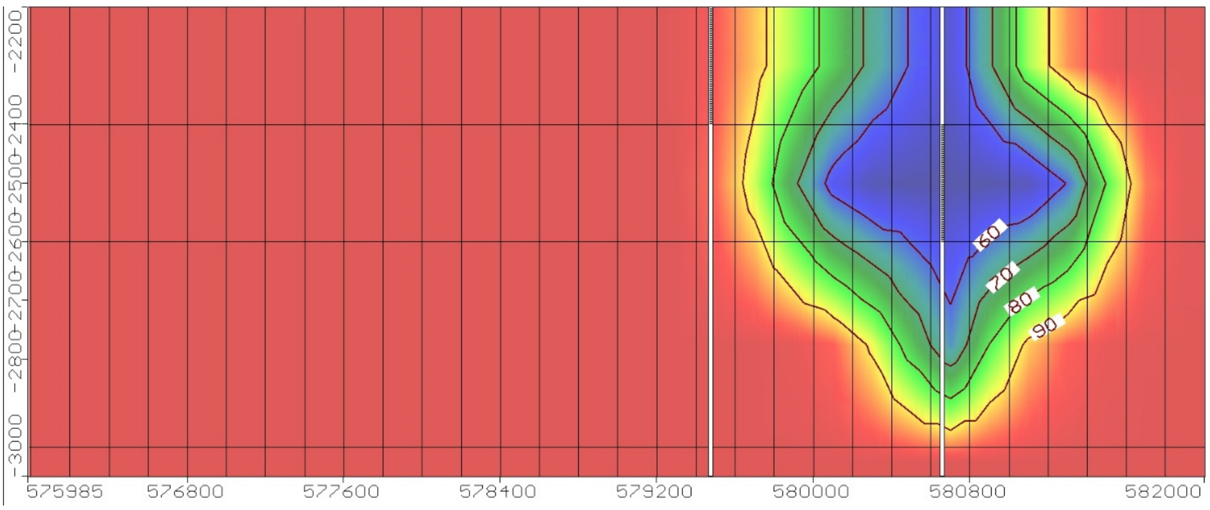

FIGURE 12: Cross-section showing calculated reservoir temperature after 10 years

Figure 13 shows the calculated reservoir temperature in layer 2 after 50 years. As the figure shows, the cooling effect is spreading further out into the reservoir with time, with the cooling effect reaching out approximately 0.8 km from the reinjection well. Figure 14 shows the results in cross-section view after 50 years.

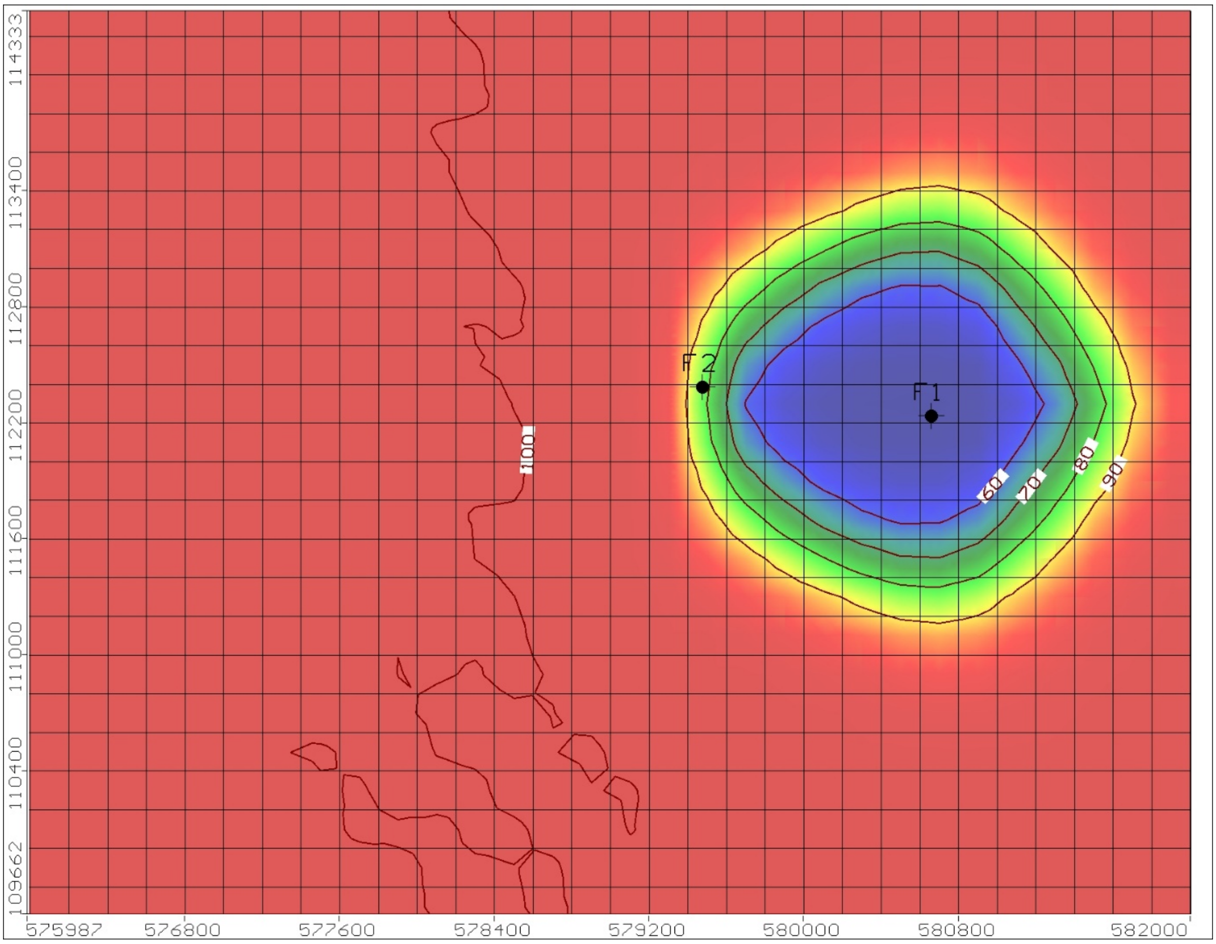

FIGURE 13: Calculated reservoir temperature in layer 2 after 50 years

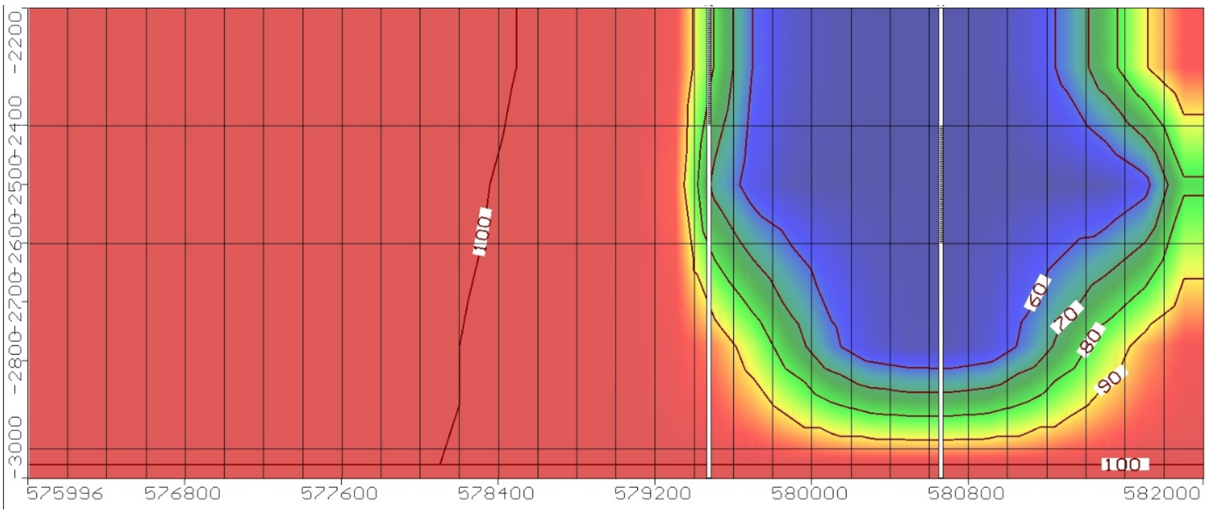

FIGURE 14: Cross-section showing calculated reservoir temperature after 50 years

Figure 15 shows the calculated reservoir temperature in layer 2 after 100 years, while Figure 16 shows the results in cross-section view after 100 years. The cooling effect now reaches out approximately 1 km from the reinjection well.

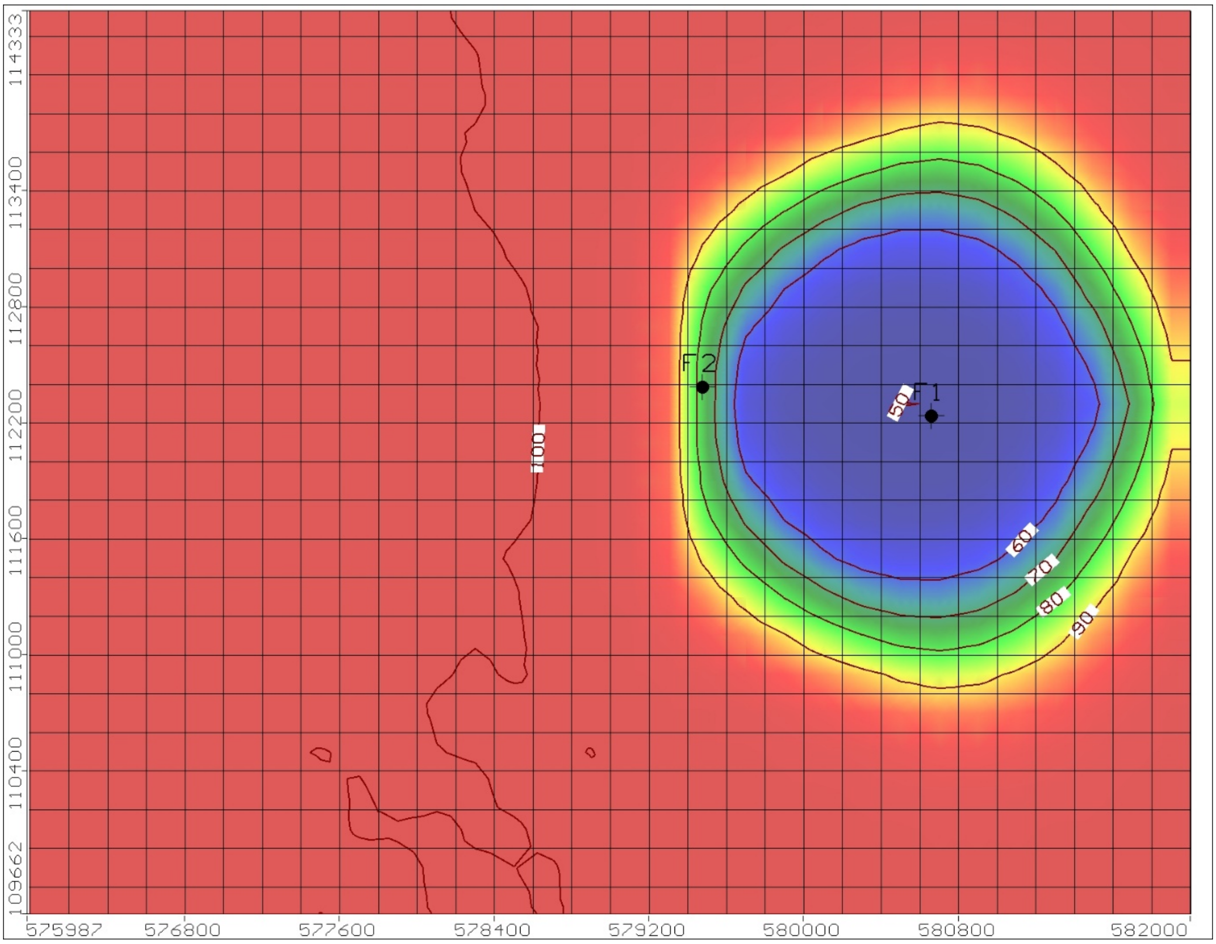

FIGURE 15: Calculated reservoir temperature in layer 2 after 100 years

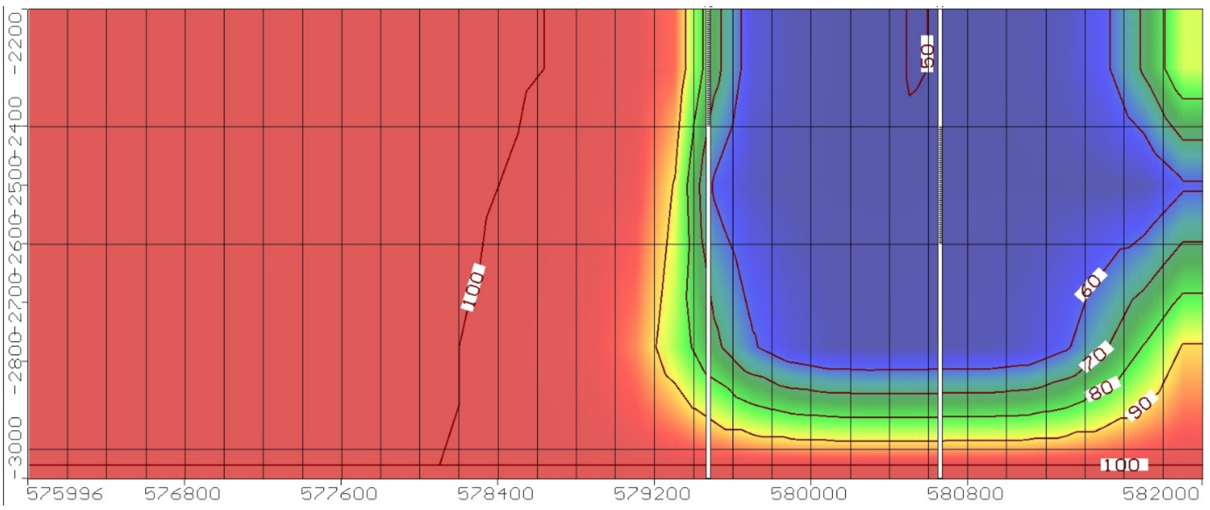

FIGURE 16: Cross-section showing calculated reservoir temperature after 100 years

The calculated mixing zone in the reinjection layer after 100 years is shown in Figure 17. As expected, the cooling of the reservoir extends furthest laterally within the layer where the reinjection is taking place (model layer 2). The cooling spreads less within the other layers. Therefore, we define the impact area of the reinjection as the mixing zone in the reinjection layer (layer 2) as shown on Figure 13. Using this definition, the impact area is a circular area centred on the reinjection well with a radius of approximately 2000 m.

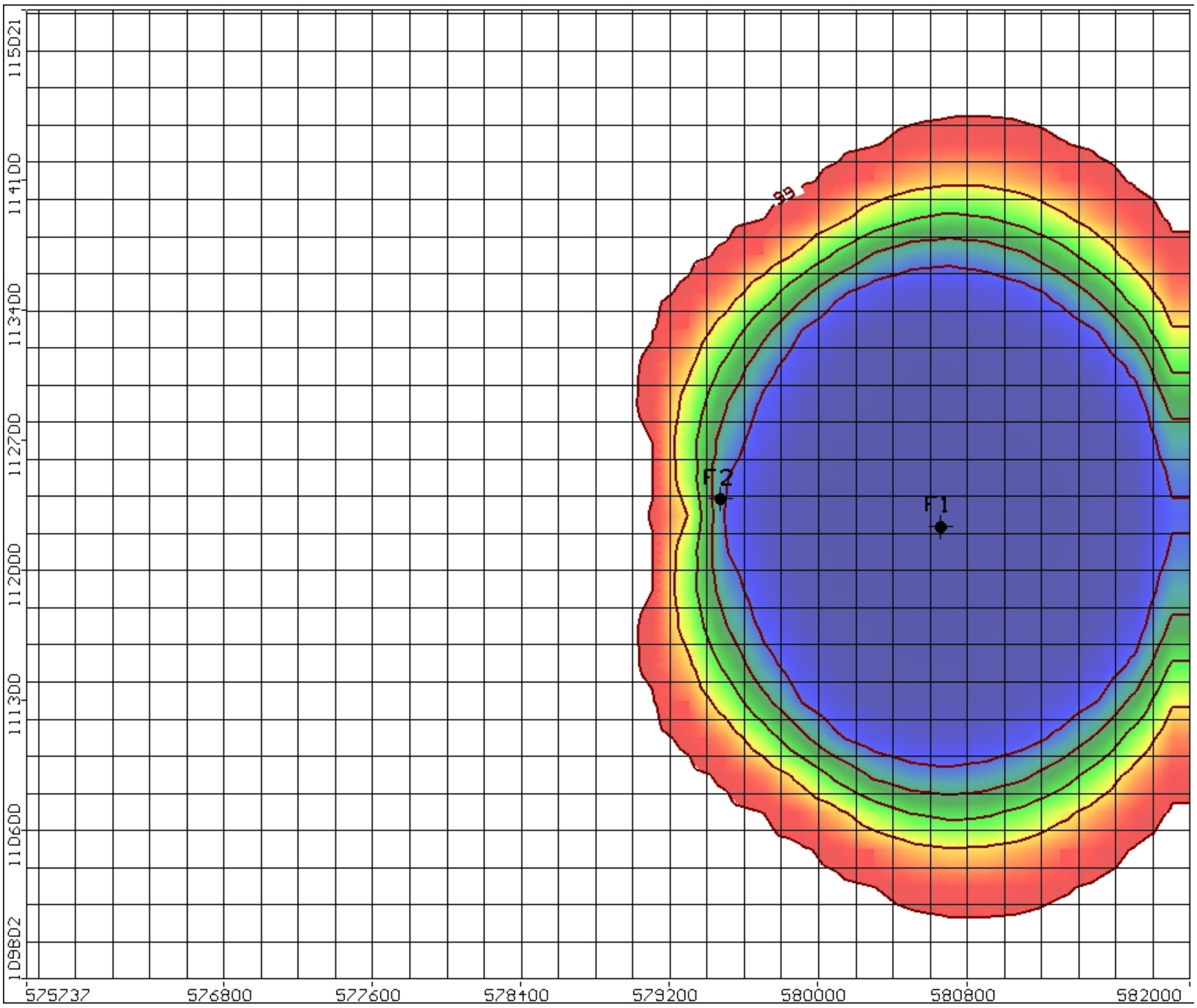

FIGURE 17: Calculated mixing zone in the reinjection layer (layer 2)

The streamlines of groundwater flow between the wells (Figure 10) indicate that there is a hydrological connection between the wells. This connection means that the cooling effects from the reinjection well are likely to lower the temperature of the reservoir fluid at the production well with time. The calculated temperature decrease at the production well is plotted in Figure 18. Calculated temperature is given in percentage of the original background temperature in the reservoir. The expected temperature values after 10 years (3650 days), 50 years (18,250 days) and 100 years (36,500 days) are marked on the diagram. According to these results, the temperature of the produced water will decline by about 20% after 50 years of production.

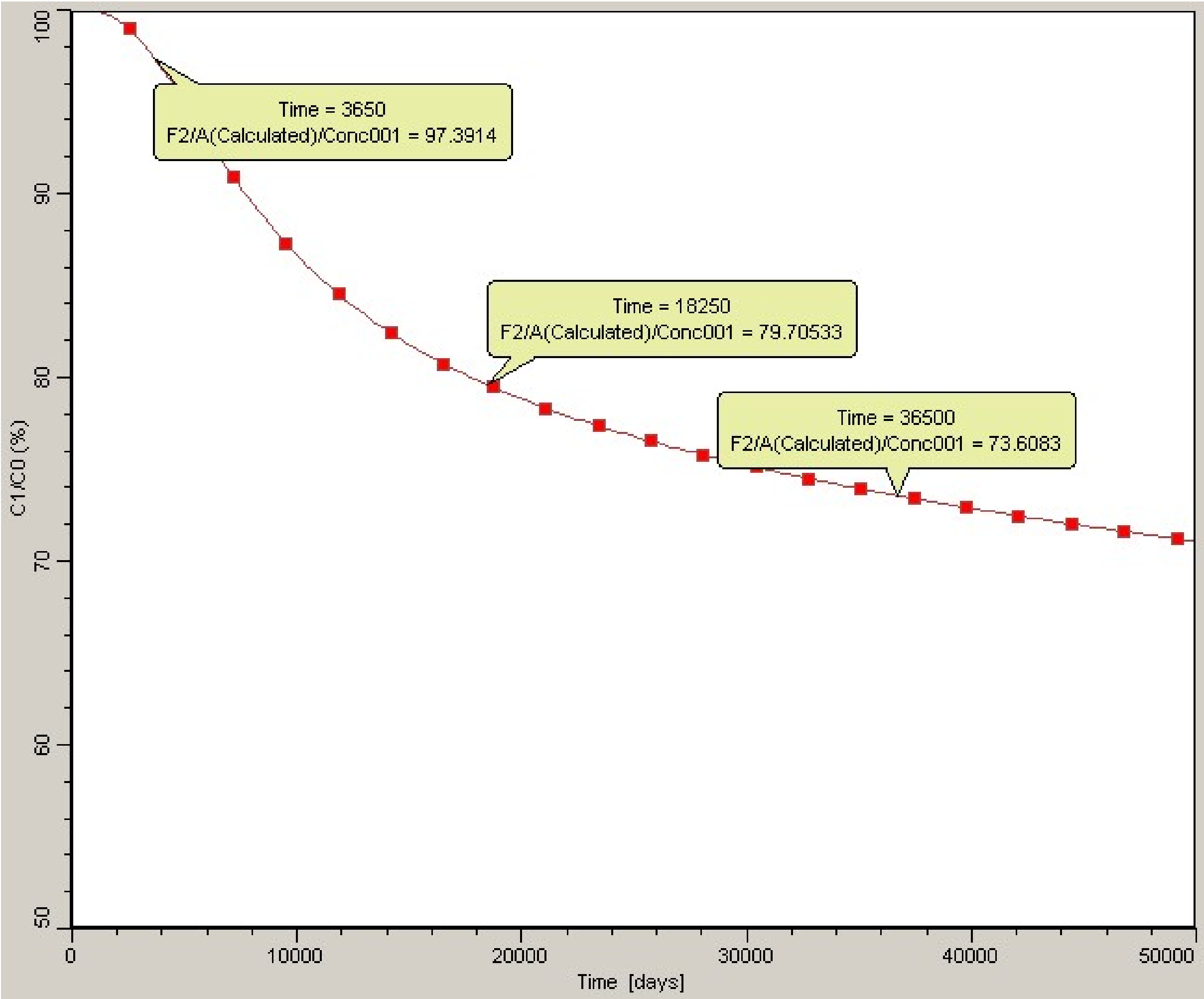

FIGURE 18: Calculated temperature decrease at the production well after 10, 50 and 100 years

5. CONCLUSIONS

Results from this preliminary modelling work indicate that the geothermal reservoir at Dombóvár can support the proposed well duplet and serve as a long-term sustainable resource for geothermal heat production. The effects of the proposed well duplet on the pressure and temperature in the reservoir are within acceptable limits for maintaining production. Therefore, it can be recommended that the next phase of the resource development plan be implemented. This next phase should focus on geological and geophysical measurements and data collection from the local reservoir in order to gain a better understanding of the system. Hydrological parameters used in the model were based on best-guess estimates due to lack of data. Updating the model with actual measured values for hydraulic conductivity and porosity from the reservoir would improve the reliability model.

The first step in the MVM geothermal development plan is to supply the industrial park with geothermal space heating. The proposed well duplet is expected to supply this demand, but additional wells could be needed. In that case, an updated reservoir model would be a good tool for determining the location and capacity of additional wells. There is an ongoing contract between the town and a local district heating company, which uses gas-driven engines for heating water. It is expected that within the next 8 years, this system will be outdated and will need to be replaced. The future goal of the town is to change the entire district heating system to a "green" geothermal energy system.

ACKNOWLEDGEMENTS

I would like to thank my supervisor Eric M. Myer from Vatnaskil for the patient guidance, encouragement and advice he has provided throughout my time as his student. I have been extremely lucky to have a supervisor, who cared so much about my work and who responded to my questions and queries so promptly.

I would also like to thank all the members of staff at UNU-GTP for the past half year, I will always keep this memory in my heart.

To my dad, Peter Unyi, and his company, Waterplan Ltd., thanks for the data and for the support from home, as well as to my mom Monika Unyi and my siblings, Laura and András, for the support.

And last but not least, to all of my new friends here at UNU-GTP, thanks for all the great memories, the running team for unforgettable races, and lots of laugh.

Thank you all!

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