Experience in diverse direct use systems applied in the northeastern Slovenia

Nina Rman, Andrej Lapanje, Dušan Rajver

Geological Survey of Slovenia, Dimičeva ulica 14, 1000 Ljubljana, Slovenia

nina.rman@geo-zs.si

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ABSTRACT

Thermal water in the Slovenian part of the Mura-Zala basin, which appertains to the SW part of the Pannonian basin, is produced from low enthalpy geothermal system set in the Neogene sediments as well as from basement aquifers in the Pre-Neogene metamorphic and carbonate rocks. The water discharges from 26 geothermal wells managed by 14 users. Their density is especially high in the central Pomurje area between towns Murska Sobota and Moravske Toplice.

Utilization schemes depend on water temperature mostly but the scaling potential and gas content also play an important role. The highest wellhead temperatures reach 72 °C in Benedikt and Moravske Toplice, however, temperatures between 50 and 60 °C are gained most often. The use is more diverse than a decade ago but the individual space heating, sanitary water heating and bathing with balneology still prevail as direct utilization schemes. Both, the installed capacity and the used geothermal energy show an increasing trend in the period 1995-2010, including geothermal ground-source heat pumps. The increase is pronounced especially after 2005 when new users in Lendava, Benedikt and Dobrovnik started to exploit geothermal heat for greenhouse and district heating. As higher abstraction rates are needed for this type of use the total annual thermal water abstraction increased noticeably in the last years and amounted to 3.29 million m^3 in 2011. The available geothermal energy is not efficiently used as relatively low capacity factor of app. 25% is calculated. But it is positive that the majority of thermal health resorts apply cascade use of water and space and sanitary water heating is applied first, followed by bathing and balneology. Terme 3000 health and spa resort in Moravske Toplice is by far the biggest geothermal energy user in the area (98.3 TJ in 2010), but a good practice is identified as some of their thermal waste water is provided to another user for greenhouse heating. Greenhouse heating systems in Dobrovnik and Tešanovci operate in colder season of the year, similar to district heating systems in Benedikt, Murska Sobota and Lendava. The latter installation has also a pavement de-icing done. In Lendava, a reinjection well operates since 2009, and together with the abstraction one they form the only operating geothermal doublet in Slovenia. Another potential geothermal doublet is situated in Renkovci but it was still in a testing phase in 2012, while the third pair has just been drilled in Murska Sobota in the spring of 2013.

Various direct use applications indicate that diverse utilization of thermal water already exist in this region and many experience on different exploitation systems has been gained therewith. However, it is estimated that the current thermal water extraction already surpasses the natural capacity of this geothermal system, which raises the need for appropriate measures to improve its hydrological conditions. As new exploitation is possible at five localities, where three wells are planned for thermal resorts and two for space or greenhouse heating, it is very important to establish threshold values of the existent state of the aquifers as well as to improve the efficiency of current use. These parameters should be controlled by an appropriate monitoring system. Together with more reinjection wells and more efficient utilization of the produced thermal water, further and even more diverse utilization systems can be developed and applied.

1. INTRODUCTION

Direct use is the oldest and most common geothermal energy use and it is a very common utilization type in low temperature sedimentary basin aquifers characteristic also for Hungary (Ottlik et al., 1981) and the Slovene part of the Mura-Zala basin (Rajver et al., 2010; Rman et al., 2011). These aquifers are very sensitive to over-exploitation (Rybach, 2003) and discussion on sustainability has been going on for decades. The basic principle that the current development should not endanger the future is still valid (United Nations, 1987), and many management principles can be applied for ground- and thermal waters. A safe yield principle (Sophocleous, 2000) is based on assumption that aquifers are renewable and the abstraction should not exceed their recharge. Additional restrictions have to be applied according to the Water Framework Directive (2000/60/EC) which results in a reduced quantity named the sustainable yield. If reinjection is applied, this amount can be enlarged or it can even reach zero depletion when total reinjection is applied. At the end, there is a planned depletion management possibility (Sophocleous, 2010) where the aquifers are over-exploited over an agreed upon scenario. When thermal water is used for balneology it should not be reinjected due to microbiological pollution, so the management plans should be aware of utilization types when selecting the appropriate policy.

The current management of regional and transboundary geothermal aquifers in the NE Slovenia is inadequate as only few water concessions have been granted and operational monitoring is poor (Vižintin et al., 2008; Rman et al., 2011; Nador et al., 2012). Their existent exploitation is described in the paper, indicating its strengths and weaknesses. From the overview we were able to identify areas with historical and extensive thermal water abstraction where the risk of poor quantity status is the highest, but good and bad practice on thermal water abstraction and use are also exemplified. This research is intended to represent a professional basis for future discussion on sustainable use of these geothermal resources among users, managers and investors.

2. SETTINGS

The NE Slovenia appertains to the western Pannonian basin and the area has been investigated within many European projects lately, such as Transthermal (Lapanje et al., 2007), T-JAM (Nádor et al., 2012) and Transenergy (many papers in this proceedings). It is characterized by an elevated heat flow with an average value of 100 mW/m^2 (Rajver & Ravnik, 2002) but due to free convection values up to 154 mW/m^2 are calculated locally. On the opposite side, rapid sedimentation has resulted in 10 to 30% lower values as expected in some areas. This heat flow plus a good permeability enable occurrence of low enthalpy geothermal aquifers in the porous sedimentary rocks of the Mura-Zala basin and its fractured basement rocks (Marton et al., 2002). The occurrence of intermediate temperature resources in the Pre-Neogene basement is not proven yet (Rajver et al., 2012).

Pre-Neogene aquifers are identified in fissured metamorphic rocks in Maribor and Benedikt, as well as in the fissured carbonates in Korovci and Zreče. Thermal water types are very diverse, from thermomineral gaseous water in Benedikt and elsewhere to rather fresh thermal water in Zreče. The Lower Badenian to Lower Pannonian Špilje formation geothermal aquifer consists of laterally limited sandstone layers (Jelen & Rifelj, 2011), captured with only few wells which produce rather stagnant highly mineralized and gaseous thermal water. The Pannonian-Pontian Lendava sandstone aquifer is of turbiditic character and becomes thicker towards Hungary. This water is also highly mineralized and has a high CO_2 content, plus oil and gas have been found and produced from both above mentioned aquifers. The Lendava Fm. water is often mixed with moderately mineralized water from the Mura Formation inside wells which tap both. The latter thermal water is stored in thick hydraulically connected gravely and sandy delta front sequence, which represents the most productive but also the most exploited regional and transboundary geothermal aquifer in Slovenia. It discharges the Pleistocene rainwater of Na-HCO_3 type which has little free gas (Szöcs et al., 2012). After the sedimentation of deltaic sand prograded to the east, it was covered by much finer delta plain sediments of the upper part of the Mura Fm. The surrounding Eastern and Southern Alps provided material for filling the alluvial plain after the Lake Pannon has disappeared in Pliocene and Pleistocene, and these deposits of the Ptuj-Grad Formation are identified between Slovenske gorice and Goričko Hills. Lukewarm water is tapped there in Ptuj but fresh drinking water is abstracted at many other localities. The Mura and Ptuj-Grad Fm. aquifers were named also the Termal 1 (Kralj & Kralj, 2000b).

3. METHODS

Thermal water sources which produce water at 20 °C and more were inspected in the area of NE Slovenia between 2008 and 2012. Data on its energetic use are collected systematically for whole Slovenia every 5 years (the latest Rajver et al., 2010) but our research was more detailed and focused on the management of these wells also. Archival technical and hydrogeological data on geothermal objects were supplemented with user's contact details, water management practice and abstraction characteristics. It was the first time the results of pumping tests were regionally compared, implying areas with higher over-exploitation risk. Utilization issues such as reinjection practice, thermal efficiency and technical problems, as scaling and degassing, were also addressed based on information provided from the archival reports and the maintenance staff. Quality of operational monitoring systems was inspected in order to denote if the existent monitoring can provide sufficient data for regional quality and quantity trend estimation, while the applied waste water monitoring indicated environmental awareness and more efficient utilization schemes often. Evaluation of the future abstraction was performed based on quantities defined in concession applications and permits, plus the number of wells prepared for activation, and is shown in the paper to start a discussion on future demands for thermal water and possible conflicts among the users (Rman et al., 2012).

The data was first harmonized and transferred in the Access and SQL databases, which was followed by graphical, statistical and spatial analyses performed with MS Office Excel, Statistica and ArcGIS software. Many collected data are freely available at http://akvamarin.geo-zs.si/t-jam_boreholes/ and www.geopedija.si, the database of thermal water uses is available at http://akvamarin.geo-zs.si/users/, while a detailed interpretation of various legal, management and utilization aspects of geothermal energy is available in series of reports and interactive maps at http://www.t-jam.eu and http://transenergy-eu.geologie.ac.at/.

4. RESULTS

The investigated area covers a surface of 3,941 km^2 east of Zreče and Maribor towns and up to the SI-HU state border. We have acknowledged that 15 users were active in this area, with 26 production wells and one reinjection well in 2011 (Table 1). 15 active wells operate throughout the year while 12 mainly in the winter season. An average density of active wells is about one well per 145 km^2 and their spatial distribution depends on geological settings of the area much as well as the development stage of the site (Fig. 1).

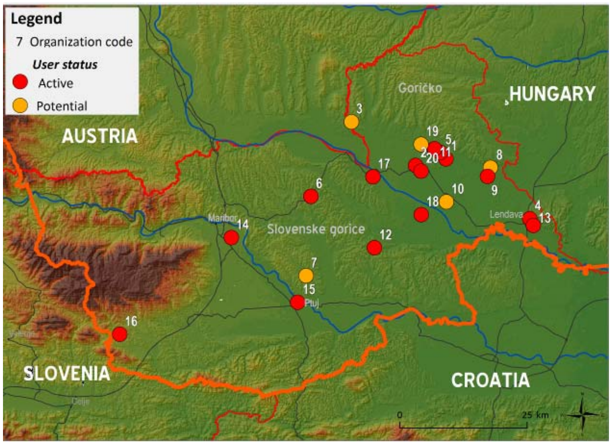

Fig. 1. Active and potential thermal water users in NE Slovenia.

New production wells were drilled in 2011 in Renkovci and in 2012 north of Murska Sobota but they are in a testing phase and therefore they are not presented. Beside, a reinjection well Sob-4g was completed in spring 2013 in Murska Sobota.

4.1 Thermal water temperature

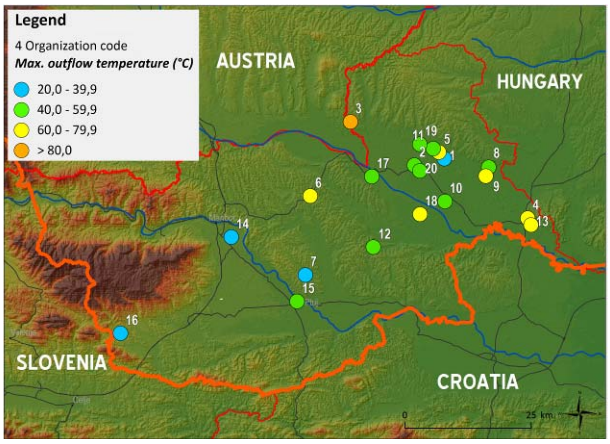

Fig. 2. The highest thermal water temperature at the user sites.

Thermal water use highly depends on the temperature of discharge. The highest outflow temperature of 83 °C is measured in Korovci (Fig. 2), where the Pre-Neogene carbonate basement aquifer is captured. Waters at 72 °C are produced from the metamorphic basement rocks in Benedikt and from the Špilje Fm. sandstone in Moravske Toplice. Temperature of 68 °C is characteristic for Lendava Fm. water in Banovci, while the outflow temperature from the Mura Fm. reaches at maximum 66 °C in Lendava, 62 °C in Banovci and 61 °C in Dobrovnik. Other wells screened in this formation discharge water at between 50 and 60 °C. Water from the metamorphic basement rocks in Maribor has only 39 °C at the wellhead due to low yield, while the water discharged from the dolomite in Zreče reaches only around 30 °C.

Table 1. List of thermal water users in the NE Slovenia (codes are used in Figures 1, 2, 5, 6 and Table 2)

Well code	User code	Organization name and wells location	Geothermal well	Water production
1	16	Terme Zreče, Zreče	B-2/85	Yes
2			B-3/88	Yes
3	6	Municipality Benedikt	Be-2/04	Yes
4	8	Municipality Dobrovnik	Do-1/67	No
5	9	Ocean Orchids, Dobrovnik	Do-3g/05	Yes
6	10	Paradajz, Beltinci	Fi-14/57	No
7	7	Municipality Destrnik	Jan-1/04	No
8	3	Kotrman, Korovci	Kor-1gα/08	No
10	4	Nafta Geoterm, Lendava	Le-2g/94	Yes
11			Le-3g/08	Reinjection
12	14	Terme Maribor, Maribor	Mb-1/90	Yes
13			Mb-2/91	Yes
14			Mb-4/91	Yes
15	12	Segrap, Moravci	Mo-1/58/73	No
16			Mo-2g/08	Yes
18	19	Zdravilišče Rimska Čarda	Mt-2/61	No
17	5	Naravni park Terme 3000, Moravske Toplice	Mt-1/60	Yes
19			Mt-4/74	Yes
20			Mt-5/82	No
21			Mt-6/82	Yes
22			Mt-7/93	Yes
23	11	Terme Vivat, Moravske Toplice	Mt-8g/06	Yes
24	15	Terme Ptuj, Ptuj	P-1/73	Yes
25			P-2/88	Yes
26			P-3/05	Yes
9	13	Terme Lendava, Lendava	Le-1g/97	Yes
27			Pt-20/49	Yes
28			Pt-74/50	Yes
29	2	JP Komunala, Murska Sobota	Sob-1/87	Yes
30	20	Zvezda Diana, Murska Sobota	Sob-2/88	Yes
31	17	Zdravilišče Radenci, Radenci	T-4/88	Yes
32			T-5/03	No
33	18	Terme Banovci, Banovci	Ve-1/57	Yes
34			Ve-2/57	Yes
35			Ve-3/91	Yes
-	1	Grede, Tešanovci	Geothermal waste water of Terme 3000	

4.2 Historical thermal water abstraction

Mineral water in Radenci has been exploited for centuries while thermal water was not discovered until oil and gas research drillings in the middle of the 20th Century. Thermomineral oil water from the Špilje Fm.

has been produced since 1962 in Moravske Toplice, while Banovci and Radenci wells were drilled some years later. Due to high scaling tendency, a low number of captures were done in total and up to 72 °C water is used for space and sanitary water heating plus balneology.

Water from the Lendava Fm. is produced in Banovci, while it is tapped together with the Mura Fm. thermal water in many other wells. The latter was first captured in abandoned oil boreholes in the early 1970’s in Moravci in Slovenske gorice and Petišovci, but in 1983 a first dedicated well for a geothermal heat use was made in Moravske Toplice. Many new wells were put to operation there, in Murska Sobota, Dobrovnik, Lendava and Ptuj in the following decades, and this aquifer now produces the most thermal water in the region. It is interesting that the first geothermal well in the Mura-Zala basin targeted the Ptuj-Grad Fm. in Ptuj but due to rather low temperature the abstraction from it has not increased much over the years. On the contrary, the Pre-Neogene fissured metamorphic aquifers were first captured in 1992 in Maribor and in 2006 in Benedikt, while the shallower dolomite in Zreče was tapped a decade earlier (Fig. 3).

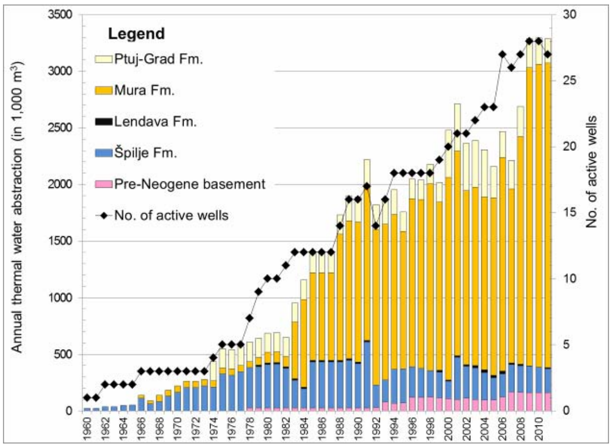

Fig. 3. Number of active wells and annual thermal water abstraction in NE Slovenia in the period 1960-2011.

As much as 3.29 million m^3 of thermal water was abstracted in 2011, which is the highest value ever. The highest share appertains to the Mura Fm. (82%) even though only 54% of active wells tap this aquifer, which indicated its good hydraulic characteristics. The historical overview shows that the total annual abstraction has increased significantly in the 1980’s when many new sites were established for geothermal heat use, while the water was used only for swimming and bathing previously (Fig. 3). After 2000, some new wells were put to operation but the abstracted amount did not changed much. This fact is attributed to improved efficiency and reduced abstraction rate at some older sites mainly. The third boom followed after 2006, when 5 new wells were activated and have been used for direct and greenhouse heating plus the individual space and sanitary water heating in thermal resorts. Beside these 26 wells, one reinjection well drilled into the Mura Fm. sand has been operating within the district heating system in Lendava since 2009. About 3% of the regional abstraction is injected through it, so it can improve the quantity status only locally.

Total abstraction from all geothermal aquifers between years 1960 and 2011 is estimated to 68.51 million m^3, and again as much as 65% appertains to the Mura Fm. The most vulnerable areas due to the long-term water withdrawal are Moravske Toplice and Murska Sobota, where rather high abstraction has been applied for over 20 years.

4.3 Current thermal water use

The geothermal heat use has risen but the individual space heating of thermal resorts and bathing are still the most abundant utilization types (Figs. 4 and 5).

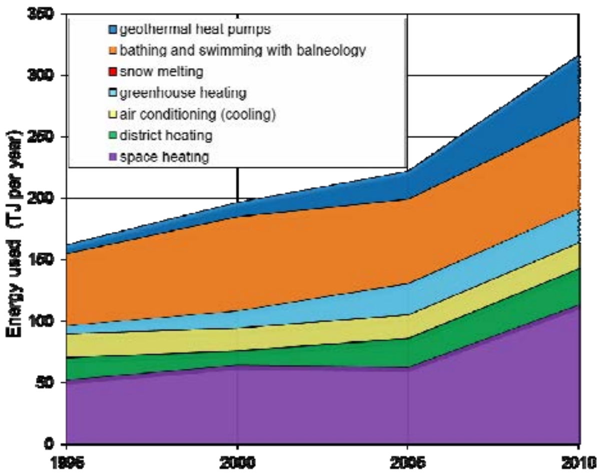

Fig. 4. Used geothermal energy in the period 1995-2010.

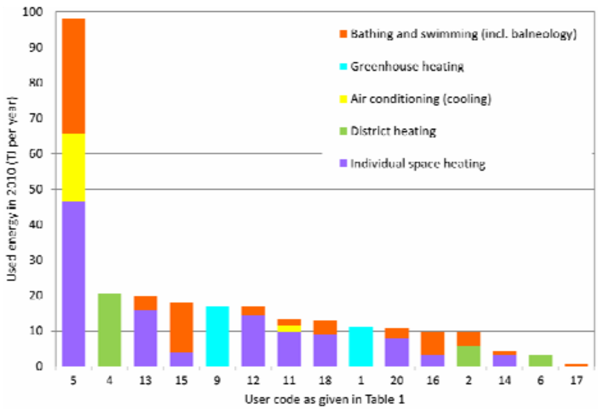

Fig. 5. Used geothermal energy in 2010 by users and distributed in categories of use.

The current average thermal water abstraction (reference year is 2010) and the used geothermal energy are shown in Table 2, where the utilization parameters are denoted for all 15 active users. Geothermal ground source heat pumps are not included in the table but they are estimated to represent 15.8% of the total energy use in the region.

These calculations are based in a simplified way on measured quantity and temperature values for an individual well and summed together for a user. The installed capacity and used energy increased in the last years for some types, especially for district heating systems in Lendava and Benedikt, while not much change is noticed for bathing and air conditioning. It is worth to mention that the actual abstracted quantities are well known for the last 7 years, while only rough estimations are available for more distant years.

Table 2. Utilization of geothermal energy for direct heat use in 2010 (without GHPs).

User Code	Utilization Type[1)]	Capacity (MWt)	Annual Utilization		
			Q aver. (kg/s)	Energy (TJ/yr)	Capacity Factor
1	G	1.16	8.3	11.0	0.30
2	D,B	0.94	9.8	9.6	0.32
4	D	2.72	15.0	20.6	0.24
5	H,C,B	10.62	30.9	98.3	0.29
6	D	0.71	2.1	3.1	0.14
9	G	5.90	2.8	17.0	0.09
11	H,C,B	1.44	3.8	13.3	0.27
12	H,B	1.87	7.1	16.8	0.28
13	H,B,C	1.33	6.7	19.8	0.47
14	B	0.16	1.4	4.3	0.85
15	H,B	1.15	14.0	18.0	0.50
16	H,B	0.57	15.0	9.9	0.55
17	B	0.38	0.3	0.5	0.04
18	H,B	3.05	3.7	12.8	0.13
20	H,B	1.05	4.5	10.6	0.32
Total		***33.05***	***125.36***	***265.5***	***0.25***

1) Types of use:

H = Individual Space Heating (other than heat pumps)

D = District Heating (other than heat pumps)

C = Air Conditioning (cooling)

B = Bathing and Swimming (incl. Balneology)

G = Greenhouse and Soil Heating

Nine thermal spa resorts are known in the investigated area and they often apply cascade use. Usually, thermal water at temperature 60 to 72 °C is used for individual space heating of hotels, spa resort and near-by buildings by plate heat exchangers first, representing 35.9% of the total annual geothermal energy use. The heat of water at 40 to 50 °C is used additionally for sanitary water and air heating plus air conditioning, summing to 6.6% of used annual energy. A part of the cooled water at 30 to 35 °C is used for direct or indirect heating of swimming and bathing pools, reaching 23.5% of annual geothermal energy use. Heat of this waste water is sometimes additionally extracted with geothermal heat pumps. Beside, a football court is heated with thermal water in Terme Vivat in Moravske Toplice, while the well B-2 is Zreče is a spare drinking water well. The third interesting example are Terme 3000, which give a part of their waste water with temperature at around 40 °C to a near-by tomatoes greenhouse in Tešanovci. Together with an orchids greenhouse in Dobrovnik, they attribute 8.9% to the total geothermal energy use in the region. The latter user can be pointed out as a good example, as it uses thermally exploited water for indirect heating of rainwater which is used for plants irrigation. The district heating systems of towns Benedikt, Lendava and Murska Sobota operate between October and April mainly, contributing 9.3% of the annual energy use. In Lendava, a geothermal doublet of the Nafta Geoterm Co. is applied as a good example plus pavement de-icing occurs within this system. Moreover, inactive wells Jan-1 and Mt-2 are planned to be used for balneology, while Do-1, Fi-14 and Kor-1gα for individual space and greenhouse heating.

As reinjection of approximately 40 °C waste thermal water operates only in Lendava, the rest is emitted to surface waters. Only four users chemically treat the waste water (dechlorination and treatment in public sewage plants), while no special chemical or physical treatment is applied at others. This may cause chemical and thermal pollution of the streams and the practice is ecologically unacceptable. Only two users cool the water to an average annual waste water temperature of 15 °C, the first in Dobrovnik and the second in Maribor.

4.4 Future thermal water abstraction trends

The existent users would like to increase their water abstraction to 4.97 million m^3 annually according to the applied concession permits (Table 3). Production from currently inactive wells with concessions could hypothetically add 1.05 million m^3 more, while the ones with no concessions are presumed to be able to produce extra 1.39 million m^3 annually. Due to favourable hydrogeological conditions most wells aim at the Mura Fm. for heat utilization schemes, while some are planned to be used predominantly for balneology.

Table 3. Expected annual abstraction of thermal water by aquifers in future

Aquifer Fm.	With concession permit		No permit
	Active (m^3)	Inactive (m^3)	Inactive (m^3)
Ptuj-Grad	441,504	220,752	0
Mura	3,933,108	656,720	1,046,995
Lendava	52,560	0	141,912
Špilje	176,602	176,602	15,768
Pre-Neogene basement	362,664	0	189,216
Total	**4,966,438**	**1,054,074**	**1,393,891**

These amounts are only a legislative evaluation of the trends while hydrogeological factors, such as interference between users and recharge, were not interpreted at this stage due to lack of field tests and the collected data. However, as many research indicate that the current abstraction highly endangers good quantity state of the aquifers it is suggested that the future development should follow the suggestions of best practice on different levels, from reinjection, efficient use of thermal water to monitoring systems and similar as described by Rman et al. (2011).

4.5 Exploitation characteristics

The Pre-Neogene basement rocks often show limited recharge and therefore the optimum abstraction of 8 l/s is suggested from the dolomite in Zreče and only 1.5 l/s from the metamorphic rocks in Maribor. On the opposite, there is no need for submersible pumps in the well tapping the metamorphic aquifer in Benedikt as gas lift enables discharge of 8 l/s on average. Thermomineral waters from the Špilje and Lendava formations discharge naturally in Banovci, Radenci and Moravske Toplice due to gas and thermo lift, but the yield is only 1 to 5 l/s and scaling is a major issue. Self-discharge from the Mura Fm. wells has significantly decreased in the last decades and therefore submersible pumps are used to abstract 10 to 30 l/s per well on average. A reduced discharge is observed also in Ptuj-Grad Fm. wells in Ptuj, where the optimum abstraction with pumps does not exceed 8 l/s.

Hydraulic connections between wells tapping the same aquifer; 2 wells in Ptuj-Grad Fm., 17 in Mura Fm., 2 in Špilje Fm. and 5 in the Pre-Neogene basement; are proven. The other fact is that in 35% of active wells a mixture of waters from two formations is produced, usually the Mura and the Lendava Fms. (Fig. 6). This is in conflict with the Water Framework Directive (2000/60/EC) as artificial hydraulic connections between otherwise separated aquifers are enabled.

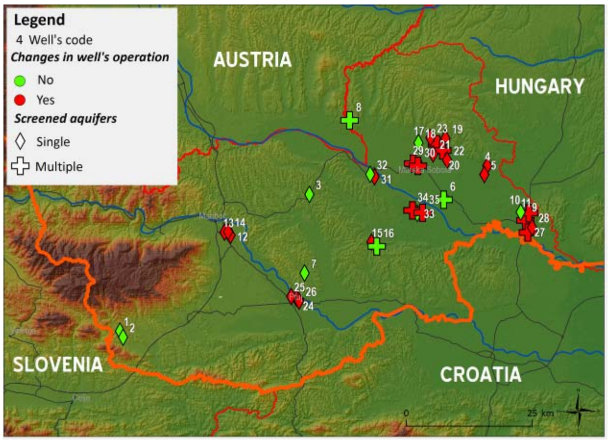

Fig. 6. Number of tapped aquifers in a well and occurrence of changes in its operation

The 50-year thermal water withdrawal resulted in hydraulic changes observed in 24 wells. Its occurrence may be attributed to deteriorating technical status of the old wells sometimes but regional changes as decreased groundwater levels, yield and availability have also been observed and proven at many sites (Kralj & Kralj, 2000a; Rman & Lapanje, 2013 these proceedings).

4.6 Operational monitoring

The operational monitoring survey performed in 2011 has showed that at least some measurements of groundwater level exist for 37% of active well, while in 22% this parameter is measured automatically hourly or daily. The latter frequency of outflow temperature observation was applied only at one third of the wells, while the measurements are more random in 56%. The total abstracted annual quantity is well known in general (for 78% of active wells) but only approximately the third of them have daily measurements available. The annual chemical analyses are performed only at few user sites, while many have very sparse chemical datasets. The general status of the operation monitoring was evaluated as poor and this is attributed to only few granted water concession permits in the region, the lack of legislative measures and the poor environmental awareness of the wellbore managers.

3. CONCLUSIONS

This research has shown that direct use of geothermal energy and thermal water in the NE Slovenia has a long history and the resources are in a stable development phase. The cascade use is well applied and many systems can serve as a good example for efficient use of thermal water, however, the exploitation management of these low enthalpy geothermal aquifers is not equally good. Hydraulic changes due to high thermal water abstraction, lack of reinjection and other anthropogenic variations in water production can be named the geothermal mining, which is caused by an inappropriate resource management of both, the users and the authorities. The users should try to improve the efficiency of their system more and in such a manner that they will gain more heat from the same or even less abstracted water than today which can be achieved by lower emitter waste water temperatures already. On the other hand, the national and regional authorities should ease and fasten the regional concession granting process (which has not been realized for almost a decade now), enhance sustainable planning of geothermal energy exploitation and financially support professionally sound projects.

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