Geothermics 39 (2010) 357–364

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Utilization of geothermal systems in South-East Hungary

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ARTICLE INFO

Article history:
Received 19 June 2009
Accepted 3 September 2010

Keywords:
Geothermal resources
Sustainability
Injection
Pannonian basin
Hungary

ABSTRACT

Thermal wells have been used in Hungary for over 140 years. As thermal water production has increased during the past decades, the pressure drawdown has increased in the geothermal systems of the Pannonian basin, showing that their sustainable management is lacking. The Hódmezővásárhely, Szeged, and Szentes case histories are presented, including the very first indications of stabilization and recharge of the Pannonian thermal aquifers, as a result of reduction of thermal water production. Sustainable production and overall resource management of geothermal systems in SE-Hungary can only be achieved by injection.

1. Introduction

Hungary is located in Middle-Eastern Europe, in the Carpathian Basin. It lies in a high heat flow area of the continent (Dövényi et al., 2002; Antics and Sanner, 2007), on the boundary of the African and European tectonic plates (Fig. 1).

Due to late plate tectonic events, subsidence of the area has resulted in the formation of a large sedimentary basin filled with deep sea sediments. The most intense subsidence was in the Pannonian Age. During the filling of the sedimentary basin, the sea became shallower and brackish; later it became isolated from the ocean (Pannonian inland lake); and finally dried out completely. At the location of the former sea and lake, a huge sedimentary basin up to 6000–7000 m thick, with high-porosity sedimentary sequences (Pannonian basin), remained (Fig. 2).

In Hungary, the earth's continental crust is rather thin (22–26 km) (Dövényi and Horváth, 1988) and is covered by low-thermal-conductivity formations. These conditions led to a high geothermal gradient anomaly (approximately 50 °C/km) with a heat flow of 90–100 mW/m^2 (Dövényi et al., 2002).

Two fluid flow regimes exist in the basin: an upper, gravity-driven flow system, and a deeper, pressure (overpressure)-driven system in the mainly fine, deep sea sediments and underlying formations. The most probable cause of the high overpressure [up to 10 MPa above hydrostatic pressure (confirmed by deep drilling)] could be the tectonic compression of the formations (Tóth and Almási, 2001), though gas formation during the maturation process of sediments could also be a factor. At the bottom of the basin are both metamorphic and carbonate rock bodies that are of geothermal interest.

The porous formations of the Pannonian basin contain water up to 130–150 °C due to the high geothermal gradient; however, some karstified and fractured carbonated aquifers in the basement with temperatures up to 300 °C provide favorable conditions for development of medium- and high-enthalpy geothermal systems (Fig. 3).

Rezessy et al. (2005) inventoried the geothermal resources of Hungary, and calculated the total heat stored both in the rock matrix and in the water present in the geological formations of various ages to a depth of 5000 m. They demonstrated that the stored heat increases with depth from the Quaternary (Q) through the Upper Pannonian (Pa_2), Lower Pannonian (Pa_1), and Pre-Pannonian (Pre-Pa) sequences of the sedimentary basin. The amount of stored heat was found to be approximately 100,000 EJ (1 EJ = 10^{18} J). Most of the heat is stored in the rock matrix, with only 5% stored in the pore waters (Szanyi et al., 2009) (Table 1).

2. Geothermal facilities in the past, present and future plans

The first thermal well in Hungary was drilled into a shallow uplifted limestone reservoir in 1865, in Harkány. The first deep drilling was performed in 1868–1878, in Budapest, by a mining engineer, Vilmos Zsigmondy, who discovered 73.8 °C thermal water

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doi:10.1016/j.geothermics.2010.09.004

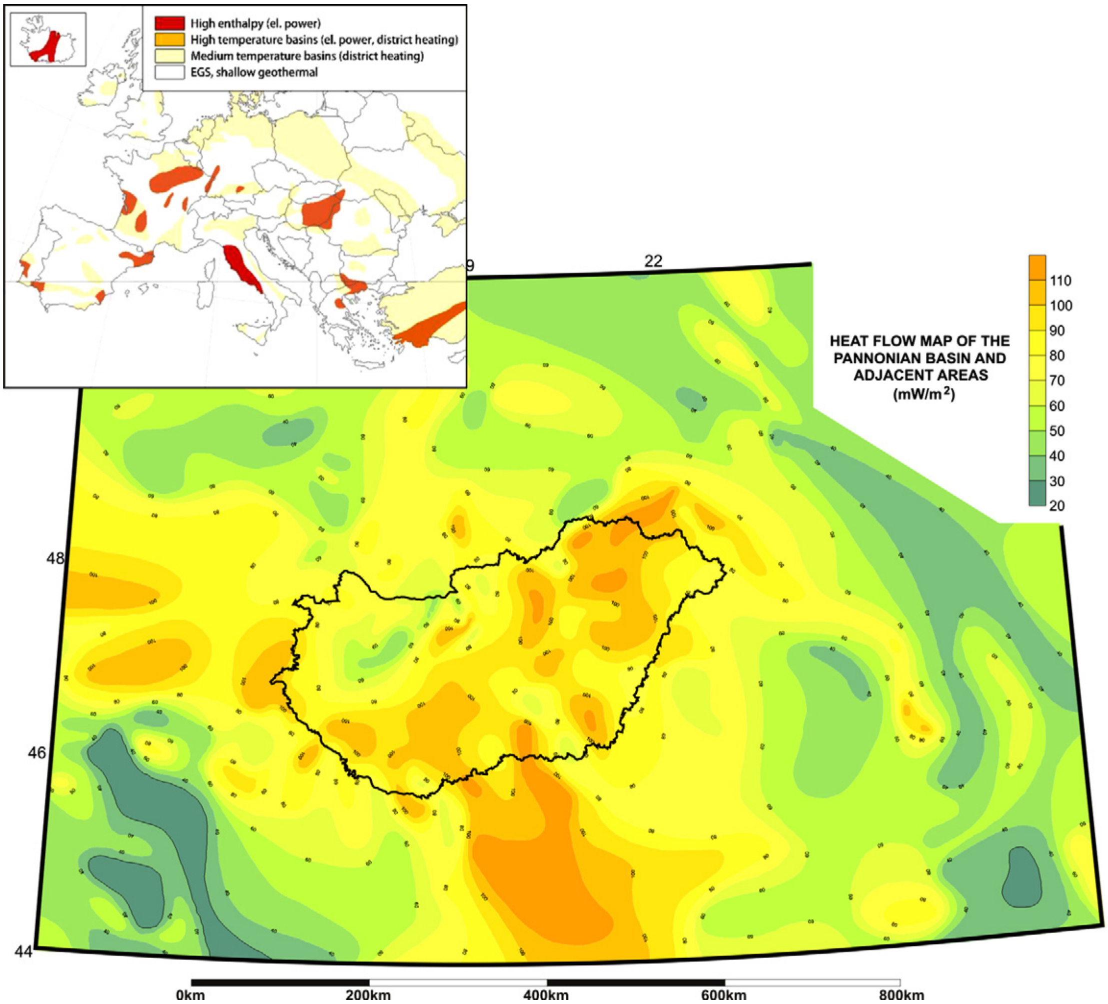

Fig. 1. Heat flow map of the Pannonian basin and adjacent areas, based on Dövényi et al. (2002). Inset (top left) is a geothermal thematic map of Europe, based on Antics and Sanner (2007).

with 1200 m^3/d yield at 970 m depth. After World War 1, several thermal reservoirs in Hajdúszoboszló, Berekfürdő, Szolnok, Szeged, Bükkszék, etc. were discovered by hydrocarbon exploration activities.

The balneological use of the Pannonian sandy thermal aquifers began in 1925, when a 1091-m deep well in Hajdúszoboszló yielded 70 °C thermal water. Later several drillings into this thermal aquifer were done in SE Hungary (Szeged, Karcag, etc.).

In 1958, the agricultural use of thermal water began in the Szentes area, where in addition to green-house heating, the water from 32 thermal wells is used for district heating. The Hódmezővásárhely Municipal Geothermal System, which is one of the most complex cascade use systems in the country, started operating in 1998. Several municipalities in SE Hungary (Szentes, Hódmezővásárhely, Kistelek, etc.) use thermal water directly for communal purposes and also for district heating. In addition, thermal-water-based spa and wellness use has been established in many other places (Mórahalom, Kistelek). Furthermore, several district heating systems using geothermal resources are currently in the planning and development phases.

To date, more than 1400 registered deep wells in Hungary have found thermal water, though only 950 are in production at present. Some of them are abandoned oil and gas wells, but they also include wells drilled for thermal water exploitation purposes. About 220 wells are used for balneology, and another 200 wells with water above 30 °C are used for public water supply. Approximately 200 such wells are used for agricultural purposes, of which half produce water over 70 °C. Unfortunately, only about 20 are injection wells, which shows that the direct use of water without injection is the current standard. Recent legislation prohibits new geothermal systems from being established without injection; only waters used for balneotherapy are allowed to be discharged at the surface.

For the shallower gravity-driven aquifer systems, the low pressure, and therefore, more sustainable injection into the porous sandy formations, started only about 10 years ago. Injection into

Table 1
Calculated heat potential in different geothermal formations; the rock formations are the same as in Fig. 2 legend (Rezessy et al., 2005).

Stored heat (EJ)	Q	Pa$_2$	Pa$_1$	Pre-Pa	−2500	−5000	Total
Rock body	140	4,030	6,318	16,741	12,053	57,765	90,047
Water body	35	636	351	893	568	2,652	5,135
Total volume	175	4,666	6,669	17,634	12,621	60,417	102,182

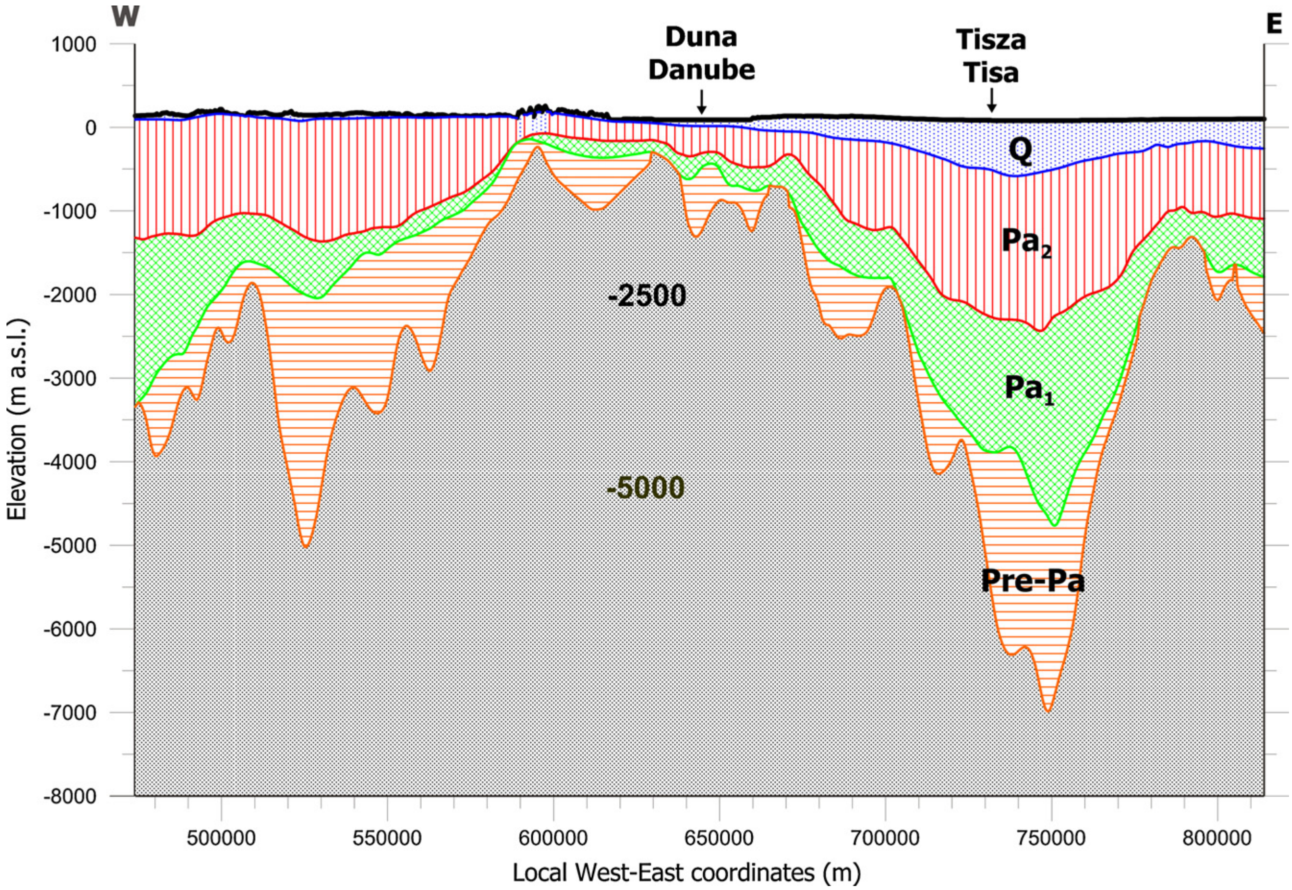

Fig. 2. A W–E cross-section through the South Pannonian basin. Q: Quarternary; Pa_2: Upper-Pannonian; Pa_1: Lower-Pannonian; Pre-Pa: Pre-Pannonian strata. For location of the geologic cross-section, see the geologic map in Fig. 7.

deep sedimentary layers is widely used by the oil industry, but huge overpressures are used since long-term sustainability is not required, and the high cost is not a significant issue.

The current estimated total production rate from thermal wells, which are mostly used about 6 months a year, is 84 million m^3/year, with a heat content of 15.2 PJ/year. In Csongrád County alone, where 172 wells are located, the estimated thermal water production is over 20 million m^3/year. Before 1990, the total thermal water production reached 130 million m^3/year, but under a high production tax, it has decreased since then. Currently, the production tax is about 9.5 eurocents/m^3.

Up to now, no electric power plants have been established using geothermal resources. In an unsuccessful first attempt (*Iklódbördöce, West Hungary, 2007*) using abandoned petroleum wells, the yield of the wells and the productivity of the aquifer were below the required levels. Several investors are interested in developing high-enthalpy geothermal reservoirs in Hungary, in spite of the problems posed by the frequently changing and not investor-friendly legislative system, which adds further risk to the already existing geological risk.

Some new projects are now in the planning and geological, hydrogeological, and geophysical prospecting phases, increasing the possibility that a geothermal power plant will be established in the near future.

The geothermal potential of Hungary and the three main sites (Hódmezővásárhely, Szeged and Szentes) with a widespread usage of thermal water resources in SE-Hungary are presented in detail below. These case studies demonstrate the problems concerning sustainable use of geothermal energy resources (Rybach, 2003).

3. The Hódmezővásárhely municipal geothermal system (HMGS)

The HMGS is one of the oldest geothermal systems operating in Hungary and demonstrates their sustainable management. It consists of ten deep thermal wells to produce lukewarm water (30–32 °C) from 600 to 650 m, warm water (45–66 °C) from 1000 to 1500 m and hot water (75–90 °C) from 1800 to 2500 m depths. The thermal power capacity of this system is 10 MW_{th}. Two wells provide a municipal warm water supply to 3000 flats and several large communal buildings (city hall, schools, high schools, libraries, swimming polls and sport halls, etc.), three wells are used for medical purposes and balneotherapy, and two production and two re-injection wells supply a district heating system that serves the city with almost 50,000 inhabitants.

The first well for medical and district heating use had been drilled in 1954. The intensive use of 14 wells completed in the Upper Pannonian sandy aquifers in the 1970s and 1980s decreased the hydraulic heads continuously, which was the reason for initiating injection. As the system increased in size, new wells for providing the warm water supply and municipal heating were drilled, as were injection wells. This made it possible to investigate the effects of injection into the 1450–1700-m depth interval and also the sustainability of the system. The HMGS consists of several geothermal loops and operates a geothermal cascade system where the yearly production rate is 350,000–420,000 m^3/year. The thermal water demand of the city was slightly reduced after the reconstruction of the swimming pools' water system and the establishment of recycling used water.

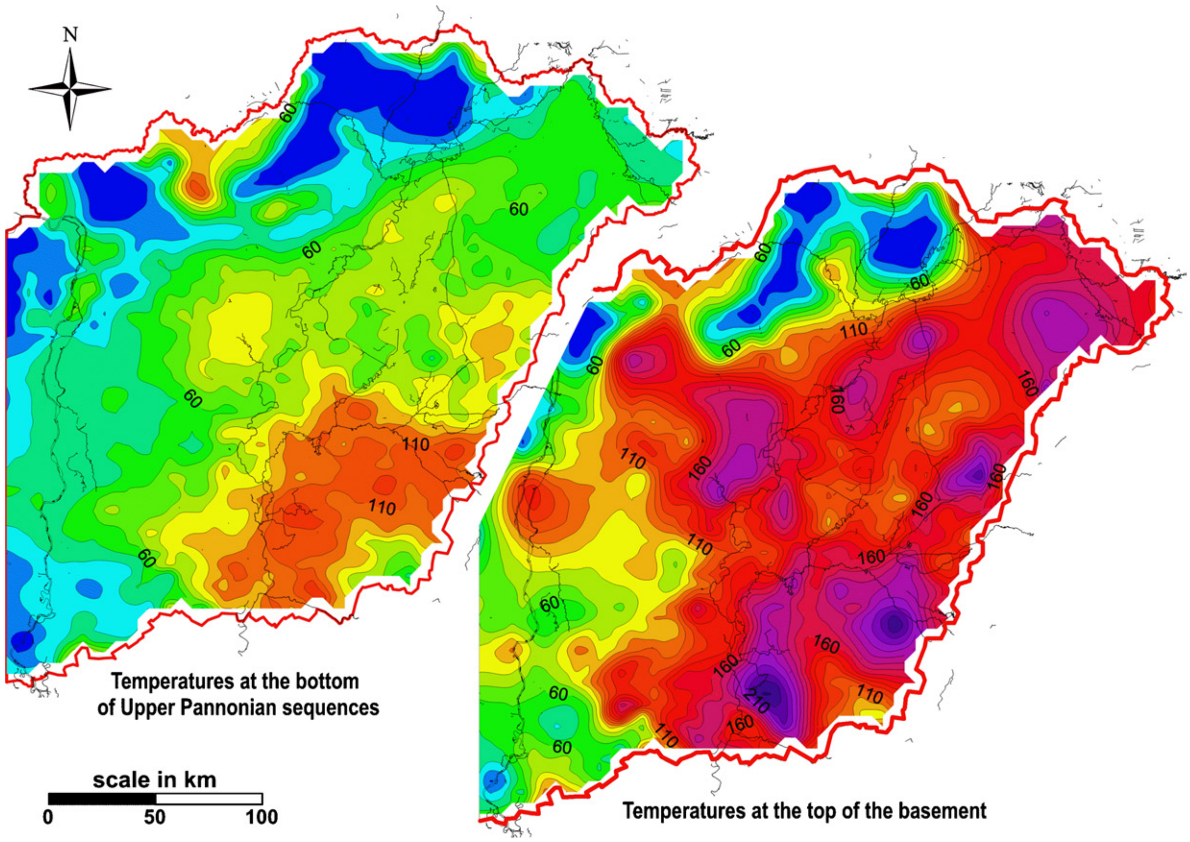

Fig. 3. Temperature distribution at the bottom of the Upper Pannonian sequences and at the top of the basement in Eastern Hungary (Rezessy et al., 2005).

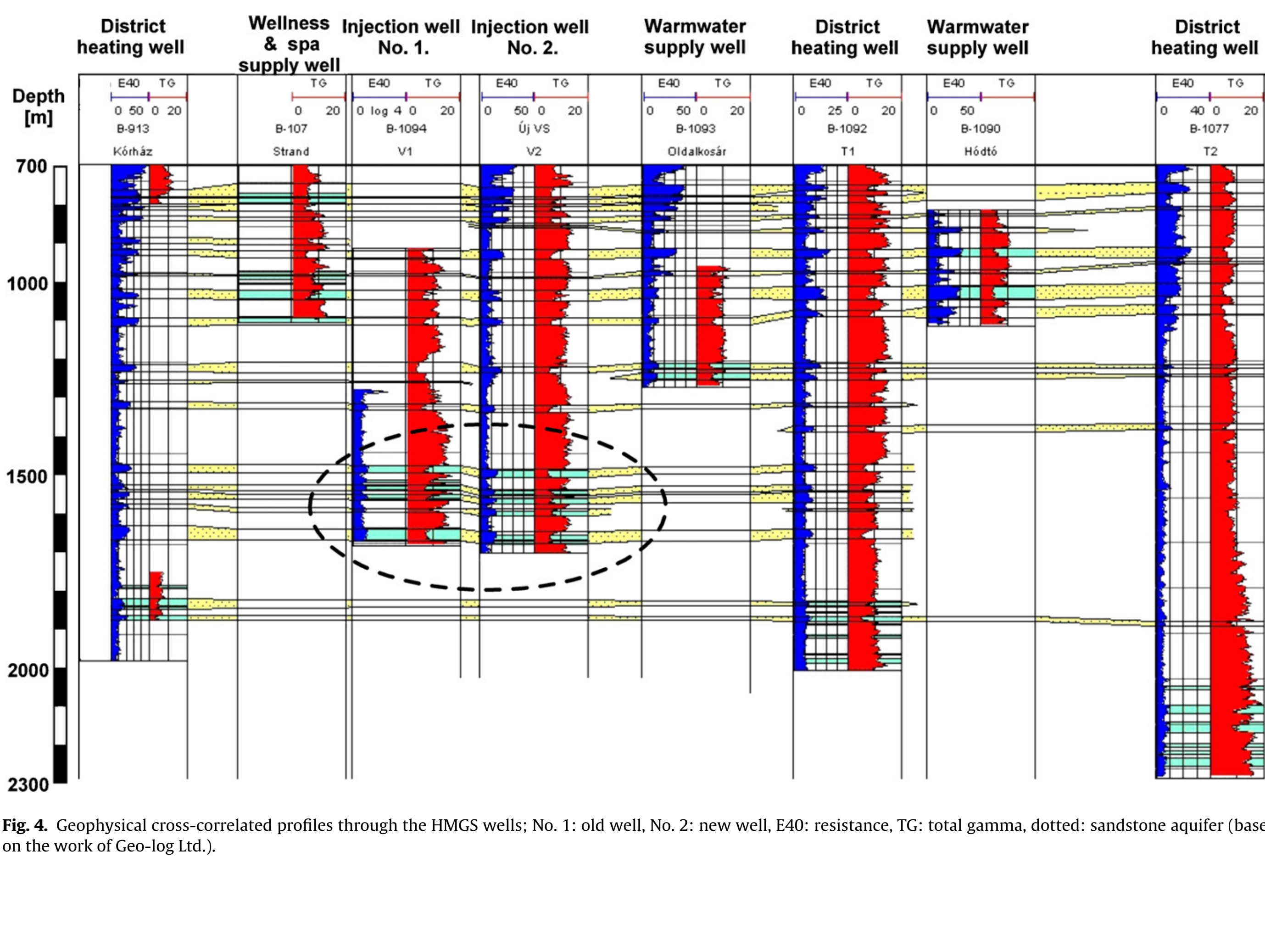

Fig. 4. Geophysical cross-correlated profiles through the HMGS wells; No. 1: old well, No. 2: new well, E40: resistance, TG: total gamma, dotted: sandstone aquifer (based on the work of Geo-log Ltd.).

Table 2
Comparison of produced and injected thermal water volume at Hódmezővásárhely site-I. (Szanyi et al., 2009).

Volume (thousand m^3/year)	1998	1999	2000	2001	2002	2003	2004	2005	2006
Thermal water production	423	360	330	355	389	379	366	374	350
Injected thermal water	94	113	115	106	278	286	280	259	253

The injection started in 1998, with one-third of the production recycled. Under constraints of technical development and relevant laws since 2002, 75–80% of the thermal water production, used predominantly for heating, has been injected. The injection pressure is 3 bar, and the specific injection flux is about 15 l/s/bar. Well maintenance using compressor cleaning is needed only every 2 years since the injected water is filtered using a microfiber filter system. Without the surface filters, the well had to be cleaned or revived almost every year. Using the microfiber filter system, well maintenance was considerably reduced. The pressure up steam of the filter is 4–6.5 bar, depending on the actual clogging of the filter, but at the wellhead, 3-bar injection pressure is maintained.

In 2008, a detailed, long-term pumping test (3 × 1 month periods) was performed using the two injection wells completed in the same aquifer and at a distance of 300 m from each other. The geological cross-section with geophysical log correlation shows that the old (No. 1) and the new well (No. 2) are completed in the same aquifer (hydraulic conductivity: $1.15–5.8 \times 10^{-5}$ m/s, effective porosity: 0.13–0.16) (Fig. 4).

In spite of the injection of 250,000–280,000 m^3 of water with a temperature of 30–45 °C (average 35 °C), no detectable temperature decrease occurred in the aquifer at 300 m distance from the injection well, because of the high heat capacity of the rock matrix. This result assures the company providing the public services that this system is sustainable, or at least, it has a long lifetime before thermal breakthrough could cause problems (Table 2).

The pumping test consisted of several different tests: long-term pumping of each well and observation of drawdown in the other well, cyclic pumping and recovery to determine the transient behavior of the aquifer system, and injection into each well separately and into both wells. Pressures and temperatures were measured both at about aquifer level (1200 and 1450 m) and at the wellhead; production rates monitored also.

The hydraulic parameters (hydraulic conductivity, transmissivity, storativity) of the aquifer system were determined and the hydrodynamic characteristics of the system were investigated from the pumping test. The cyclic test showed that the transient pressure signals are detectable at 300 m distance less than 20 s. The long-term well hydraulic tests revealed a significant vertical leakage into layers in which the wells are completed. The yields arriving from surrounding aquifers can reach 10–15% of the total production rate, which is very high and which shows the Upper Pannonian aquifer system is vertically connected by semipervious layers. The pumping tests show the shallower coldwater aquifers are in

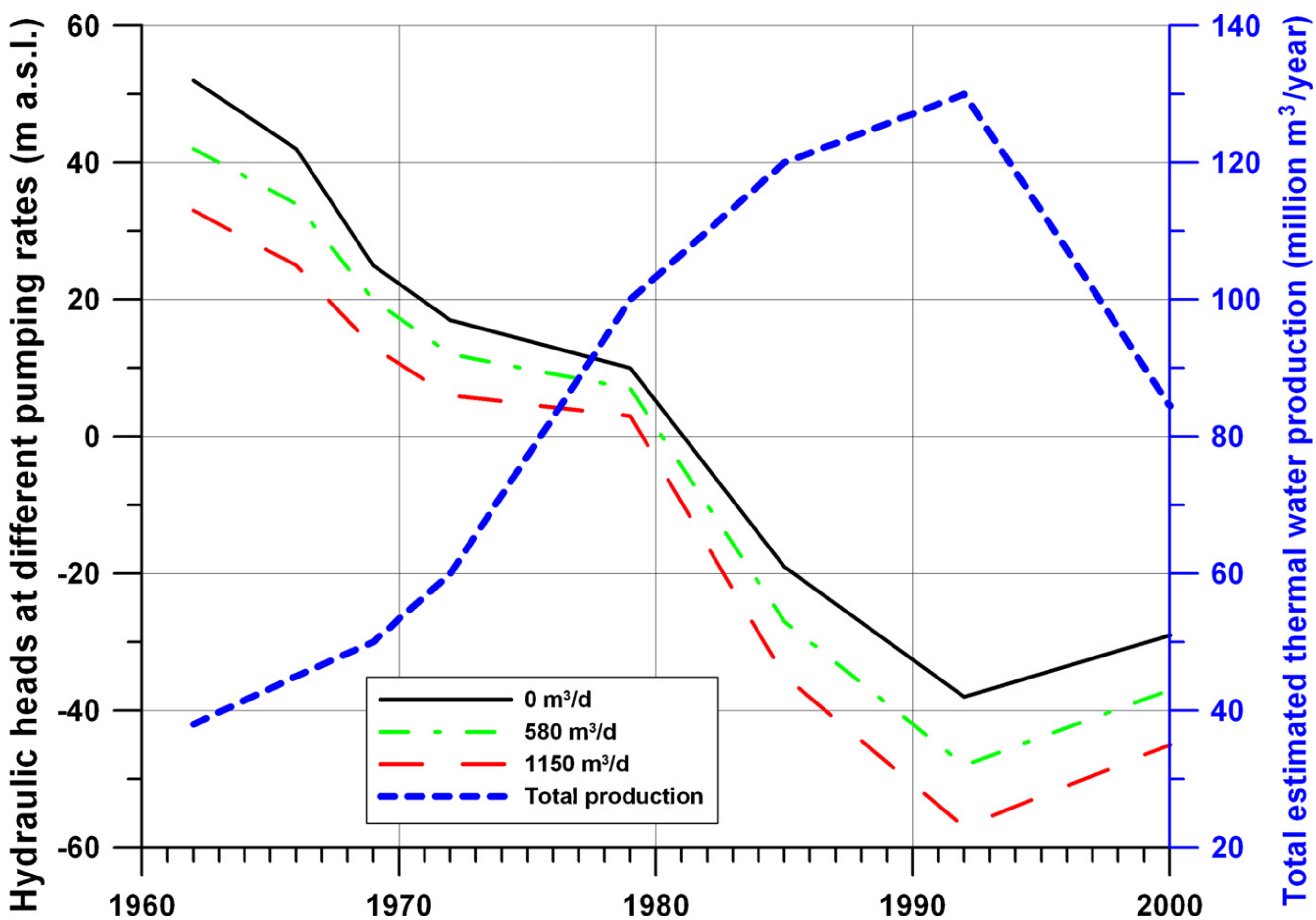

Fig. 5. Changes in measured hydraulic head for pumping tests of the Székelysor well with time for different well flow-rates, and the estimated overall thermal water production in Hungary.

hydraulic connection with the deeper thermal aquifers, and that it is possible that an overproduction of thermal water bodies could cause a long-term decrease in hydraulic heads in coldwater bodies above. In addition, it is also possible the overexploitation of drinking water layers could reduce the recharge of the thermal water bodies. Understanding this interaction of cold and thermal water aquifer systems is the key to sustainable management of subsurface waters in the Pannonian basin.

4. Geothermal energy use in and around Szeged

In the Szeged area, hydrocarbon exploration dates back to the 1960s, during which hundreds of wells were drilled to depths of 1500–3500 m. Approximately 40 nonhydrocarbon-producing wells have been perforated for thermal water extraction. More than half of these have been closed because applicable laws required drilling of injection wells for the disposal of the extracted water, costs of which the owners were unable to pay since subsidies were unavailable at that time.

Unfortunately, there is no accurate database on thermal water production in Hungary because of missing production and pressure gauges on the wellheads. The Székelysor well in Szeged is one of the few exceptions; it is well documented well test and hydraulic data are readily available. The increase of thermal water production in the vicinity of the Székelysor well has dramatically decreased the hydraulic head. To demonstrate the general process Fig. 5 shows the hydraulic head of the well and the estimated thermal water extraction of Hungary vs. time, for comparison, on the same chart. This figure shows that increasing thermal water production led to continuously decreasing water levels until the early 1990s. After the water production decreased in the early 1990s, the hydraulic head started to recover. The increase in water production taxes in 1992, and the introduction of a fine on wastewater disposal into surface waters forced thermal water producers to optimize or reduce withdrawal, or to discontinue thermal operations. The hydraulic head decreased by 90 m (the highest recorded decrease in all thermal wells perforated in Upper Pannonian sandstone in Hungary) from 52 m a.s.l. in 1962 to 38 m b.s.l. in 1992. Meanwhile, the average static water level decrease detected was 30–50 m.

5. The use of geothermal resources in Szentes area

The use of geothermal resources began in 1958 in the Szentes area, where currently 20 wells produce water over 60 °C, and another 12 wells produce water over 90 °C. At the start, the hot water was only used for warm water supply; later the utilization became more complex and a thermal-water-based communal heating system was also established. At present, both the communal heating and the warm water supply systems work with heat exchangers. As a result, the running expenses of the heating centers decreased significantly, and the release of gases was also reduced. By 1987, the municipal system supplied 1300 flats, and communal buildings equivalent to 1500 flats. The area is well known for geothermal heating of 30 ha of greenhouses, and another 30 ha of agricultural plastic tube systems. The heat is also used in 35,000 m^2 of poultry yards. The thermal water production at its peak was 6.5 million m^3/year; but today it has decreased to 5.7 million m^3/year. There is no injection at all; the used water is

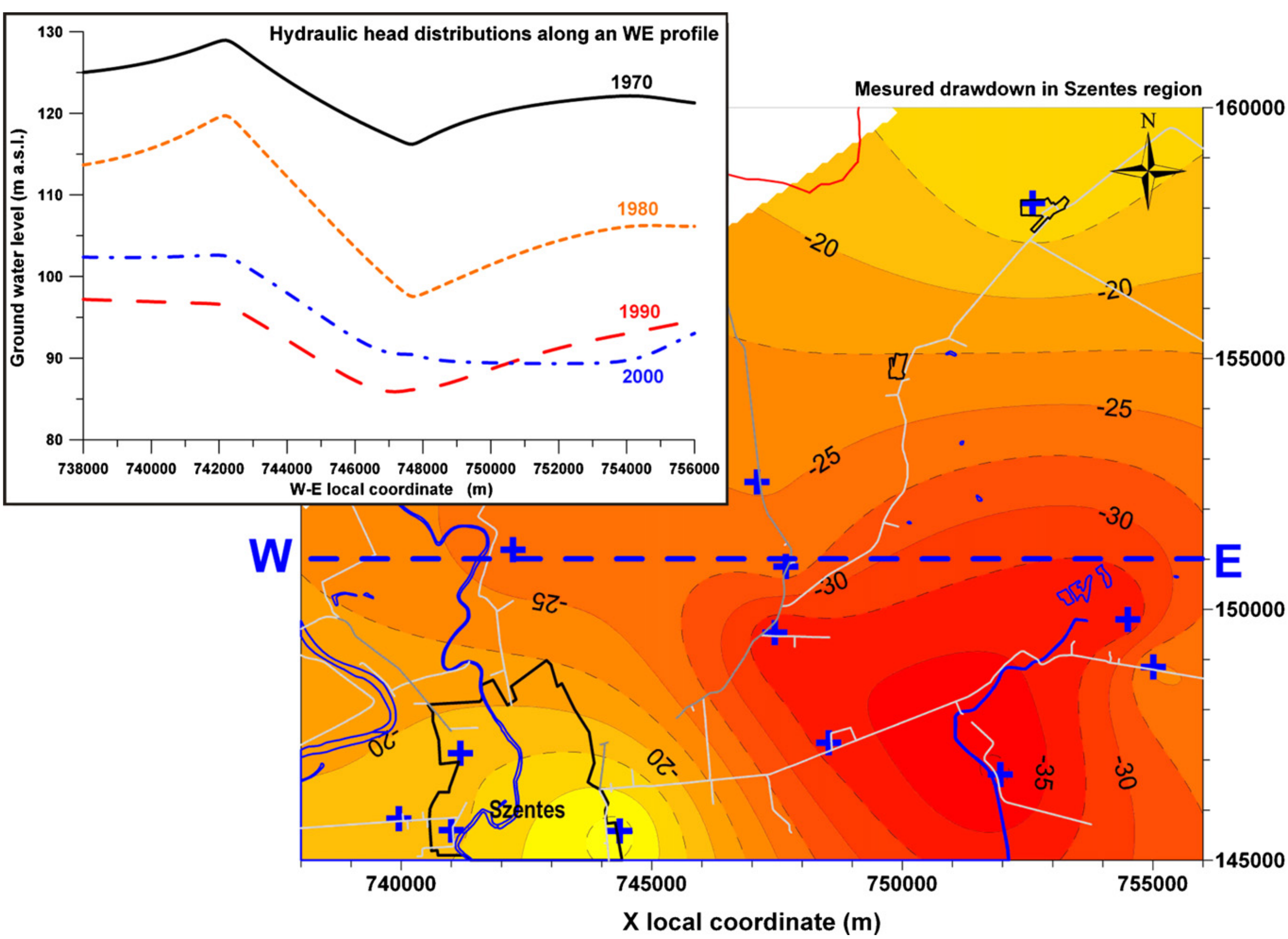

Fig. 6. Changes in the drawdown at Szentes from the 1970s along an EW profile and the shape of hydraulic depression cone in 2000. For map location see Fig. 7.

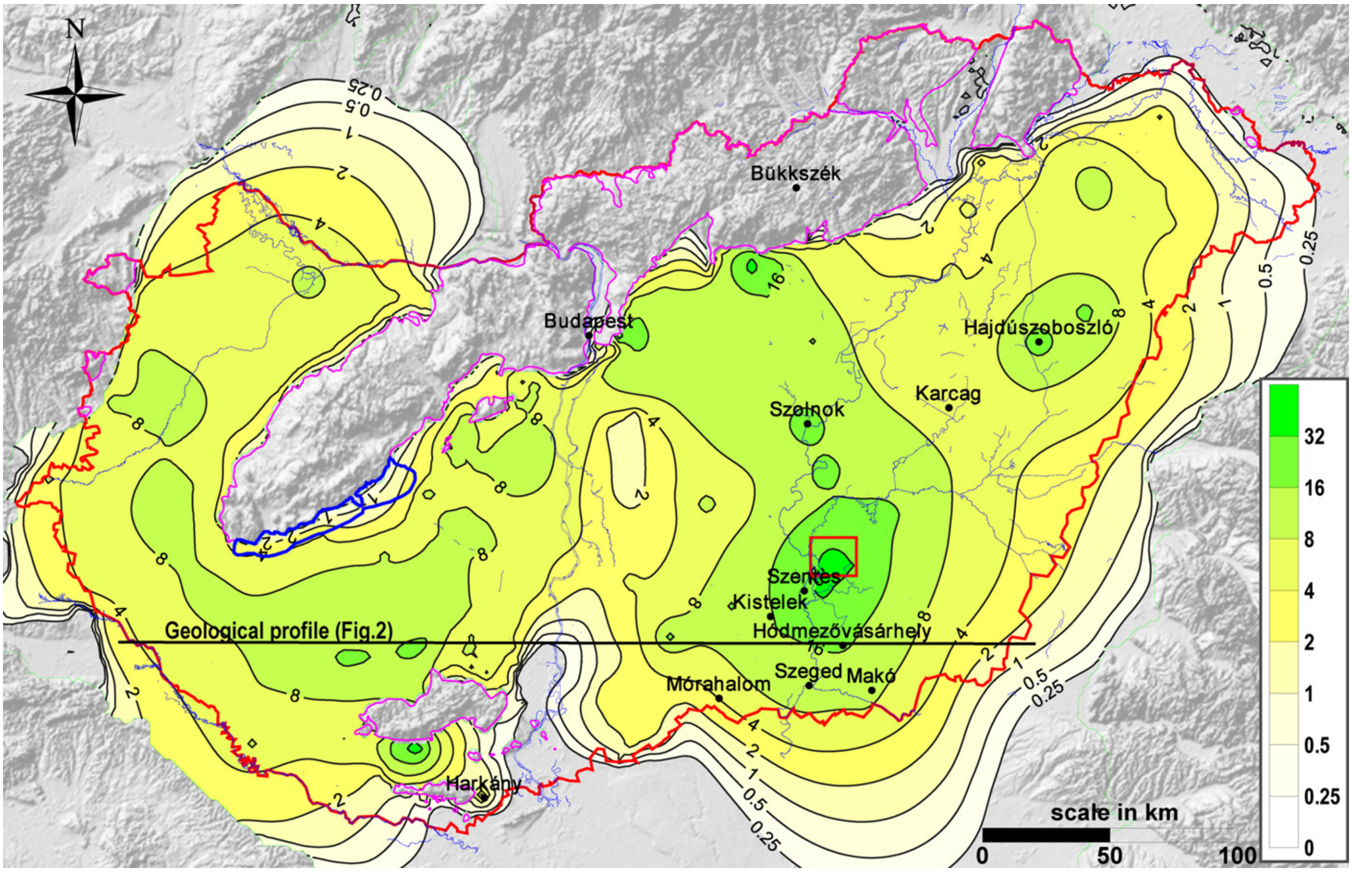

Fig. 7. The calculated drawdown (meters) at the bottom of the Upper Pannonian sequences (Tóth, 2009). Also shown is the location of the geothermal sites discussed in the paper and geological profile of Fig. 2.

sent to a small creek called Kurca and to two lakes with a surface area of 40 and 100 ha.

The high density of wells and their long-term operation (40–50 years) makes the Szentes area a very suitable region for research on the decrease of hydraulic head caused by thermal water withdrawal. Unfortunately, no regular data collection or well tests have been carried out in this region. Thus, 13 wells out of 32 were selected with perforations at 1800–2200 m and with hydraulic head measurements at least every 5–10 years. Since simultaneous measurements have not been performed, data for four time intervals have been chosen (1965–1970, 1978–1983, 1988–1992 and 1998–2004), and changes in the hydraulic heads along a profile were plotted (Fig. 6).

The decrease of hydraulic heads reached its maximum in the early 1990s, with 25–40 m drawdown. Later, the heads increased 4–8 m due to decreasing thermal water production up to 2000. Today, the measured decrease in hydraulic heads is 12–38 m (Fig. 6).

6. Conclusions, future tasks and sustainability

Based on more than 100 years of thermal water exploration and production in Hungary, several conclusions concerning sustainability can be drawn.

Hungary's huge, but only partially exploited, geothermal potential is based on thermal waters both in high-porosity aquifer systems and in fractured formations in the basement. Since this situation is rather unique in the European Union (EU), the geothermal development in Hungary differs slightly from other countries, where mostly EGS-type geothermal power plants would use fractured rocks or carbonated reservoirs at great depths. In Hungary, the focus must also be on medium enthalpy systems that supply large municipal district heating and warm-water systems, in addition to spa and wellness establishments (Lund et al., 2005). However, another goal of development is to generate electric power at high enthalpy sites.

The currently available data (Tóth, 2009) show that a period of over 30 years of over exploitation of the porous thermal aquifer system led to an average 30–50 m (peak 90 m) decrease in hydraulic heads (Fig. 7). After reduction of the thermal water production, hydraulic recovery of the system began. The pumping out more thermal water from the reservoirs than was received from recharge, resulted in unsustainable resource management.

Since the geothermal resources inventory showed more than 90% of the Hungarian thermal energy reserves are stored in the rock matrix, the only way to extract this energy is to use injection to keep the hydraulic head at an acceptable level. Injection is the key element for increasing the geothermal heat use of the medium-enthalpy systems. Since injection into the porous Pannonian aquifers can be technically problematic, according to the experiences in Germany, Northern Italy, Denmark, and Northern Poland (Seibt and Kellner, 2003; Ungemach, 2003), the sustainable path for long-term injection has to be worked out based on local experiments. The 10 years of experience in HMGS described above shows that long-term sustainable injection is possible, but instead of ad hoc approaches, scientifically sound solutions must be found.

Comparative analysis of areas with and without injection has shown that the gravity-driven hydraulic system's vulnerability varies with location. At some sites the local decrease of hydraulic heads can be rather slow compared to the thermal water production, but since the whole gravity-driven sedimentary system is one continuous hydrodynamic unit, it is just a question of time when harmful effects will be detected.

The analysis of available data has shown that the current information for Hungarian thermal wells is insufficient; the hydraulic heads, the yields, and the volume of production data are not measured in many regions, and only estimates are available. One of the urgent tasks is to establish a monitoring network of hydraulic potentials and temperatures using abandoned hydrocarbon and thermal water wells, and to organize the data from the national monitoring system in a central database. The well owners should be required to perform head, temperature, yield, and production measurements using data-loggers in order to provide accurate information on the thermal water bodies delineated by the Hungarian Water Framework Directives.

Acknowledgements

Most data for the work reported in this paper were provided by local Water Authority ATIKOVIZIG, and some by György Gruber and Mihály Kurunczi. We appreciate the support of György Tóth from the Hungarian Geological Institute. The project was financially supported by the Hungarian National Technology Program (No. TECH_08_A4 DA_THERM), and the NKTH (No. DA_HALO_06/007_GEOTERMA)

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