Proceedings of the
2nd IAH Central European Groundwater Conference (2015)

"GROUNDWATER RISK ASSESSMENT IN URBAN AREAS"

Volume of papers and extended abstracts

Edited by
Adrian Iurkiewicz and Iulian Popa

Bucuresti, 2016

ROMANIAN ASSOCIATION OF HYDROGEOLOGISTS (AHR)
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Sustainability of Szentes Geothermal Field operations

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Abstract
The Szentes region is the biggest and one of the oldest geothermal fields in Hungary. The geothermal operation was started in the area more than 50 years ago. As a consequence of the high thermal water production from the 45 wells, the hydraulic head of the aquifers decreased by 25-40 m in the early 1990s, but due to a reduction of the thermal water production an increase of 5-10 m was observed during the last decade. Initially most of the wells were free flowing up to 50 m, but as of now a continuous pumping of the wells is required. At present, there is no reinjection well at all. During this study a numerical model based on pressure measurements was made to investigate the recharge process and sustainability of this system. This model was also used to investigate the effects of potential reinjection wells.

Keywords: *geothermal energy, reinjection, temperature logging, numerical modelling, Hungary*

Introduction

The geological and hydrogeological conditions make the Pannonian basin favorable for the use of geothermal energy, due to the occurrence of a positive geothermal anomaly based on a high geothermal gradient (Dövényi and Horváth 1998, Stevanovic at al. 2015). The South Great Plain Region has the Hungary's most important thermal water reservoirs, as the Quaternary and Upper Pannonian aquifer formations reach their maximum thickness in this area. The most intensively utilized reservoir in this region is Szentes geothermal area, where the first thermal well was made by converting an abandoned hydrocarbon well in 1958 (Bálint and Szanyi 2015).

At the beginning, the geothermal energy was used to produce domestic hot water, for medical purposes and balneotherapy. Nowadays, out of 38 operational wells, 12 are producing thermal water with more than 90°C temperature (Figure 1). This water supplies 3000 flats, several large communal buildings and agricultural firms. Árpád-Agrár Ltd. is the operating company of greenhouses with the area of 65 ha. The company also uses a fodder drying plant and by supplying all the energy needs with geothermal energy, through 20 wells, the horticultural and livestock breeding facility utilizes 654000 GJ geothermal energy. This energy is equivalent with 19,2 million m^3 natural gas or with 15500 tons of oil.

The amount of total annual thermal water production is around 6.5 million m^3 in Szentes region (Szanyi and Kovács 2010). Between 2009 and 2011, hydraulic and logging tests were conducted in 20 wells of the Szentes geothermal field by Geo-Log Ltd Hungary. Based on the tests, a prognosis of the long-term production resulted in 1.5-4 bar pressure decrease over the natural conditions in the sandstone reservoirs. Due to lack of reinjection wells the most significant pressure decrease was noticed in the most intensively exploited depth interval i.e. lower layer group (Bálint and Szanyi 2015). In this study the optimal location of prospective reinjection wells is proposed based on temperature log-survey. The effects of these wells were investigated by numerical modelling.

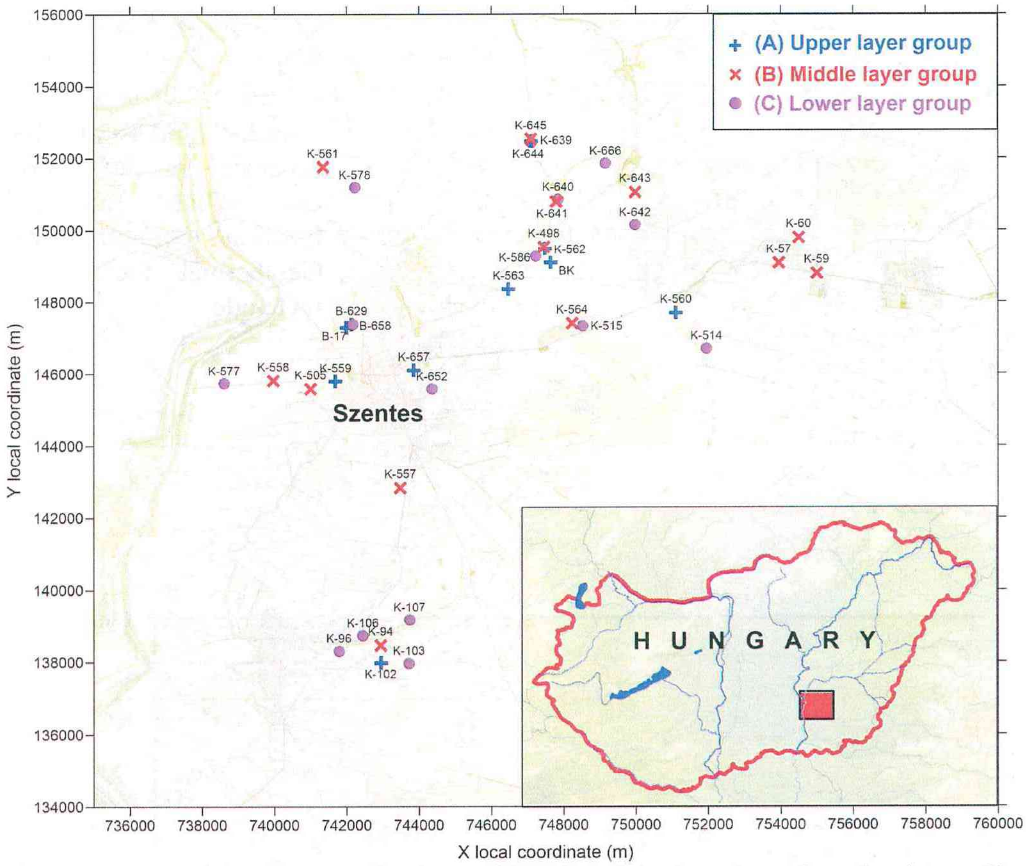

Figure 1. Map of the Szentes Geothermal Field and the location of production wells

Geological, hydrogeological conditions

From a geological point of view, the Pannonian Basin is a large sedimentary basin, the basement of which consists of variously subsided basins and horst-like blocks. The level difference between different structural sub-units can reach 5000 m, especially in the South Great Plain (Figure 2). Apart from the main mass of the basement, which is made up of metamorphic Palaeozoic rocks, the Mesozoic carbonate formations, which can be good aquifers, can be found in some areas as well (Horvath *et al.* 2015). The two main depression of the South Great Plain were formed in the Miocene: the Makó Depression and the Békés Basin, these being divided by the Battonya Ridge. The Szentes Geothermal Filed is located on the Northern corner of Makó Depresssion (Figure 2). A thick layer of porous sediments can be found on this subsiding basement, which deposited in the Pannonian period (Juhász 1991).

Due to the effect of marine transgression at the beginning of the Lower Pannonian period, a basalt conglomerate known as the Békés Conglomerate Formation, was formed on the emerging higher territories. This is covered, in the deep basins, by the Endrőd Marl

Formation, consisting of calcareous marl and clay marl. The latter is covered by the fine sand turbidite set of the Szolnok Formation, reaching several hundreds of metres at some points.

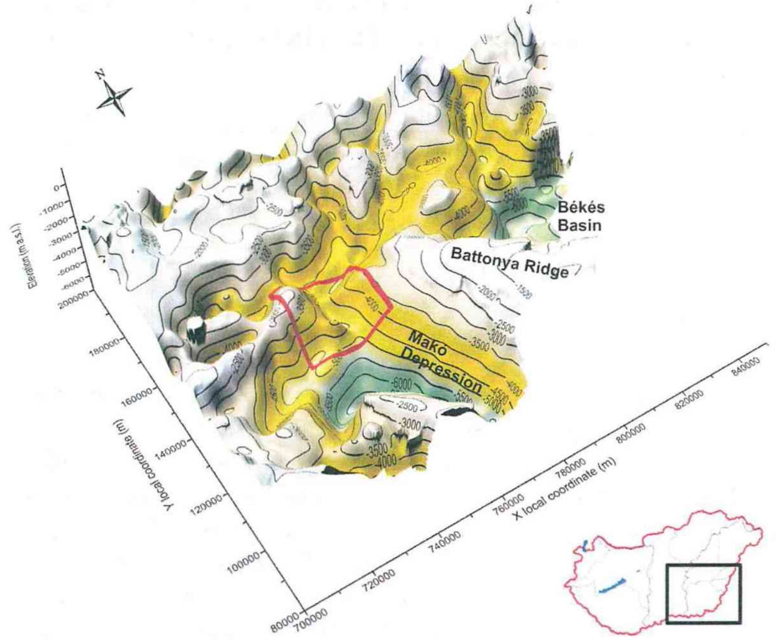

Figure 2

Terrain model of the basement in the South Great Plain and the location of Szentes Geothermal Field (red rectangle)

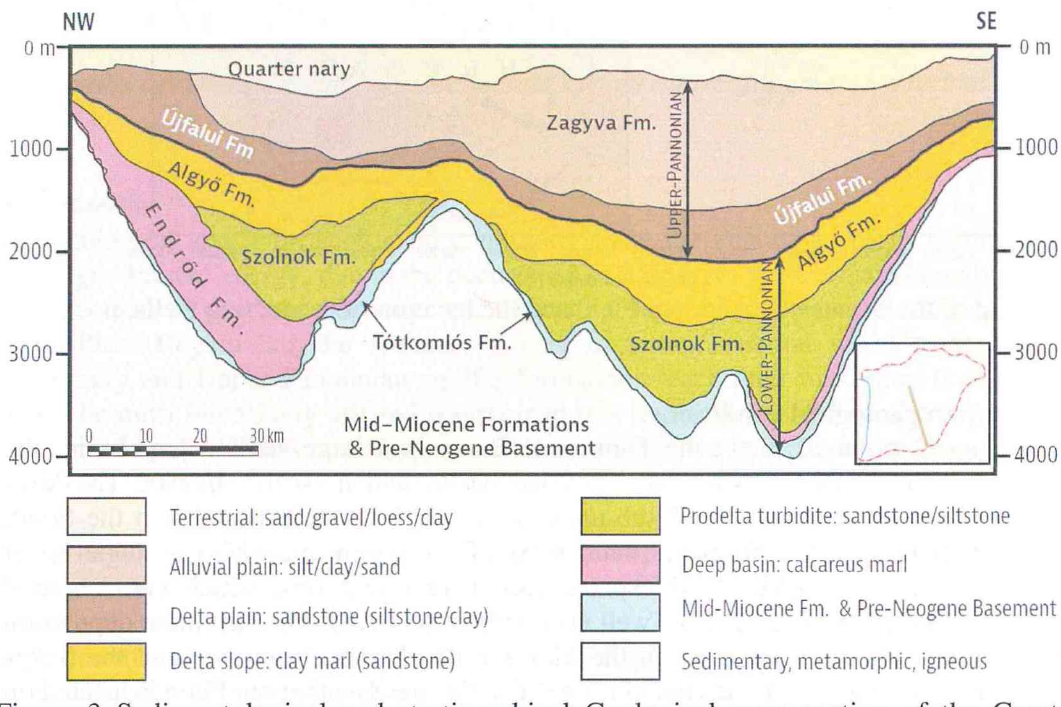

Figure 3 Sedimentological and stratigraphical Geological cross-section of the Great Plain (based on Juhász 1991, Almási 2001)

Above the turbidites, in the shallower basin areas, the hemipelagic marls are covered by the thick clayey-silty layers of the Algyő Formation with a prodelta facies (Figure 3) (Haas *et al.* 2012). The main feature of the set is the extremely high overpressure below it and everywhere in it. The sand content of the Algyő Formation increases in the areas with a shallower basement, thus the upper part of the formation can be regarded as water-bearing at some points. Generally, the Lower Pannonian formation is characterized by poor water-bearing features.

These mentioned layers are covered by the Újfalu Formation, with a delta front and delta plain facies, which is the most important Upper Pannonian sediment from a hydrogeological point of view, and by the sediment layers of the Zagyva Formation, with a deltaic background and alluvial plain facies. The dominant sediments are bed-filling and bay-mouth bar sediments that have good water-bearing features and limited horizontal dimensions, but they are hydrodynamically connected due to multiple linear erosions and overlappings (Juhász 1991). The bottom of the Upper Pannonian sequences is 2500 m from the groundsurface at SW part of the study area and 2000 m at the NE wing (Figure 4). The thickness of Upper Pannonian sediments in the South Great Plain can reach 1800 m in the Makó-Hódmezővásárhely depression, and can exceed 2000 m in the Békés Basin.

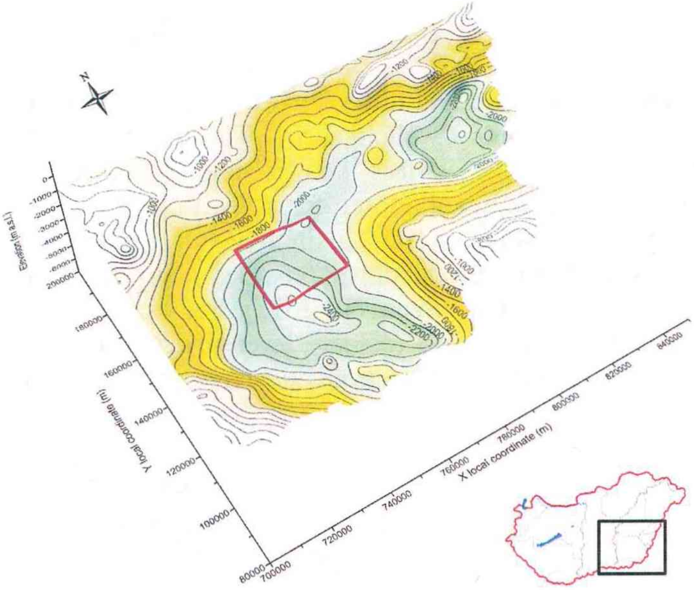

Figure 4

Terrain model of the bottom of Upper Pannonian sediments in the South Great Plain and the location of Szentes Geothermal Field (red rectangle)

In the Carpathian basin there are two flow regimes: an upper, gravity driven flow system (Upper-Pannonian sequences) and a deeper, overpressure driven system (Lower-Pannonian) concerning essentially the finer deep sea sediments and underlying formations (Tóth and Almási 2001, Mádl-Szőnyi and Tóth 2009). The cause of the high overpressure (up to some 40 MPa above the hydrostatic pressure) can be the tectonic compression of the formations, whereas gas formation during the maturation process of the sediments can also be a factor (Tóth and Almási 2001).

The Szentes area was then classified according to its place in the flow system and the vertical component of the flow direction. In the regions of Szentes, the flow regime can be defined through the change of the piezometric level in relation to depth during well construction. According to pressure-depth profile, the dynamic pressure gradient was exceeding the hydrostatic pressure in the Quaternary formations by 0.13 MPa (approximately 13 m), and in the Upper Pannonian set by 0.44 MPa (approximately 44 m). While in the Lower Pannonian sequence the super-hydrostatic pressure was built up, the dynamic pressure gradient exceeded the hydrostatic pressure by more than 60 MPa! The study area was part of the discharge zone. The effective porosity of Upper Pannonian sandstone can reach 22-25%. According to the literature and our measurements, the permeability of the Upper Pannonian reservoir, which consists of highly permeable sand layers, can reach in the Szentes region up to 2000 mD; this corresponds to hydraulic conductivity of 5-10 m/day. Depending on the cementation (usually by quartz overgrowth, calcite or kaolin) degree of the sandstone grains, we may speak of consolidated and unconsolidated sandstone. The cementing status of the sandstone plays a key role mainly in porosity and stability, especially during production/reinjection. The sandstone induration increases with depth, since the cementitious material precipitates into the pores from the fluid pressed out during compaction. The sand bodies are divided by the thinner, fine-grained sediments. Most of thermal water production is carried out from the Újfalu Formation in three depth ranges (Korim 1991, Balint and Szanyi 2015):

- Upper layer group: Layers filtered above 1800 m
- Middle layer group: Layers filtered between 1800 - 2000 m
- Lower layer group: Layers filtered below 2000 m

Geophysical inspection of wells

The complex geophysical inspection (caliper, acoustic and differential temperature logging) of thermal wells is the most suitable for investigating well integrity. The utility of static temperature survey which is made in shut wells, is less known among geophysical measurements. This survey should be carried out in a well closed for at least one day, when the static temperature of the water in the well has stabilized. This temperature – especially when compared to the temperature recorded during production - provides many important data on the pressure conditions of the opened aquifers (Szongoth 2012). For example, in a non-producing (steady) state, there is a flow from a top (colder) layer towards a deeper (warmer) layer, which significantly cools down during longer production-free periods or vice versa.

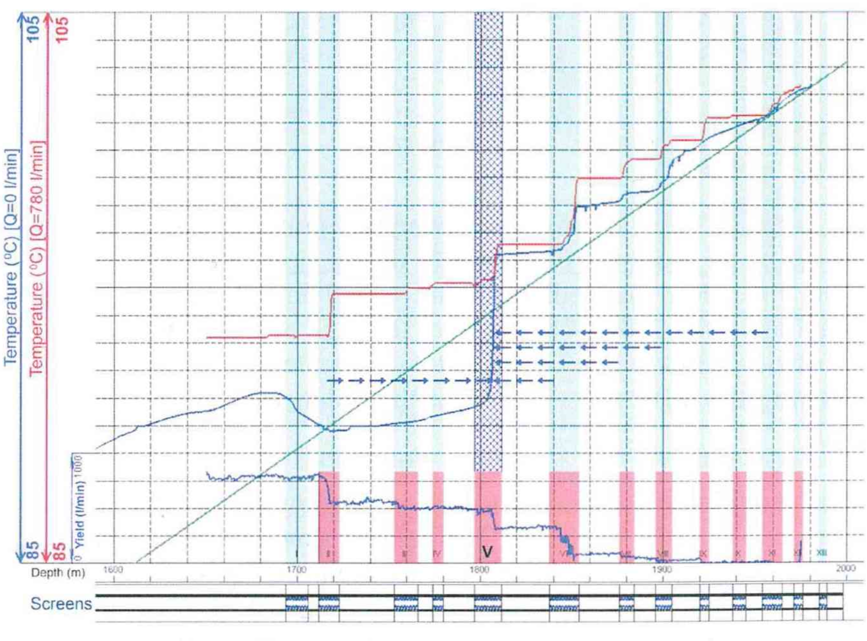

Figure5. Plots of Dynamic (red) and static (blue) temperature survey data vs geothermal gradient (green) line. Static temperature survey is indicating the flow (blue arrows) to V (fifth) screened layer from the adjacent layers (based on Szongoth 2012).

Based on the results of such static temperature survey, a great diversity of temperature difference between a producing and a shut well can be observed (Figure 5). An explanation for the aforementioned diversity is the leakage among layers, which differs from well to well. The leakage from highlighted wells is shown in Figure 6, which indicates the lowest pressure among producing layers (*A*, *B* and *C*). The observations based on this figure can be grouped as follows:

- Layer group *A* is always leaking downwards the top of the layer group *B* (K-643, K-639)
- In case of leakage between *B* and *C*, *B* is leaking towards *C* (K-94, K-103)
- If only *B* is screened, the lower part of it is leaking upwards (K-645 K-643)
- The bottom of *C* is always leaking upwards (K-103)

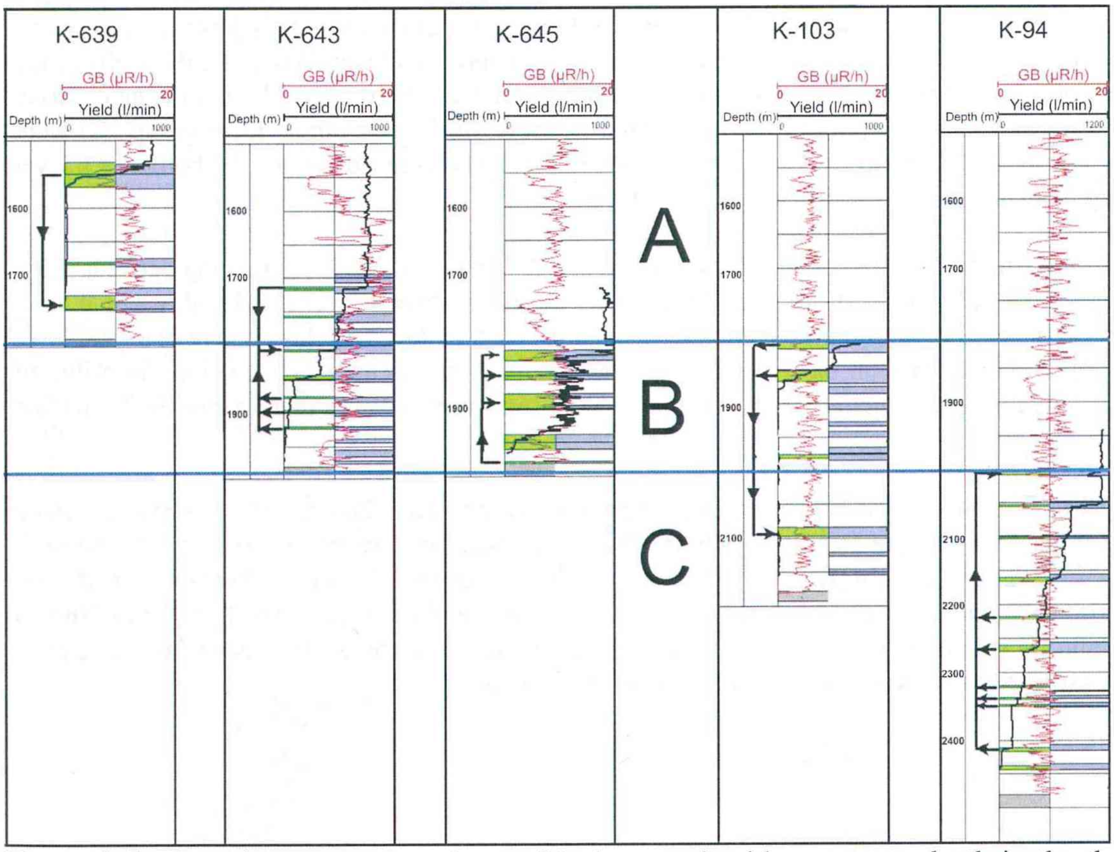

Figure 6. Leakage between porous layers (black arrows) with respect to depth in the three layer groups (A, B, C) (based on Szongoth 2012).

Therefore, based on the temperature survey, pressure status of each screened layer can be concluded. These measurements help to refine the hydrodynamics of the reservoir and to identify the location of the reinjection wells.

Modeling

Reinjection is one of the most important aspects of sustainable management of geothermal resources. Choosing the position of a new reinjection well is an important part of the entire geothermal field operation. The position and the depth of the planned reinjection well essentially determine the lifetime and the profitability of the geothermal project. A proper location of the reinjection well help avoiding the thermal breakthrough and will efficiently increase the recharge of the geothermal reservoir. On the basis of the reservoir hydrodynamics and static temperature survey new locations for injection wells were proposed.

A Processing MODFLOW model was built to simulate and analyse the effect of the proposed reinjection wells. The study area was of 25×22 km^2; the emphasized wells were located in the central region of it (Figure 1). The orientation of the model grid was chosen parallel to the water flow through the main aquifer. The model has been horizontally divided to elements of 100×100 m, furthermore refined to elements of 25×25 m in the proximity of the wells. The sedimentary sequence from the surface to the bottom of the Upper Pannonian was divided into 21 layers, based on the stratigraphy according to Juhász (1991).

The bottom of the modelled area was assumed to be impermeable, due to the clayey layer (Algyő Formation). The top of the model is represented -by the Pleistocene layers hosting cold water, while the bottom consists of the overpressured Lower Pannonian layer. Basically, the wells of the uppermost layer group (A) were allocated to layers 11 and 13, the wells of the middle layer group (B) were assigned to layers 15 and 17, while the wells of the lowermost layer group (C) were allocated to layers 19 and 21. Obviously, in case of the wells screened beyond the border of a layer group, both layers were shown as producing layers.

The horizontal hydraulic conductivity at layer group A (layers 11 and 13) is ranging between 1,0 – 5,2 m/day, at layer group B (layers 17 and 17) it was ranging between 0,7 – 2,8 m/day and at layer group C (layers 19 and 21) it was ranging between 0,4 - 2,5 m/day. The clay content of a sand layer was taken into account in the vertical hydraulic conductivity. As an approximation, the value of vertical hydraulic conductivity was considered as of two orders smaller than that of the horizontal one.

As it was discussed at the hydrodynamic properties, at initial state the hydraulic head is increasing with depth, therefore the area belongs to the discharge zone. The direction of regional groundwater flow is considered from East to West. In the model layers, the initial hydraulic head was determined by the static hydraulic head of the wells. The initial pressure – elevation profile (shown in Figure 7) was taken into account during the calculation. The General Head Boundary conditions were assigned to the west and east side borders of the model.

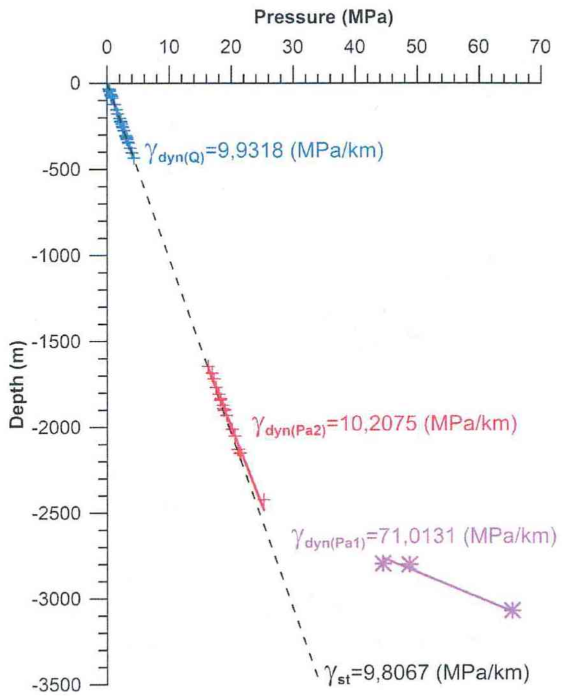

Figure 7.

Presure-Depth profile in the Szentes region, showing the static (st) and dynamic (dyn) gradient of different aquifers:
Q - Quaternary,
Pa2 - Upper Pannonian,
Pa1 - Lower Pannonian

Discussion

As a result of the hydrodynamic modeling the depression caused by the production wells has been specified for all the screened layers. It was confirmed that the biggest effect on the hydrodynamic system of the area is caused by the production wells of the Árpád-Agrár Ltd. (Bálint and Szanyi 2015). According to the static temperature survey, when there was no production, a considerable amount of leakage was happening into model layers 15 and 19 from the neighbouring layers. This would be an excellent location for reinjection wells, because injection into these layers requires the least amount of energy. Without reinjection, the depression in layer 15 was of 21 m and in layer 19 was of 27 m (Figures 8, 9).

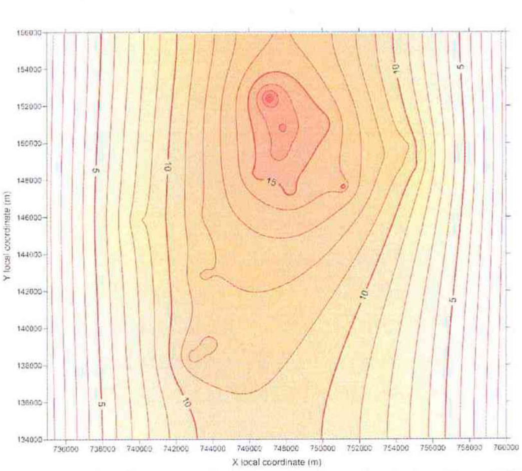

Figure 8. Cone of depression (m) in the 15th model layer

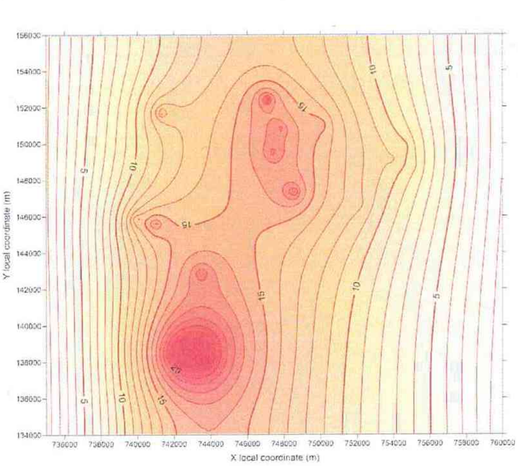

Figure 9. Cone of depression (m) in the 19th model layer

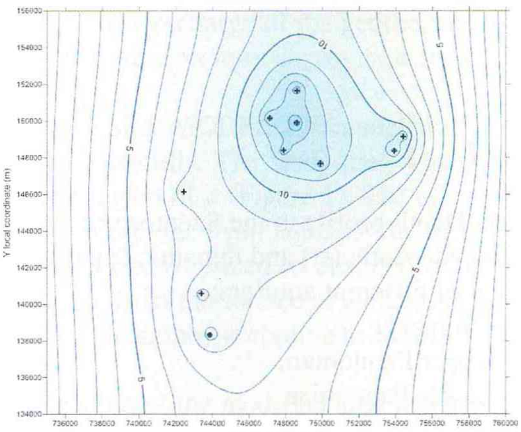

Figure 10. Value of recharge (m) in the 15th model layer by the reinjection wells (black cross)

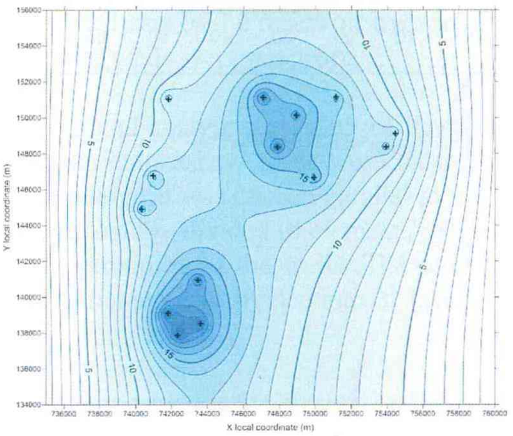

Figure 11. Value of recharge (m) in the 19th model layer by the reinjection wells (black cross)

The main goal of this study was to determine the amount of recharge in the system by reinjecting one third of the total produced fluid. The production rate of the study area was of 18090 m^3/day, out of which 2090 m^3 were extracted from layer 15 and 3300 m^3 were extracted from layer 19. During the simulation, an amount of 6000 m^3 of fluid was reinjected daily, or 2500 m^3 into layer 15 and 3500 m^3 into layer 19. Reinjection wells with the rate of 250 m^3/day were located at sites with the biggest depression. A safe distance of at least 1 km was maintained from production wells, in order to avoid thermal breakthrough. Based on the simulation, the largest amount of recharge was of 16 m in layer 15 and of 23 m in layer 19 (Figures 10, 11).

In the layers of reinjection, the initial depression was more than 20 m however, after reinjection, the long-term depression did not exceed five meters. Layer number 17 was not directly affected by reinjection, but because it is positioned between the two reinjected layers, a five meters amount of recharge through leakage was noticed in this layer (Figure 12). Layers above and below the reinjected layers were also affected by a two meters amount of recharge (Figure 13).

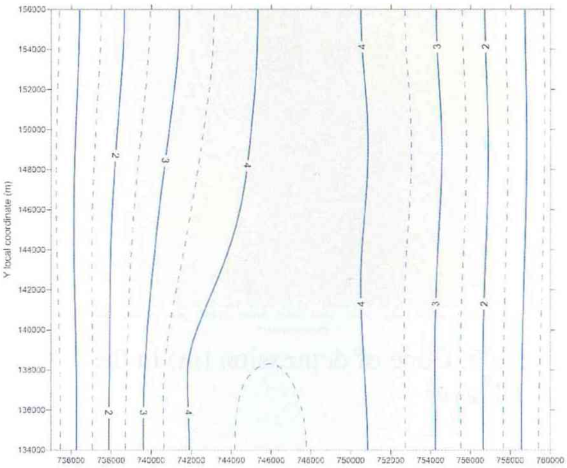

Figure 12. Value of recharge (m) in the 17th model layer caused by reinjection wells

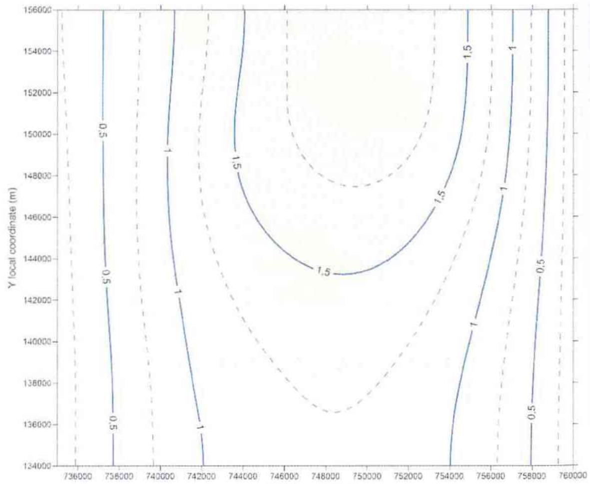

Figure 13. Value of recharge (m) in the 21st model layer caused by reinjection wells

Conclusions

The direction of leakage could be used to control the production rate of wells and design new production or reinjection wells by conducting static temperature surveys. A hydrodynamic model with a proposed reinjection system was built on this information and resulted in a remarkable increase in pressure not only in the injected layers but also in adjacent layers, due to vertical leakage in the system.

Based on the simulation data, a proper reinjection system can be designed in order to minimize the cost of reinjection and to maximize the exploitable energy of the reservoir, contributing to the sustainable utilization of geothermal energy.

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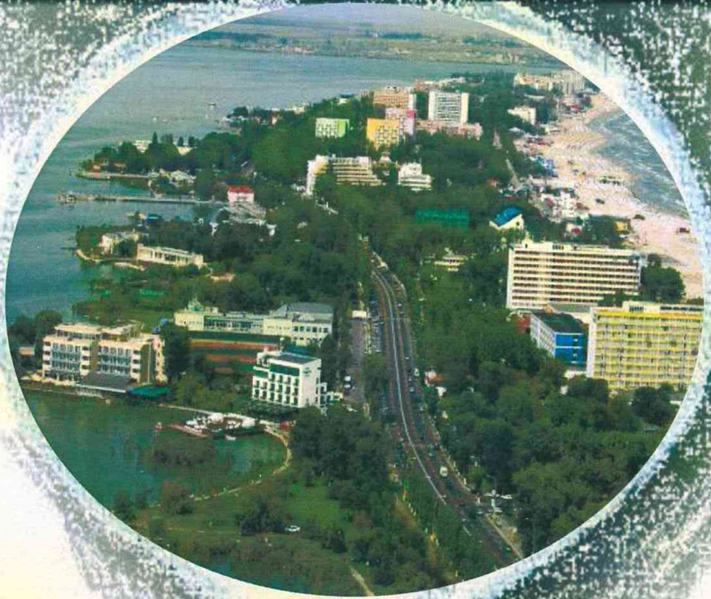

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