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Hydrogeological Expert Basis to Water Permitting in the Low Temperature Geothermal System in the Mura-Zala Basin in the NE Slovenia

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ABSTRACT

Thermal water demand is constantly increasing in the Mura-Zala basin, a part of the Tertiary Pannonian sedimentary basin. The shallowest Mura formation geothermal aquifer is the most affected. To preserve existent water capacities guidelines for thermal water permitting were elaborated by inspecting 23 geothermal boreholes in 2008. Interpretation of obtained data enabled assessment of current and long-term state of thermal water availability. Results show that in some cases changes in well operation are already evident. Efficiency of thermal energy abstraction is not sufficient, and no reinjection is applied till now. Current operational monitoring is not satisfactory, plus no national surveillance monitoring is yet applied.

Proposed legal actions for water permitting focused primarily on mandatory, unified and integrated operational monitoring establishment. Secondly, stimulation of better efficiency of thermal energy use, best available technology application, sustainable aquifer management, and national surveillance monitoring were proposed. This should enable implementation of adequate actions regulated from the national Environmental agency to meet good status of thermal groundwater body according to the EU Water Framework Directive.

1. INTRODUCTION

Implementation of the Water Framework Directive (2000/60/EC) in Slovenia has increased activities in granting water permits for numerous types of water uses. Geothermal aquifers exploitation in Slovenia is managed by two ministries and legislations at the moment. Ministry of the Environment and Spatial Planning manages actions with regards on granting permits for thermal water users with implementation of tourist activities by the Water Act (Ur.l.RS, No.67/2002, 110/2002, 2/2004, 41/2004, 57/2008), which includes most of thermal and thermomineral water users with prevailing thermal resorts, health centers, etc. These users discharge waste water into the environment, as direct return of waste water into the aquifer is forbidden. On the other side, Ministry of the Economy issues permits by the Mining Act (Ur.l.RS, No. 56/1999, 110/2002, 46/2004, 98/2004, 68/2008) for geothermal energy users whose exploitation does not have an impact on groundwater. This type of natural resource is called geothermal energetic source, and some spatial heating systems are subjected to this group at the moment. However, as drilling into thermal aquifer, extraction and potential reinjection of thermal water do have an impact on hydraulic, heat and chemical field of the aquifer we believe that these users should also be obliged to follow the Water Act.

Discrepancy arose clearly during the process of granting water permits for thermal water users in the northeastern Slovenia, where overexploitation has already been identified in the Mura formation aquifer in Murska Sobota (Kralj & Kralj, 2000), and also indicated on some other locations. Both types of users, the one managed by the Water Act as well as those by the Mining Act, exploit the same aquifers. We believe that uniform expert approach, monitoring implementation and legal actions are needed in order to preserve existent water capacities. Thus expert basis and guidelines for water permitting on thermal water use in the Mura-Zala basin were elaborated as presented in the following text.

2. GEOGRAPHICAL AND GEOLOGICAL SETTINGS

2.1 Geographical Settings

Investigation focused on the central area of the Mura-Zala basin in the northeastern Slovenia, where Mura river plain is surrounded by Slovenske gorice and Goricko hills. Here 19 wells currently exploit thermal water, but 3 inactive and 1 potentially reinjection well were also included in the investigation (Figure 1). There are also quite some abandoned oil and gas boreholes, which are possible to remake into thermal water exploitation or monitoring wells in the future (Vizintin et al. 2008). Operating information on investigated 23 wells was acquired by Geological Survey of Slovenia in 2008.

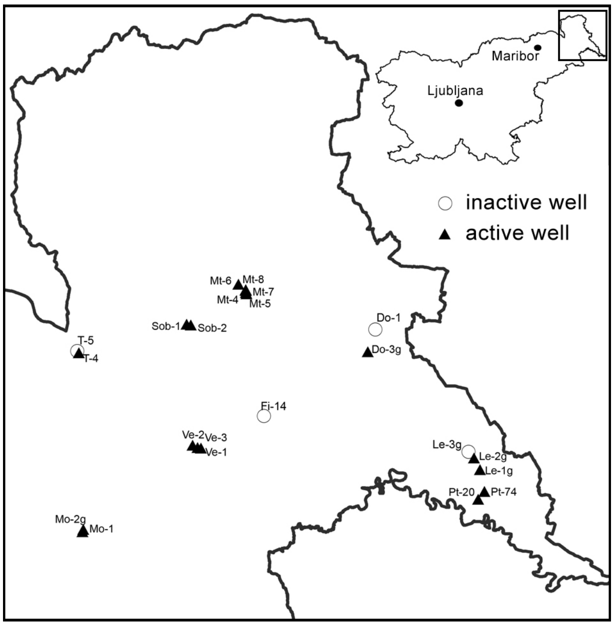

Figure 1: Location of thermal wells.

2.2 Geological Settings

Two types of low temperature geothermal systems are identified in the Mura-Zala basin (Lapanje, 2006). Aquifers in sedimentary basins within Tertiary clastic rocks and sediments overlay basement aquifers below sedimentary basins, which occur in Paleozoic and Mesozoic carbonate and clastic rocks in the same area. According to the Rules on determining water bodies of groundwater (Ur.l.RS, No.63/2005) groundwater bodies in the NE Slovenia are divided in three main aquifer types: thermal aquifers in deeper Tertiary sediments and Pre-Tertiary carbonate or metamorphic basement rocks, aquifers in shallower Tertiary sediments with fresh or thermal water; and alluvial aquifers in Mura and Drava river plains of Quaternary age.

The Mura-Zala basin (Fodor et al. 2002) appertains to the extensive Pannonian sedimentary basin. Thermal water with temperature between 80 and 200°C is identified in narrow patches of Mesozoic carbonates in Radgona and Haloze-Ljutomer-Budafa half-trenches. Pre-Tertiary sequence is covered by stratified Tertiary clastic rocks which represent the most important regional thermal aquifers in Slovenia. The lowermost is Spilje and Haloze formation aquifer (Jelen et al. 2006), previously called Murska Sobota aquifer (Kralj & Kralj, 2000b). Above, Lendava and Mura formation aquifers are situated. As the shallowest Mura formation aquifer produces thermal water with temperatures up to 65°C, and without technological problems such as degassing or scaling, its water demand is constantly increasing (Kralj, 2001; Pezdic et al. 2006).

3. METHODOLOGY

Methodology included technical and hydrogeological data collection, and extracted yield forecast, which enabled assessment of current and long-term thermal water availability.

General technical data consists of well's location, depth, drilling purpose, and wellhead status. Information on captured formations, screening depths, hydraulic tests, and performance changes were also gathered. Data on water use, schematic usage system, mode of well operation, exploitation characteristics, thermal water yield, and waste water management were listed. Interpretation was done by grouping wells which capture the same formations, and analyzing each aquifer separately, plus all together.

Observed operational monitoring parameters were: presence, location, type and recording characteristics of installed pressure, water level and temperature probes, flowmeters, outflow valves at the wellhead that enable insitu chemical sampling, and date of the last chemical analysis of thermal water. Herewith, best practice and needed future adjustments in monitoring can be identified.

Thermal efficiency was determined by comparison of used and available heat energy (Eq.1).

$$E_i = V_{aa} \cdot 4.18 \frac{kJ}{kgK} \Delta T \qquad (1)$$

where E_i, V_{aa}, ΔT are used or available annual heat energy, average annual quantity of produced thermal water, and temperature difference. In the case of used heat energy, difference between temperature of thermal water at the wellhead and emitted waste water from the system was taken. For available heat energy, waste water temperature was assumed to be 12°C, as this is the reference defined in already granted water permits (Ur.l.RS, No.104/2008, Ur.l.RS, No.125/2004). Thermal efficiency was calculated by Eq.2.

$$\mu = \frac{T_{wellhead} - T_{emitted}}{T_{wellhead} - 12°C} \qquad (2)$$

where $T_{wellhead}$ and T_{outlet} correspond to the prior described parameters.

For balneological efficiency data on annual quantity of produced thermal water, annual number of bathers and swimming pool volumes were gathered and different combinations checked in order to gain representative indicators.

4. RESULTS

Eight wells were primarily drilled for oil and gas research, 14 for capturing thermal water, and 1 for reinjection. Only 3 are deviated, and all of them are shallower than 2 km. Wellhead is most commonly positioned in properly maintained shafts, but in 3 cases these are poorly maintained and flooded. Wellheads above the ground (8 wells) are well taken care of.

Thermal wells capture three formations with quartz sand and sandstone layers: strictly Mura formation aquifer in 8 cases, joint Mura and Lendava formation aquifers in 9, mostly Lendava in 1, mostly Spilje and Haloze in 3, and Lendava plus Spilje and Haloze formations aquifers in 2 wells. Screening depths range from 400 to 1900 m below the ground. Hydraulic tests were performed at all wells, but in more than half cases they lasted less than 30 days, and sometimes no data on its duration is available. Ten wells that capture predominately Mura formation aquifer were tested by interference tests, showing hydraulic connection among them. From interviews with the maintenance staff it was denoted that changes are noticed on 10 thermal wells, which usually show lower yields, lower dynamic water levels, and changed water temperature or its chemical composition.

Eleven thermal wells are permanently in operation, 8 only in winter season, and 4 currently inactive, one of which is also the potential reinjection well. Only 4 active wells produce water by outflow, while in others pumping is needed. Depth of installed pumps varies between 35 and 160 m, depending on location. Wells registered in Mura formation aquifer have recommended yields 4-35 l/s, but short-term yields can reach up to 60 l/s per well. Lendava formation aquifer has much less favorable hydraulic conditions therefore recommended average yield is below 2 l/s per well, while short-term maximum 4 l/s. Spilje and Haloze formations aquifers can have higher values, 2-10 l/s for short term exploitation, and 2-4 l/s for average yields.

Demand for thermal water extraction has risen rapidly in the last years (Table 1), exceeding 2 million m^3 in 2008. Growing demand affects mostly Mura formation thermal aquifer, while deeper do not perceive bigger changes, as due to different chemistry their thermal water is much harder to use. Exploited quantity after 2008 is an unofficial predicted value reported by users with which they express their very-near-future plans for thermal water extraction. On the other side, quantities submitted in applications for water permits are officially reported values. Difference among them arises from the facts that for a new well, which is currently in a test phase, water permit has not yet been asked for, a few new users, which do not plan to use thermal water in the very near future, are also asking for water permits, and some existent users are asking for much higher quantities in water permits than they plan to actually produce in the very near future.

Table 1: Exploited quantity of thermal water from formation aquifers in 1000 m^3 per year.

Prevailing aquifer	In 2007	In 2008	Predicted after 2008	Water permit application
Mura & Lendava f.	1285.3	1919.7	3752.4	4820.4
Spilje & Haloze f.	267.2	255.0	501.0	416.3
Sum	**1552.5**	**2174.7**	**4253.4**	**5236.7**

In general, thermal water extraction rose for one third from 2007 to 2008, and is expected to rise further to over 4 million m^3 in the very near future. If all water permits are granted unconditionally, the future extraction can rise to over 5 million m^3 per year, of which Mura formation aquifer will contribute more than 90 %.

Exploitation systems are designed only for direct use, as the highest produced thermal water temperature is 72°C. In some greenhouses and spatial heating systems thermal water is isolated from the surroundings, but more often cascade use is common, where pure thermal water is eventually mixed with fresh water to fill the pools. All waste water is released to surface streams at the moment, with an average annual emitted water temperature between 27 and 30°C, only in one case 15°C.

Results of the investigation show that operational monitoring is only rarely satisfactory managed (Table 2). Computer managed systems usually support display of present values, but recording is too often not used. This is very common at older systems, while newly installed have better surveillance with digital instruments which also record and store measured data. Yield from individual well is vital parameter for exploitation, however, one well does not have any flowmeter installed at all, and for 3 of them only joint quantity from accumulation is measured, so no individual values are available. All four inactive wells do not have any permanently installed monitoring equipment therefore they are excluded from the table.

Table 2: Installed operational monitoring devices.

	Not measured	Measured, Not recorded	Measured, Recorded
Groundwater level	11	6	2
Wellhead pressure	3	16	0
Temperature (well/wellhead)	10	7	2
Temperature (engine room)	4	8	7
Water yield	4	7	8

Outflow valve on wellheads is installed only at 17 wells out of 23. Chemical analysis of pure thermal water is done approximately every 3 years, but there are also 4 wells, where the last chemical analysis was done more than 12 years ago. Otherwise, chemical analysis for 11 wells was done in the last 3 years, while for others in the last 8 years.

Heat of thermal water is exploited by plate heat exchangers (68%), heat pumps (11%) or both systems (16%). Total installed capacity was 87 GWh$_t$ in 2007, and 119.3 GWh$_t$ in 2008. Comparison of available and actually used heat energy calculated separately for different purposes of use is presented in Table 3.

Table 3: Used and available heat energy in the NE Slovenia in 2007 and 2008.

Purpose of use	Used energy	Available energy	Average efficiency
	TJ/year	TJ/year	%
Balneol_07	2.5	5.3	48
Balneol_08	*17.6*	*30.5*	*58*
Heat_07	24.8	32.0	78
Heat _08	*77.3*	*101.9*	*76*
Both_07	175.6	275.6	64
Both _08	*187.0*	*297.1*	*63*
SUM_07	**202.9**	**312.9**	**65**
SUM_08	**281.9**	**429.5**	**66**

Results show that thermal efficiency above 75% is reached when water is used for space and/or water heating only, while strictly balneological use has the lowest efficiency. Thermal efficiency for individual wells is in the range of 27 to 94%, with an average around 65%.

Balneological efficiency was evaluated for 7 thermal resorts based on precise data from 2007. Value of average annual bathers per pool volume is in range between 21.4 to 198.8 person/m^3, with an average of 97 person/m^3. If average annual bathers per annual extracted thermal water quantity are calculated, 0.6 to 16.0 person/m^3 is obtained, with 3.2 person/m^3 on average. The ratio of available extracted thermal water per person per day varies between 0.1 and 3.9 m^3/person/day, with an average of 1.4 m^3/person/day.

5. DISCUSSION

Based on Water Act, Mining Act, and Water Framework Directive groundwater users must not deteriorate current quantitative and qualitative conditions of the individual groundwater body. Therefore, a review of 23 thermal wells situated in the Mura-Zala basin in the NE Slovenia was performed to attain hydrogeological expert foundation for granting water permits. It indicated the following topics to be addressed in details for each thermal well gaining water permit, regardless the purpose of use: best available technology, operational monitoring, thermal and balneological efficiency, feasibility of reinjection, and recharge of thermal aquifers.

Stimulation of **best available technology** application is proposed, as this will have direct impact on decrease of produced thermal water, increase of usage efficiency, mitigation of potential system failures, and diminishing environmental pollution. Herewith, properly maintained wellheads with water release valves, computer managed frequency pumps, and computerized phases of the cascade use are recommended, together with documenting and regularly updating supporting well documentation.

As long as temperature of emitted waste water stays around 30°C thermal efficiency cannot improve. But since one user cools thermal water to almost average annual air temperature, this should not be problematical to repeat by others. Higher thermal efficiency would directly result in reduction of produced thermal water, as well as lower heat influence on surface streams to which it is emitted. Therefore, indicator of good thermal efficiency should be at least **70%**. This means that if water wellhead temperature is 60°C, emitted waste water will have maximum 26.4°C or in case of 40°C at the wellhead, emitted temperature will be below 20.4°C. In Slovenian legislation the value of **10 m^3/person/day** (Ur.l.RS, No. 73/2003, 96/2006) is determined as the limit when pool water does not need to be disinfected, so this value for thermal water should not be exceeded by anyone who uses it for balneological purposes. Better representative indicators of balneological efficiency could be chosen only if additional data on actual thermal water use for pool filling were available such are temperatures and actual yields.

Mura formation aquifer is the most exploited thermal aquifer in which hydraulic connections and changes on wells have already been noticed, but unfortunately they were not systematically measured and reported. Calculated optimum and maximum extraction rate usually does not consider interference effects between the wells, therefore newly performed hydraulic tests should include interference tests, and precise monitoring during the operation. It was also realized that current operational monitoring is not satisfactory, as it should be unified, automatic and constantly recording. Therefore, proposed legal actions for water permitting need to focus on mandatory, unified and integrated **operational monitoring** implementation, which enables continuous recording of groundwater level or wellhead pressure, water temperature, yield and chemical composition. The latter can be checked by annual chemical analysis, but if variation in composition is suspected, it should be monitored by permanently recording water conductivity probe. Monitoring results should be interpreted annually on users and national basis and its data should eventually be combined with newly established **national surveillance monitoring** of thermal aquifers. As soon as sufficient monitoring data is available nationally managed regional computer model of flow and heat transfer should be established for thermal aquifers in the Mura-Zala basin. Results of performed simulations should enable estimation of available thermal water reserves in individual aquifers, which will furthermore represent an expert basis for distribution of water permits. As such, the model should be integrated and continuously re-evaluated in order to manage thermal aquifers in a sustainable way.

There have been some efforts to restore **reinjection** into Mura formation aquifer before year 2000, but only smaller quantities of produced water were injected, and later this well was changed into the production one. Potential reinjection well is already drilled in Lendava, and will be tested in 2009. If results are satisfactory, practice of reinjection should become more widely used in the NE Slovenia in order to diminish thermal and chemical pollution of surface waters. However, reinjection is not legally obliged for any thermal water user in Slovenia at the moment.

To sum up the presented ideas, we propose that each thermal well on which water permit is granted should satisfy the following requirements: installation of best available technology, fully performing operational monitoring, thermal efficiency of at least 70%, balneological efficiency (if water is used also for balneological use) below 10 m^3 thermal water/bather/day, feasibility of reinjection should be checked, and availability of thermal water evaluated by appropriately performed hydraulic tests.

Interpretation of operational monitoring should be done on a yearly basis, and followed by adjusting granted water permit if negative trends are noticed. As long as no negative impact on thermal aquifers is seen, and all other requirements are fulfilled, users can be granted water permit for specified and already tested annual quantity. For any increase in quantities or changes of other requirements, temporary 1-year water permit should be granted to acquire information on their impact on thermal aquifers.

Until regional fully performing operational monitoring is established, and operating for one year, no new captures of thermal water should be allowed. Thus, until this is implemented only reinjection research should be conducted. In any case, extraction of thermal water quantities greater than available reserves is not allowed where each aquifer formation is treated individually.

When negative quantity or qualitative trends in thermal aquifers are identified, responsible user should be ascertained from the attained monitoring data, and his implementation of conditions defined in granted water permit checked. If all requirements are fulfilled, no further action is needed. In the opposite case, his water rights should be limited or cancelled. If responsible user is not detected, all users in the potential influential area should be treated in the latter way, and if needed, issued proportionally diminished water rights.

Existent thermal water users are recommended to be granted adjustment period of 1 year from the date of issued temporary water permit to fulfill the latter requirements. Until then, especially not before interpreted results of 1-year-long fully performing operational monitoring show good condition of thermal aquifers, no increase in thermal water production exceeding the current should be allowed. Moreover, if any of the requirements is not reached or monitoring shows negative inmpact on thermal aquifers, water extraction rate should be reduced, and new temporary water permit issued. If monitoring shows good aquifer conditions, water permit for existent quantities can be issued.

New thermal water users should implement all requirements before beginning of actual production. Quantity of thermal water submitted in application for water permit should be extracted in the first year of production, and for this period a temporary water permit should be issued. The following actions are the same as with existent users.

6. CONCLUSIONS

Water permits for thermal water production in the Mura-Zala sedimentary basin should be based on fulfilling consecutive requirements on implementation of best available technology, operational monitoring, high thermal and balneological efficiency, reinjection, and aquifer sustainable use. Suggested activities enable control over thermal water availability, and therewith they should result in meeting good status of thermal groundwater body according to the EU Water Framework Directive. Its implementation should be managed and regulated from the national Environmental agency.

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