D.7.2.1. Summary report on the results of testing of the Decision Tree for the pilot areas

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Content

1. Introduction

The main aim of the Decision Tree tool is to raise the awareness on the complexity of geothermal project development and educate the readers what kind of various decision gates might occur during project development. The tool is presenting the most likely occurring questions during the project development from the initial idea until the geothermal system is set up and running. The type of questions is referring to the four most important fields:

1. Resource: including technological aspects of the subsurface and the surface part of the system,
2. Market: referring to the aspects of selling the product of the system, in our case the heat
3. Licensing: permitting, procurement of licences to be submitted to the relevant authorities,
4. Funding: aspects of project financing.

In this report we sumarize the main results of testing of the Decision Tree tool based on certain real, or future planned projectsin the three cross-border pilot areas. At least one project from each pilot area was selected.

2. SI-HU-HR pilot area

2.1. Krapinske Toplice (HR)

2.1.1. Introduction to the area / current project

Krapinske Toplice Municipality is one of the 32 local governments of the Krapina-Zagorje County, situated in the northern part of Croatia, where a significant geothermal potential is known with the average geothermal gradient of 0.049°C/m and terrestrial heat-flow density of 76 mW/m^2. Thermal springs of Krapinske Toplice occur in a narrow valley of the stream Topličica. There are three main springs and a few smaller springs of lower yields. The development of tourism has been based from the very beginning on the use of these thermal springs. The first bath was built in 1772. Real tourism development started in 1862, when Jacob kupelj new baths, hotel and health resorts were built. In that period Krapinske Toplice became a modern health resort within Austro-Hungarian monarchy. The era of modern tourism development began in 1956, when a hospital department for rheumatic diseases and orthopedic rehabilitation was established.

Today in Krapinske Toplice, the thermal water from springs is used in:

- the Special hospital for medical rehabilitation Krapinske Toplice, which uses thermal water in therapeutic treatments, swimming pools and for space heating of hospital using the heat pumps
- Clinic Magdalena next to the Special hospital uses geothermal water for space heating
- Waterpark Aquae vivae of 18.000 m^2 of closed space, which uses water for swimming pools and for heating the entire complex

Also, 5 km from the thermal springs in Jurjevac village, Company Samek Ltd. uses thermal water for heating of greenhouses for tomato production (water temperature at the well head is around 33°C). The company drilled a new well and the yield is 8 l/s.

Thermal water is used for water supply of 271 households in Krapinske Toplice.

Within previous investigations (Mraz et al., 1998), five exploration-piezometric wells were drilled in the vicinity of the thermal water springs. Below the Quaternary alluvial-diluvial deposits, Sarmatian marly limestone/limestone marl occur, and their thicknesses ranges from 3.9 to 7.8 m. Due to the tectonic activity, secondary porosity developed in these Miocene sedimentary rocks, and they are very permeable. Beneath them (after 60 m) Badenian Lithothamnium limestones and Triassic dolomite occur (Figure 1). Triassic dolomites represent the primary geothermal aquifer, the fractured limestones of Badenian age - which are often transgressive on the Triassic deposits - represent the secondary geothermal aquifer. They are also the source of cold water which is feeding the underlying Triassic geothermal aquifer. Quaternary alluvial deposits (sandy clay with conglomerates) are low-permeable deposits, but they still allow the flow of ''cold'' groundwater from the hinterland and the mixing with thermal water occurs (Larva et al., 2018).

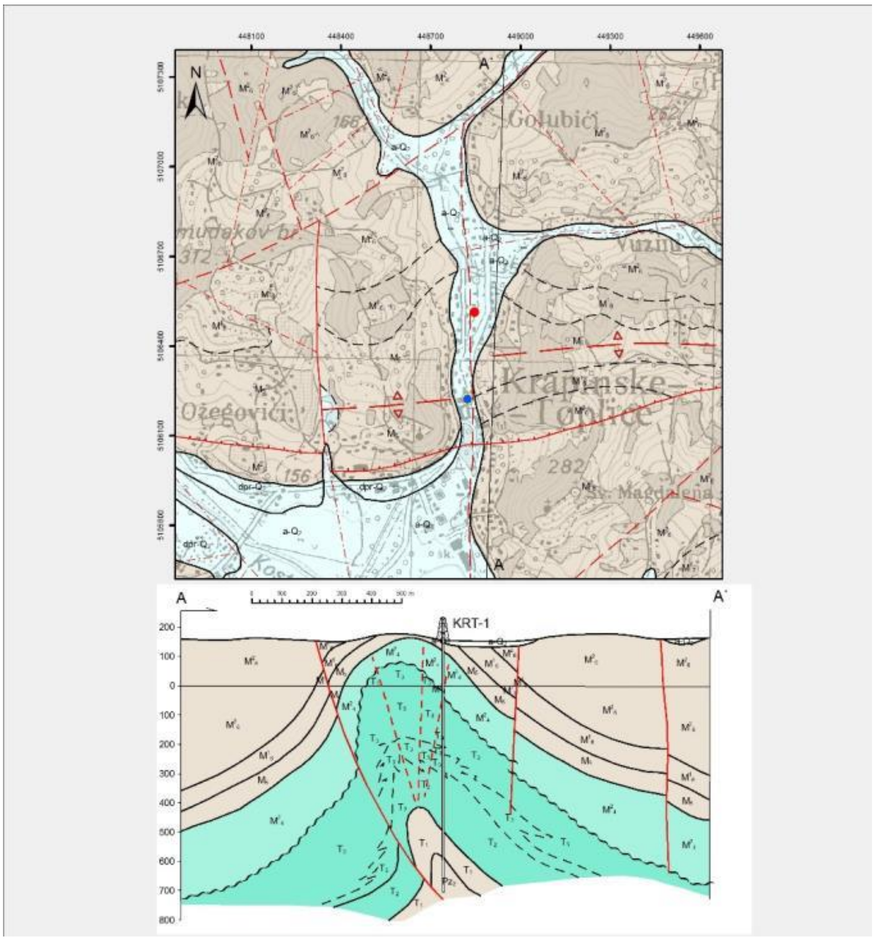

Figure 1. Shematic hydrogeological map of the spring area (modified according Šimunić, 2008)

The main thermal springs are Pučka and Jakobova kupelj. In 1879. Vukasović stated that the total yield of springs are 46 l/s. Bać & Herak (1962) estimated the total yield around 81 l/s. In 1986 deep well KRT-1 (862.5 m) was drilled about 250 m north from the thermal springs. Britvić in 1986 performed the pumping test and measured the yields in springs and well. The measured yields were Pučka kupelj – 26 l/s and Jakobljeva kupelj 10 l/s. The interaction between borehole and springs was observed. In 1995 Capar et al., reinterpreted the results of this pumping test and defined new amounts:

- Pučka kupelj (pumping) and Jakobova kupelj (natural outflowing) 51 l/s
- Borehole KRT-1 (pumping) 24 l/s

The most recent measurements (Larva et al., 2018) have determined the following yields:

- Pučka kupelj – 38 l/s (natural outflowing)
- Jakobova kupelj – 10.4 l/s (natural outflowing)

The total amount of natural outflowing at the thermal water source is 48 l/s and does not differ significantly from the previous measurements.

Hydrochemical features of Krapina's thermal water are the consequence of the mineralogical-petrographic composition of sediments that are building the thermal aquifer. Spring water by its ion composition belongs to CaMg-HCO_3 (calcium-magnesium bicarbonate) type of water. Old and new chemical analysis of the water showed that the water type has not changed over the years.

The Special Hospital for Medical Rehabilitation, in accordance with the concession, uses the total amount of 534 500 m^3/y (for water supply up to 183 950 m^3, for technological needs up to 287,300 m^3, for health and recreational needs up to 63,250 m^3). The hospital has heat pumps: GEA HAPPEL type EUWH 240FSD - 1992.god. - COP 3.6 - which use thermal water (water from 40^{o}C is heated to 60^{o}C – delta T= 20^{o}C) for space heating, but only at night and during the wintertime.

The water park Aqua Vivae uses thermal water for swimming pools and heating of the entire complex of 18.000 m^2. The water temperature at the inlet of the park is around 40.5°C. The temperature of the outlet water (waste water) is 28°C. In the water park, the energy difference of water is 12.5°C. For 12.5°C, in the winter it takes up to 100 m^3 of water to keep running for normal operation, that is equivalent of 1.2 MWh. Water used for swimming in swimming pools first goes to the hottest pool, then to less hot and finally to the coolest swimming pool. The heating in the water park is performed in the way that the heating condensators (accumulators) use the bottom plate of the water park in which 50 km of pipes were built-in for under-floor heating. The bottom plate is made of concrete, and has a mass of 5 000 tons and a volume of 2 700 m^3. It is heated during the night (when the prices for electrical energy are at their lowest) to a temperature of 33°C, and during the day it cools down to 30°C. This way the thermal energy is stored at the lowest part of the premises that ensures the natural circulation of hot air from the floor to the ceiling, where the air conditioning chambers suck in the heated air and transport it to the previously mentioned recuperators. Then there is a roof and wall thermal insulation that reduces mechanical and static losses to a minimum. The primary construction goal is to achieve the building of a complex with an integrated thermal insulation that ensures very low thermal conductibility. The insulation of the outer walls is designed in such a way to achieve a high very coefficiency in the passing of warmth through the wall's material. This coefficiency is = 0.26 W/m^2K. On the vertical walls, we have 60 mm thick glass bricks, with a coefficiency of: 0.9 W/m^2K. The roofs are made up of a laminated wood construction and are insulated in such a way that they have a coefficiency of: 0.2 W/m^2K. The glazed areas of the roof are designed with triple-glazing to lower emission so that the coefficiency of the passing of heat in that part of the roof is 1.1 W/m^2K. From the heat leaving the water park, which still has a temperature of 28°C and which can be cooled by 20°C further, another 2.2 MWh energy can be obtained for some another object. Water temperature is exploited to a temperature of 8°C when it can no longer be used.

All the apartments at Villa Magdalena Hotel have jacuzzis in rooms that are using the thermal water from the spring, and the temperature in jacuzzis is around 39°C. Annual consumption of thermal water satisfying these needs is 4000 m^3. Unfortunately, Spa & Wellnes center Villa Magdalena has no built infrastructure to use the thermal water for the heating of the whole building.

2.1.2. Planned future project

Water park will build new apartments for accommodation in the vicinity of the exisiting water park that will need to be heated during cold months using T= 29°C. The average number for days when heating is need is 223 days. The total average pumping rate is 25% of total amount that naturally outflows from springs, and the maximum pumping rate is 50% of total amount that naturally outflows from springs. At the moment for heating the Park is using 267.7 MWh. In the new conditions, it will be 711.4MWh in total, so it is necessary to provide additional 443.7 MWh. Assumption about the volume of the thermal aquifer is based on spring data, well data, geological mapping data, chemical and isotopic data, pumping tests data.

2.1.3. Reults of the Decision Tree testing

The planned project can easily decide on procuring the exploration permit, as the resources are well-known, hydrogeolocal parameters are available with a good level of confidance, the heat market conditions are promising (existing deamands), and the basic knowledge about funding possibilities and licensing propcedures is available. The only restriction for future exploration is the protection zones of the thermal springs.

Decision on heat purchase agreement mainly depends on financial issues: if funds for project development and drilling of the first well are available, than there should be a green light to carry on. The success of the further phases of project development (construction of wells and the surface system) mainly depend if the development can meet the criteria of suitable market conditions and available funding, as well if hydrogeological tests and model updates confirm the availability of the resource.

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2.2. Moravske Toplice (SI)

2.2.1. Introduction to the area / current project

Moravske Toplice is located in north-east Slovenia in the Mura-Zala basin, which forms a part of the western sub-basin of the Pannonian basin extending in north-east Slovenia, north Croatia, south-west Hungary and south-east Austria (Figure 2).
The most productive and exploited geothermal aquifer is the transboundary Upper Pannonian loose sandstone aquifer of the Mura Formation, named also the Transboundary Thermal Groundwater Body Mura-Zala. Extent of this aquifer is estimated to be as much as 22,175 km^2 altogether in Austria, Croatia, Hungary, Slovakia and Slovenia, of which only 1,766 km^2 is in Slovenia (Tóth, 2016). It reaches maximum depths of 2.5 km in the Ptuj-Ljutomer-Budafa sub-basin, near the Slovenian-Hungarian state border. These hydraulically connected coarse-grained lenses were deposited between silt and clay, forming a 50-300 m thick sequence of delta front environment (Figure 3). Thermal water with active gravitational regional groundwater flow regime was recharged in the Pleistocene and flows through loose sandstone with good intergranular porosity (up to 30%) and hydraulic conductivity (between 10^{-5} and 10^{-6} ms^{-1}) from Slovenia to Hungary (Rman, 2013). Regional monitoring of observation wells has shown that wells producing from Mura formation aquifer are hydraulically connected. Therefore, interference must be accounted for modelling the long-term productivity of the aquifer (Rman, 2016). The thermal water is of Na-HCO_3 type with mineralization below 2000 mg l^{-1} and almost no free gas. No major scaling or corrosion is observed, and no additional geochemical treatment of water is needed (Rman et al. 2016). Thermal water from this reservoir with temperatures up to 65 °C at the wellhead is produced for direct use at 10 user sites in Slovenia. Even though deterioration of the aquifer's quantity state is evident at least locally also in Moravske Toplice area, therefore it is expected that only reinjection will enable current production rates in future (Rman, 2016, Rman et al. 2016).

The second important aquifer in the region is the Badenian to Lower Pannonian Špilje Formation. This local aquifer of limestone and turbiditic sandstone does not form a part of the active regional flow system. It has a predominant fissure porosity. Thermomineral waters from this formation are tapped with six 400 to 1300 m deep wells in Radenci and at two sites in Moravske Toplice. In the first temperature does not exceed 35 °C while it reaches 77 °C in Moravske Toplice. A diluted brine of Na-Cl and Na-HCO_3-Cl type in Moravske Toplice is probably the oldest infiltrated water in the basin and has a high TDS of up to 15 g/l. The water has been modified by evaporative conditions during its recharge and shows very strong water-carbonate-CO_2 interaction as large amounts of CO_2 gas are emitted along the Raba fault zone. Large volumes of degassing CO_2 at the surface cause rapid carbonate scaling in surface installations (Figure 4). High TOC and some methane content in this water are expected as the site was primarily explored for hydrocarbons (Rman, 2016).

In the area of Moravske Toplice both waters are used for individual space heating, sanitary water heating, balneology and bathing in Terme 3000 spa and hotels. Part of their waste water is supplied to tomatoes greenhouse of Grede Tešanovci Co.

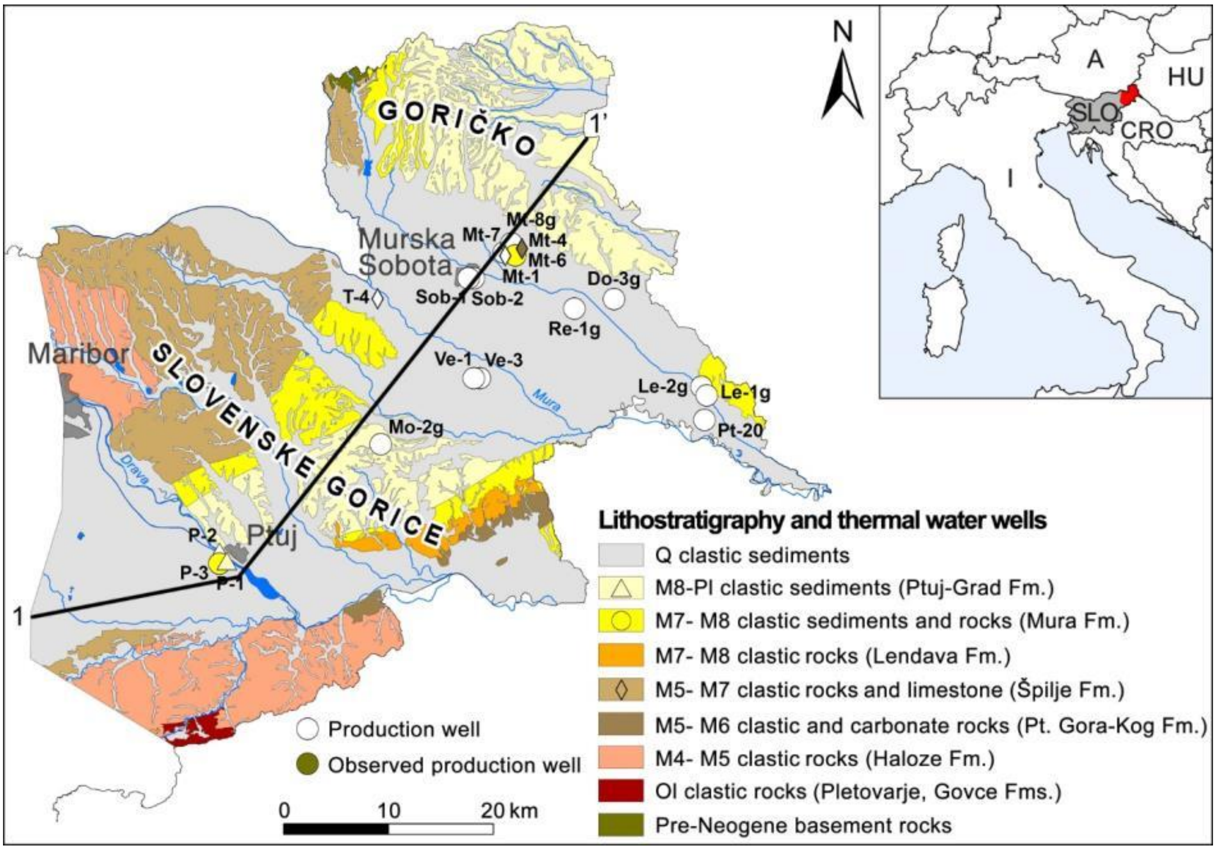

Figure 2: Simplified surface lithostratigraphic map of NE Slovenia (modified from Jelen and Rifelj (2011)) with locations of active geothermal wells open in the Neogene geothermal aquifers (source: Rman, 2016)

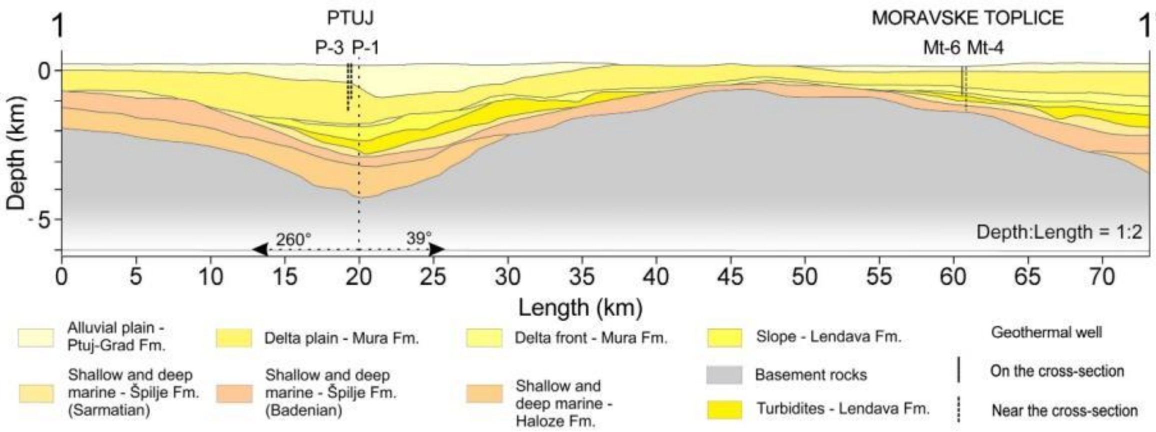

Figure 3: Schematic lithostratigraphic cross-section in SW-NE direction with location of geothermal wells positioned directly and near the cross-section. Evidently two aquifers are tapped in Moravske Toplice (source: Šram et al. 2015)

Figure 4: Scaling from thermomineral water from Badenian sandstones (photo: N. Rman).

In Moravske Toplice itself five thermal water wells are active in Terme 3000 Spa and one more in a near-by Terme Vivat (Figure 5). These are Mt-1/60, Mt-4/74, Mt-5/82, Mt-6/82, Mt-7/93, and Mt-8g. The first three, and the bottom section of Mt-8g produce water from Špilje Formation while the last two and the top section of Mt-8g from the Mura Formation aquifer.

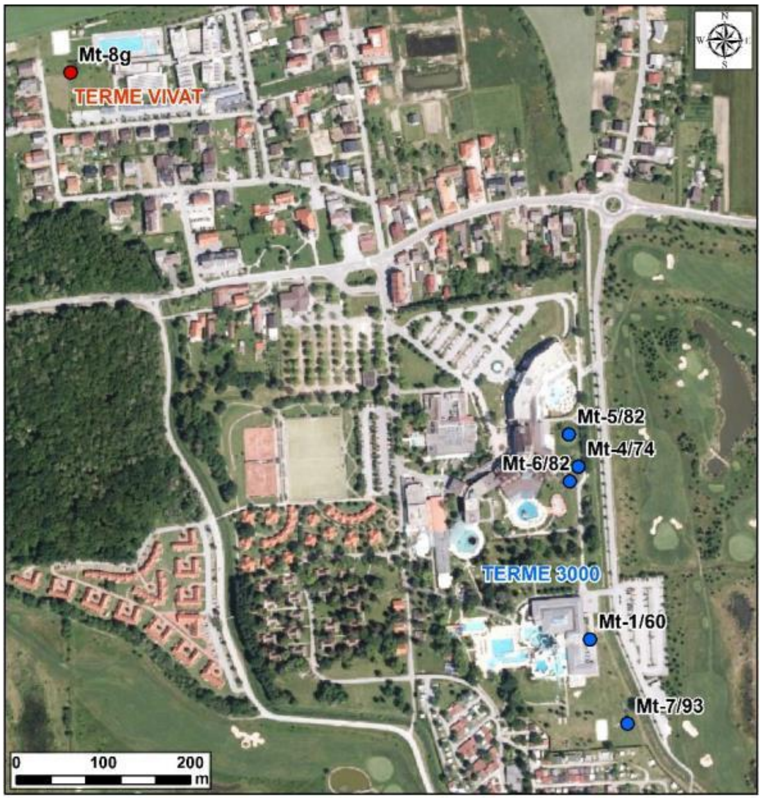

Figure 5: Locations of geothermal wells in Moravske Toplice which are managed by two users

Wells Mt-1/60 and Mt-8g are vertical, wells Mt-4/74 and Mt-5/82 are inclined and all produce from vertical depths between 1100 m and 1300 m (Figure 6). Mt-5/82 is not planned to be an operating well anymore and was turned into an observation well in 2018. Maximum discharge of these wells is rather low, mostly between 1 and 5 l/s.

Vertical well Mt-6/82 (Figure) and inclined one Mt-7/93 produce water from vertical depths between 700 and 1000 m.

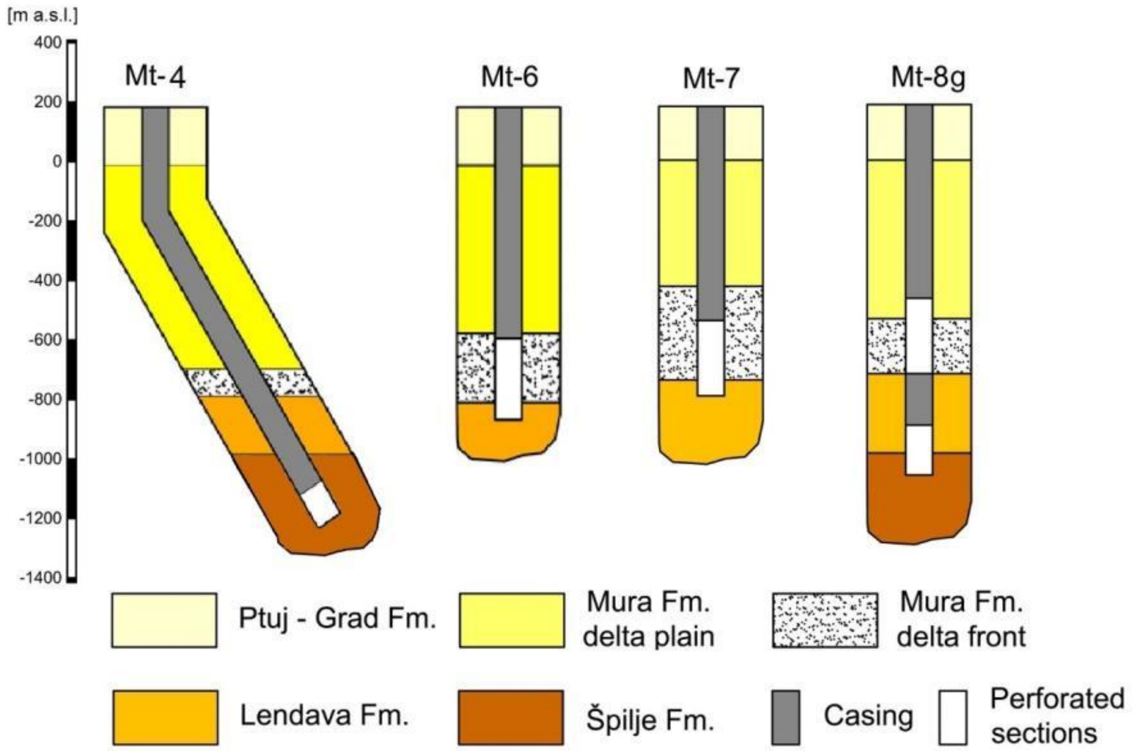

Figure 6: Schematic lithostratigraphic columns of some investigated multiple-screened geothermal wells. Mt-8g from a neighbouring Terme Vivat has a special design so it produces two different waters through two tubings from only one well.

Properties of wells' depth and reservoir thickness are given in Table 1 (Rman, 2013). The oldest well is almost 60 years old, the youngest over 25 years, therefore we expect that investment into makeup wells will be needed in the following decades to ensure currently abstracted thermal water quantities.

Table 1: Production wells depth and reservoir thickness

Production well	Vertical depth (m)	Screened section (m)	Reservoir thickness (m)
Mt-1/60	1417	1115-1263	119
Mt-4/74	1289	1176-1263	87
Mt-5/82	1302	1090-1246	156
Mt-6/82	974	720-974	254
Mt-7/93	991	751-985	234

Production parameters are given in Table 2.

Table 2: Production parameters (Anonymous, 2015, Rman, 2016, Rman et al. 2016)

	Mt-1/60	Mt-4/74	Mt-5/82	Mt-6/82	Mt-7/93
Actual Q [l/s]	1-4	1-4	0	15-31	12-31
max. granted Q [l/s]	2,8	3	6	14,9	9,5
Actual production [m³/year]	Cca 150,000		0	Cca 800,000	
Max. granted production [m³/year]	88,000	100,000	50,000	469,000	299,000
Wellhead temperature [°C]	72-77		/	52-59	

Thermal water in Terme 3000 is used in a cascaded system in several stages (Figure 7), and it is a rather complicated system (as new buildings and pools were erected sequentially). Water is used for indirect heating of space and swimming pools which produces so called geothermal waste water, and for direct heating of swimming pool water (which means also for filling the pools). The latter produces pool waste waters, which are also mixed with technological fresh water. Waste water is chemically treated and cooled down prior being emitted into the brook Lipnica. At the last stage of heat production, geothermal waste water is used for heating a 1 ha greenhouse of Grede Tešanovci (Rajver, 2017).

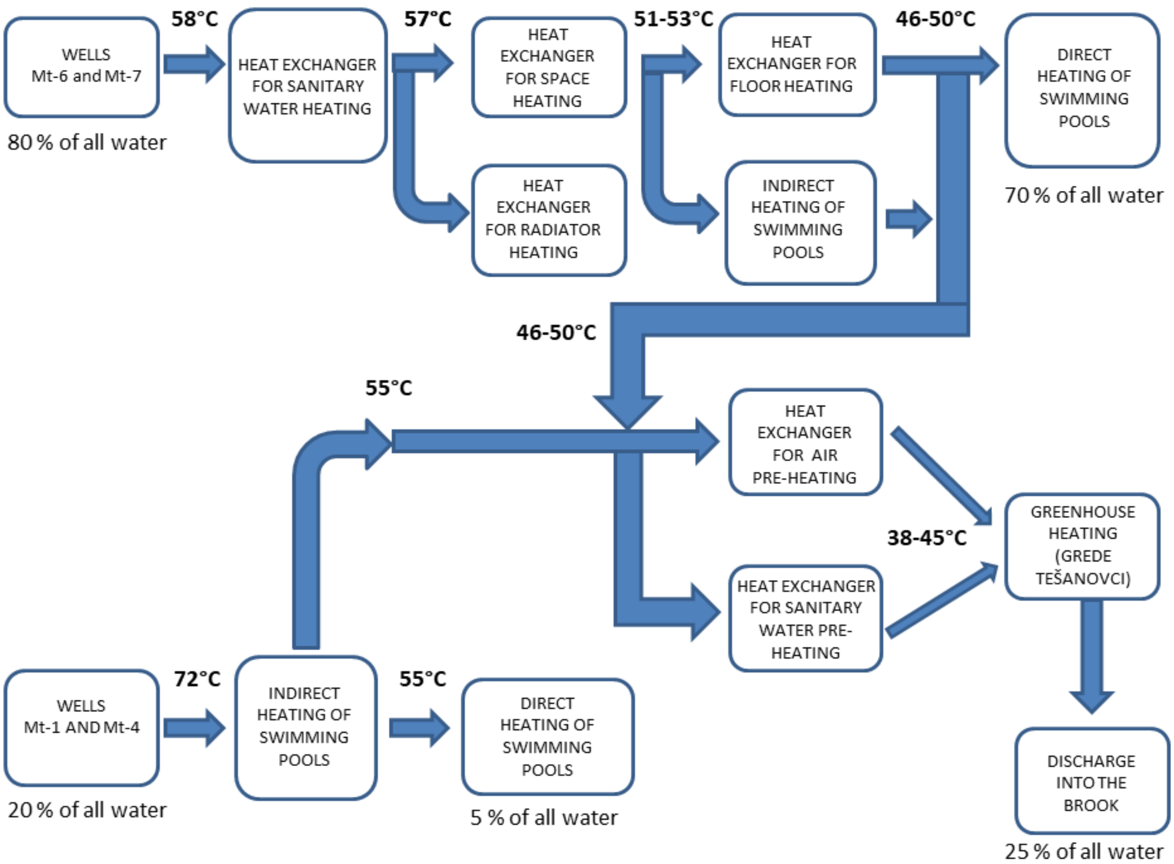

Figure 7: Scheme of thermal water use in Terme 3000 Moravske toplice (source Rajver, 2017). Waste water temperature is 25-30 °C.

2.2.2. Planned future project

The planned future project is a continuation of the current production, with an additional technical solution – a new reinjection well to be established in the Upper Pannonian loose sandstone aquifer. It will inject a major part of the waste geothermal water (about 80 %) and keep the aquifer pressures high enough for long-term future production. Production quantity will not change. The new reinjection well will have to have a continuous injection rate probably between 15-25 l/s and a large storage tank with micro-filtering system prior to the well, similar to the Le-3g well in Lendava, as the aquifer is of the same type. It will compensate large momentary production rates in winter months, when they may exceed 40 l/s in total for both wells, Mt-6/82 and Mt-7/93.

There is already some experience available about reinjection in the area. Mt-7/93 was primarily drilled as a reinjection well into the loose Upper Pannonian sandstone. The occasional reinjection of 35 °C waste thermal water from Mt-6 into the hydraulically connected Mt-7 occurred between 1994 and 1997. The reinjected amount was evaluated to be 10-30% of the abstracted one. The rather low return was attributed to improper installation of a centrifugal pump in the reinjection well. Later, Mt-7 was changed into a production well due to higher heat and thermal water demand in the year 2000 and has been producing water ever since (Rman, 2013, Rajver, 2017). In Moravske Toplice, no reinjection of thermal water is currently preformed, only in Lendava (Rman et al. 2015).

2.2.3. Reults of the Decision Tree testing

No new geological studies are needed to make the project successful as site-specific experience exists. Needed technology for a new well is known as well Mt-7 was built as a successful reinjection well in 1993 and was tested to some extent but it did not reach the needed 80% reinjection rate, only up to 30 %. No documentation for a new reinjection well has yet been prepared and no needed permits are yet applied for, but will be granted for a reinjection well with proper testing and documentation.

The main barriers in project development are related to the funding aspect. Current extraction is economic only without drilling new wells. Any new drilling has to be outsourced, which is expensive - cca 2 million €. Subsidy for a reinjection well would significantly improve economics of the project. Without some subsidy, it would probably not be drilled. The price of the Water concession fee with reinjection will be much more favourable than without it, as currently.

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3. HU-RO-SRB pilot area

3.1. Lovrin (RO)

3.1.1. Introduction to the area / current project

The area is located in the westernmost corner of Romania, Banat region (Figure 8), where the transboundary geothermal aquifer of Basin-Fill type is hosted in sands of mainly Upper Pannonian age.

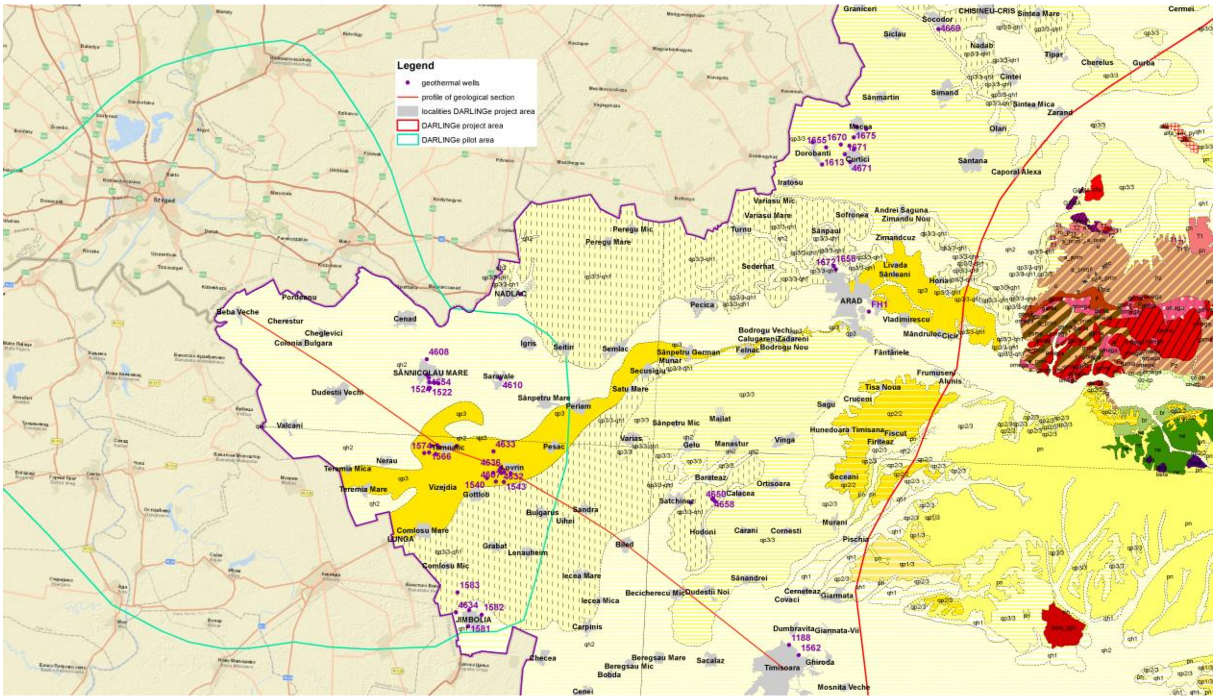

Figure 8: Geological map scale 1:200.000 (IGR) with locations of geothermal wells in the Romanian part of the transboundary DARLINGe pilot area

The geothermal aquifer is made up of Upper Pannonian sands, the productive levels being at depths between 1630 and 1930 m. The aquifer is of multi-layer type with thin permeable strata, wrapped up in a semi-permeable background, reaching 300 m total thickness. The estimated aquifer area in the Lovrin area is roughly 300 km^2 out of a total of 4,000 km^2 for the geothermal system of West Banat (Arad and Timis counties)(Burchiu et al., 1998).

The regional groundwater flow regime is of gravitational type, trending westward (Figure 9). The average flow rate recorded in 2007 in the wells drilled in the DARLINGe project area varied between 3 and 35 l/s, usually between 3 and 14 l/s (Setel, 2010). The geothermal water is artesian and the flow rate in the pilot area is between 12 and 21 l/s (Panu et al., 2002).

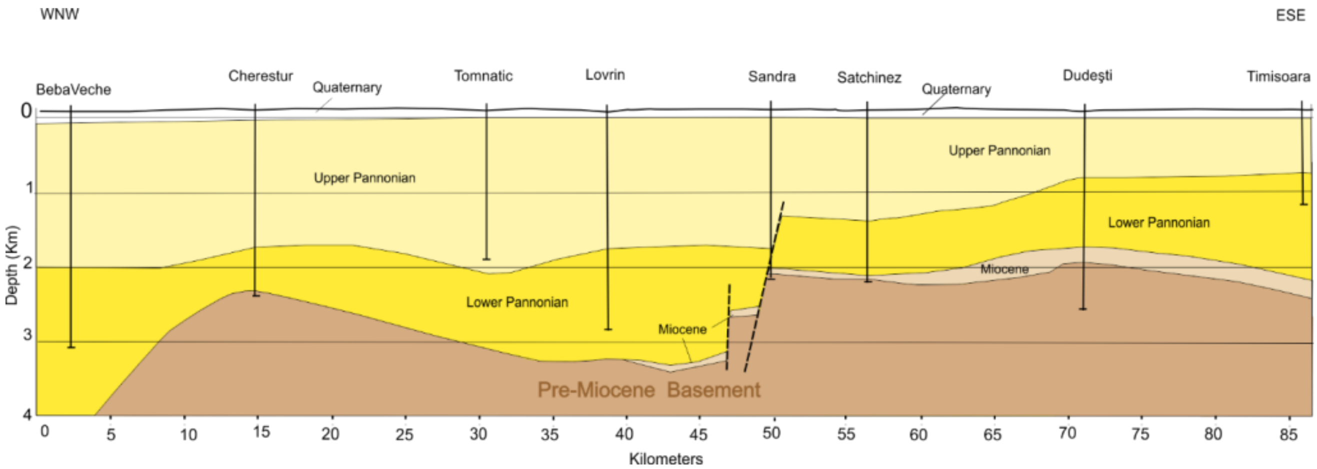

Figure 9: Geological cross-section (along the NW-SE red line in Figure 8) passing through Lovrin geothermal area

In Lovrin area the heat flow is around 91 mWm^{-2} (Veliciu et al., 1985). The thermal gradient is around 5.5°C/100 m, and the well-head temperatures are over 75°C. TDS is around 3.8 g/l, the water being of sodium-bicarbonate-chloride type, producing carbonate scaling. Therefore different technological solutions have been adopted in time for proper well operation. The gas-water ration varies in the area between 0.5 and 2.5 Nm^3/m^3, methane being the main signalled gas. Although proposals for the gas use were made for increasing the geothermal potential of the wells with up to 20% (Cohut, 1998), these were not materialized till now. The geothermal potential is in the range 0.5 – 1 GJm^{-2} (Panu et al., 2002).

Geothermal water use started in Lovrin in 1970s', when around 100 apartments were heated with geothermal water, within the framework of a pilot project. This action was followed by heating of some other blocks of flats. The wells (Figures 10, 11) were drilled by IFLGS, which later changed to FORADEX S.A. and presently to FORADEX VEST S.R.L.

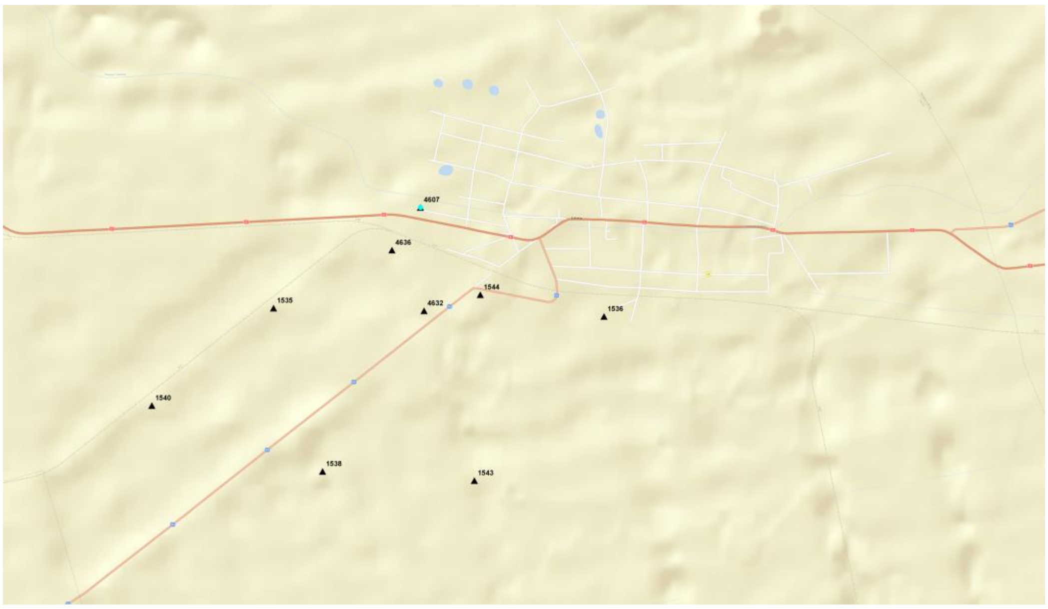

Figure 10: Geothermal wells locations in Lovrin area, overlaid on World Street map. All wells (except 4607) are presently inactive.

Figure 11: Google image of Lovrin, showing the location of the geothermal wells 4607 and 1544, as well as the thermal recreational pools.

In the Lovrin area there are 9 licensed wells (1535, 1536, 1538, 1540, 1543, 1544, 4607, 4632 and 4636 – Figure 10). Out of these, presently only well 4607 – Lovrin is active.

The exploitation of the geothermal aquifer in the Lovrin area consists in extracting the water from the well 4607, which is artesian. The average temperature of the geothermal water at the well head is 81 °C. The well 4607 Lovrin entered into operation in 1981. By the end of 2018 it had a cumulative production of approx. 2.3 million m^3, representing an energy of approx. 0.42 PJ. For the year 2018, the used energy in the Lovrin parea was approx. 0.012 PJ.

From wellhead the geothermal water is directed through the pipeline to a 28 m^3 atmospherically degasser. Then, by pumping, the geothermal water is transported through pipelines to the users. Geothermal water is used in the centralized heating system of Lovrin and the swimming pool, operated by the "Public service of central thermal energy supply in Lovrin municipality" of the city Hall. Existing heat energy production consists of a primary and a secondary circuit. Thermal water with outflow temperature of 81°C is firstly fed directly into the heating system of Lovrin municipality. The system had heated approx. 16,000 m^2 of floor surface (housing, public institutions and commercial companies) and approx. 1,000 m^2 at the covered pool.

In the secondary circuit, geothermal water output from the heating system is transported to the pools, where, through a heat exchanger, produces the necessary domestic hot water and then is used directly in the swimming pool.

After use, the waste geothermal water is discharged into the Galatca River, at approx. 35 °C temperature.

3.1.2. Planned future project

The city of Lovrin is planning modernizing and expanding the public heating system by accessing European funds, or making new industrial investments. As a result, the thermal energy production is expected to grow with a more intensive exploitation of the geothermal aquifer.

3.1.3. Reults of the Decision Tree testing

After many years of exploitation, the geological and hydrogeological conditions of the aquifers are well known. No significant decline of the aquifer has been reported till now. However, the expansion of the system will require further geological and hydrogeological studies, modelling and update of the models.

Regarding licensing, the granted mining concession is not in force until its publication in the Official Journal of Romania by a Government Decision, which approved it. However, in this phase (until the government approves) the operator is allowed to do exploitation activities, having a "pending exploitation license" and an operating license signed with the National Agency for Mineral Resources. After the entry into force of the concession, this will be valid for 20 years, with the possibility of renew it successively from 5 to 5 years.

From a technical point of view, there are no significant effects of corrosion or scaling in the well. It is expected that the well will continue to function. Anyhow, if technical problems might occur, the operator could put into operation other wells at Lovrin, which are now inactive.

Maintenance costs are reasonable if performed by the operator. For the moment no subsidies are required.The price for end-users is not high compared to the price of other energy sources. If the costs strictly related to the mining concession remain at the current level, exploitation is carried out in good conditions.

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4. SRB-BH pilot area

4.1. Slobomir (BH)

4.1.1. Introduction to the area / current project

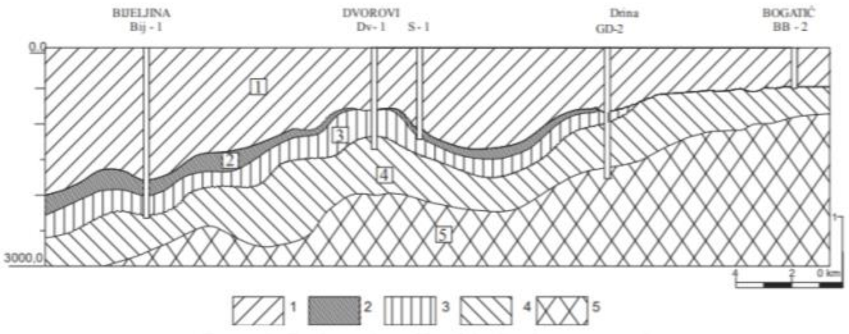
Slobomir city is a private project located in Semberija, NE part of the Republic of Srpska, B&H, in border belt with Serbia (Figure 12). The city is very well connected with other parts of the Srpska and B&H in general, as well as with Serbia and countries of the region.

The Semberija thermal aquifer (Triassic carbonates) extends on more than 400 km^2 in B&H and under current state of the art, it is a part of the huge transboundary geothermal aquifer with extension to Mačva, Serbia (Figure 13). Total area of the transboundary aquifer is estimated to be as much as 2000 km^2 (Milivojević and Perić, 1986).

Figure 12: Position of Semberija region

According to the results of the previous exploration, Semberija represents the most perspective geothermal area in the Republic of Srpska, B&H. In addition, it represents the best explored area in a geothermal sense. The highest values of geothermal gradient (> 50^0C/km) and heat flow (> 100 mW m^{-2}) in the RS are registered right here, in Semberija.

Six boreholes were drilled on an area of approximately 200 km^2, each deeper than 1.300 m (in total 10.460 m). The deepest one is borehole BIJ-1 (2479 m), very close to administrative and economic centre of the Semebrija region - Bijeljina (finished in 1984).



1. tertiary sediments, 2. Upper Cretaceous limestones, 3. Upper Cretaceous marls and sandstones, 4. Triassic limestones and dolomites, 5. bedrock sediments

Figure 13: Generalised geological cross section across Semberija and Mačva geothermal boreholes (Đurić, 2015)

The first deep borehole in Semberija, S-1, was drilled in 1957 in Dvorovi village. The borehole (1345 m) is the only one in use (Dvorovi spa), besides GD-2 in Slobomir. Until 1962 additional two boreholes were completed in Semberija (S-2 and S-3, S-2 in Popovi, 1591 m and S-3 in Svinjarevac, 1746 m). The data about these boreholes are very limited, and it is only known that borehole were finished in the Triassic limestones and registered thermal water, but not with artesian level like S-1.

The borehole S-1 has represented the "backbone" of Dvorovi spa during the last 40 years. Water well head temperature is 75°C and discharge 7.5 l/s (artesian level). This is the only borehole finished in the Cretaceous sediments (probably limestone sequence of the flysch formation).

The drilling of the borehole BIJ-1 started in 1983, as a part of the oil and gas project of Semberija. The borehole was finished at 2479 m, because the equipment crash and it was not completed to the originally planned depth (4000 m). At depth of 2410 m, the borehole reached the Triassic limestone. Qualitative and quantitative characteristics of thermal water were not tested because of the above mentioned drilling problems at 2479 m (Miošić N., 1985). Results obtained during the borehole drilling provided numerous useful geothermal data of the western part of Semberija plain and transboundary aquifer. It is calculated that it is possible to obtain water T>100°C deeper than 2500 m (Miošić N., 1985).

In 1988 the drilling of the borehole DV-1 started, one kilometre south of the borehole S-1 (Figure 14). It was the first "pure" geothermal borehole in Semberija, not oil-gas exploratory borehole. The expectation was to obtain three times more thermal water than in the S-1 (about 20 l/s), but there were similar thermal water quantity, artesian level and temperature like in the S-1. Because of the financial obstacles, the borehole was not completed (not cased till the bottom, pumping test was not provided etc). The borehole was conserved in 1989 and its current status is unknown.

The borehole GD-2 was completed in 2010 in the locality Slobomir. It was completed at 1800 m, screened for the last 200 m of the borehole. The borehole passed the Tertiary sediments and reached the Triassic carbonate rocks. Temperature on the well head is 75^{0}C, yield 44 l/s (pumping). Mineralisation is about 0.7 g/l. The borehole is planned for cascade use: heating, pools and agriculture.

Except the S-1, each borehole was drilled into the Triassic carbonate rocks. In accordance with available data, the map of depth to the Triassic limestone was constructed (Jolović, 2012). These limestones represent the most important geothermal reservoir in the Semberija and Mačva (Figure 14).

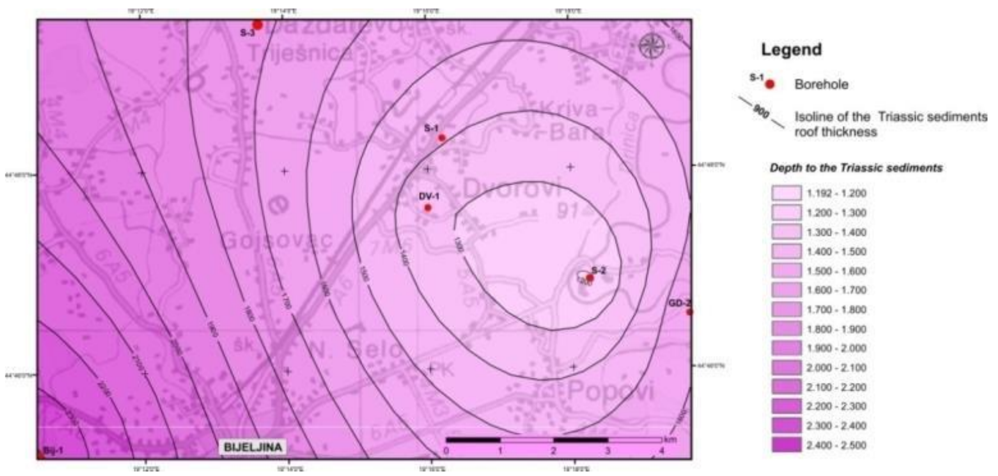


Figure 14: Isolines of depth to the Triassic limestone in Semeberija region (Jolović, 2012)

The geothermal borehole GD-2 in Slobomir is located at the overall eastern zone of RS, B&H part of the transboundary geothermal aquifer Semberija-Mačva. It is already being used for the heating of the constructed facilities in Slobomir (administrative building, bank, university).

The production history of the currently operating Slobomir geothermal heating project shows that since 2011 approximately 20.3 TJ has been produced annually, as reported by the Operator (depending on winter days temperature - heat demand). The project has been operating for 7 years and based on all experiences it is foreseen to run at least another 25 years. The project is economic under the current market conditions and is supplying a substantial and existing heat market.

On the other hand, the forecasted amount of available resources estimated for the reservoir volume within the Slobomir exploration field is some orders of magnitude higher, which is due to the excellent reservoir properties and especially to the high recharge rates (very karstified limestone identified under 1600 m from the surface, with water table close to the surface). Therefore, it is obvious that the present heating system recovers only a small fraction of the potentially extractable heat that might be utilized in the future by project extension.

4.1.2. Planned future project

There is an ambitious plan about the use of thermal water in recent future (Figure 15) also for:

- Touristic and sport-recreation centre – Aqua Park Slobomir:
  - ✓ outdoor 47000 m^2,
  - ✓ indoor 8000 m^2;

✓ 15 pools of different purposes

- Additional heating of the residential and business space
- Greenhouse heating (production of health food, medicinal herbs and flowers)
- Spa and recreation purposes
- Production of the ecologically sound electrical energy in thermal power plants (additional studyis necessary for the estimation).

Figure 15: Planned aqua-park in Slobomir, construction in progress

The estimations related with future potential projects (Figure 16) are prepared based on the results of pumping and hydrochemical tests. These results are basically exploration results used for reserves approval by the responsible authority (Ministry of Industry, Energy and Mining) in accordance with actual legal policy (Law on Geological Explorations, Official Gazette of the Republic of Srpska 113/10).

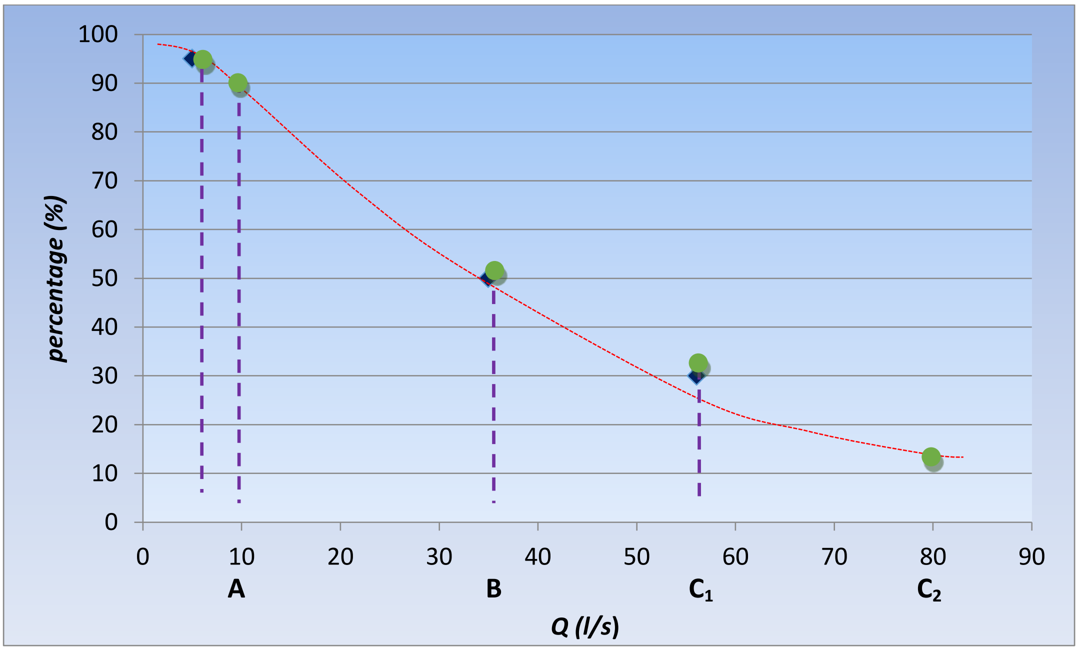


Figure 16: Well GD-2 probability of thermal water reserves

Adopted reference temperature is 20°C, in accordance with those legally prescribed for release in surface streams (Law on Water, Official Gazette of the Republic of Srpska 50/06, harmonized with Directive 2000/60/EC). Proven extraction potential of the thermal borehole GD-2 is 8 times higher than the current one, and it is proven by long-term pumping tests (40 l/s, currently 5 l/s).

4.1.3. Reults of the Decision Tree testing

The transboundary aquifer between Semberija and Macva is little explored, therefore emphasis has to put on the tasks and decisions to be made in the preliminary evaluation and preparatory work phases. This includes not only of assessment of alreday available data, but also making new masurments, CAPEX / OPEX estimations, cost benefit analyses, making heat purchase agreement with future usesrs, etc.

4.2. Domaljevac (BH)

4.2.1. Introduction to the area / current project

Domaljevac settlement with about 3300 inhabitants is located in the Municipality of Domaljevac-Šamac in Bosnia and Herzegovina on the border with the Republic of Croatia (Figure 17). Domaljevac has an excellent geographical position and a healthy environment with quality agricultural land along the Sava river and very potential thermal water reservoirs. Main population activity is agriculture, especially production of vegetables.

Figure 17: Territory of Domaljevac – Šamac municipality with settlements (http://www.domaljevac.ba/)

The population is mostly concentrated in the Domaljevac where the centre of the municipality and all public buildings are found. According to the census from 2013, the municipality has 4771 inhabitants.

The main public buildings in Domaljevac are: 1) Municipality and Police Station (both in same building), 2) Hospital, 3) Primary School, 4) Kindergarten and 5) Thermal Centre (Domaljevac Spa) is under construction (Figure 18).

1) Municipality and Police Station

2) Hospital

3) Primary School “Braće Radića“

4) Kindergarten

5) Domaljevac Spa - under construction

Figure 18 The main public buildings in Domaljevac

The wells of thermomineral waters are on distance about 0,8-1 km from public buildings (Figure 19).

Thermomineral waters in Domaljevac have high mineralization (> 11 g/l) and they are aggressive, with very intensive processes of scaling in pipes.

Figure 19: Locations of the Domaljevac spa, public buildings and thermomineral waters

Geological information at Domaljevac area was obtained predominantly from several old boreholes and geophysical surveys (seismic reflection) carried out by the oil industry in the past, and additional hydrogeological drilling after the last war (1992/95) conducted for purposes of heating greenhouses.

Two deep drillholes for oil exploration (Do-1 and Do-2) and one hydrogeological well (Do-3/B) for the purpose of capturing the thermomineral water and use for heating of greenhouses (production vegetables) were performed in Domaljevac.

Do-1 and Do-3/B obtained thermomineral waters, while well Do - 2 did not have water. Termomineral water in Domaljevac has been used for more than 20 years for greenhouse heating, but any wells have not been used since 2013 and the wells are closed by valves.

Well Do-1

The highest outflow temperature of water in Bosnia and Herzegovina is registered at drillhole Do-1 (temperature at wellhead is 96°C). The depth of the well is 1.275.4 m, and mineralization of water is 15.4 g/l. Well Do-1 was made in 1960.

Aquifers of these waters are Sarmatian, Badenian and Mesozoic carbonates. These carbonates are drilled in the interval from 1.108,0 m to 1.275,4 m and they are covered by Pannonian and Pontian insulating sediments.

Well Do-1 has been used for more than 10 years in agricultural production. The heating of greenhouses with geothermal water began in 1970s for production of flowers and vegetables. The heating surface was 30 000 m^2. In 1982 the heating stopped because of scaling process in the pipes of heat exchangers. Later, this well was used again before the last war (1992/95), but it is not known exactly when.

Well Do-2

Well Do-2 was performed in 1960 up to depth of 1.187,0 m. The well is only 700 m far from Do-1, in the same geological structure, but has no water. Sarmatian, Badenian and Mesozoic carbonates were found in the interval from 1079 m to 1.187,0 m.

Well Do-3/B

Well Do- 3 / B was drilled after the last war (1992-1995) and started operation in 2003 for the heating of greenhouses for vegetables production (Figure 20). This is a private well and information it is not available. Unofficial data are: Q=47 l/s, t=86°C, p=4-5 bar, depth 1500 m. According to analysis from 2006, water has pH = 7.53 and Ep = 19 330 μS/cm.

After ten years of work, the greenhouse production stopped and the well was closed in 2013. Reasons of finishing of production are not known.

Figure 20: Well Do-3/B in operation in 2007 (Photo: Natalija Samardžić)

4.2.2. Planned future project

In this project the revitalization of existing well(s) or – in case revitalization is nor successful - performing a new exploitation well (Do-4) at a depth of about 1500 m and the construction of one reinjection well is foreseen. Thermomineral water would be used for heating of five public buildings in Domaljevac (Figure 18), and after that for heating of greenhouses, as well a feeding a new spa (Figure 21). The total spaces for heating of buildings is approximately 15.000 m^2 and greenhouses 30.000 m^2.

Figure 21: The new spa plans in Domaljevac

Relevant project parameters are as follows:

- Wellhead temperature existing wells: t = 86 - 96°C (Do-3/B and Do-1)
- Total proven yield of existing wells (Do-1 and Do-3/B): Q=70 l/s
- The assumed yield and temperature of the new projected well Do-4: Q=70 l/s and t=96°C
- Available thermal power of existing wells (Do-1 and Do-3/B): 23 MWt (referent to 10°C)
- Prognostic thermal power of the new projected well Do-4: 25 MWt (referent to 10°C)
- Input temperature for district heating: 96°C
- Output temperature from district heating: 70°C
- Input temperature for greenhouse heating: 70°C
- Output temperature for greenhouse heating: 45°C
- Project lifetime: 30 years
- Estimated capacity of use (district heating+ greenhouses): 6 MWt

4.2.3. Reults of the Decision Tree testing

The existence of significant geothermal resources has been confirmed by the result of the deep exploration-exploitation wells (Do-1 and Do-3/B). However further exploration is needed, especially about the chemical characters of the water, because its high dissolved content and scaling character have already led to the abandonment of previous projects. Therefore detailed hydrochemical studies are needed, and also appropriate technical measures / tests on preventing scaling. It also mean, that questions related to project preparatory phase are of utmost importance (in all four fields).

The capacity of the existing wells after performing was about 70 l/s, which means that for 30 years with this capacity can be extracted 26.1 PJ. It is not known whether the same capacity will be obtained after the revitalization of the wells, so this estimate can be taken with a moderate level of confidence.

It is assumed that the new well Do-4 could be provide additional 70 l/s, which corresponds to the energy of 23,8 PJ for 30 years. This amount of energy can be taken with a low level of confidence.

The existing wells need detailed technical supervision as well in order to assess whether they can be revitalized and become active again, or drilling of new well is necessary. Additional exploration, revitalisation and testing is needed to further evaluate the well(s) discharge and resource characteristics. These all need appropriate funding, which is a critital decision gate in project development.

The potential user (Municipality Domaljevac - Šamac) is making efforts to collect all existing documentation on drilled wells and geophysical research, and at the same time searching for an expert house that could revitalize existing well(s).

Regarding the legislative issues, in the Federation of Bosnia and Herzegovina concession on thermal water is usually issued for a period of 30 years, so project`s foreseen operation lifetime is assured.

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