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Is reinjection into sandy aquifers the only sustainable solution – the Pannonian Basin case

Nina Rman[1], Andrej Lapanje[1], Dušan Rajver[1*], Simona Adrinek[1], David Gerčar[1], Mitja Janža[1]
Geological Survey of Slovenia (GeoZS), Dimičeva ulica 14, SI-1000 Ljubljana, Slovenia [1*]
* dusan.rajver@geo-zs.si

INTRODUCTION

Among several Neogene geothermal aquifers in the Pannonian Basin, the transboundary Late Miocene sand and loose sandstone aquifer, the so-called basin fill "Upper Pannonnian" sequence of the Mura (in Slovenia) or Ujfalu Formation (in Hungary), is the most productive and exploited transboundary geothermal aquifer in the Pannonian Basin (Rman et al. 2015, 2020). Only 5% of identified geothermal wells were drilled for reinjection in six Pannonian Basin countries and because current permits allow much higher water abstraction as is the actual, further unsustainable developments can pose a threat for over-exploitation (Tóth et al. 2016).

In Slovenia, Upper Pannonian sandy aquifer provides about 2.3 million m^3 of thermal water per year, and had only one active reinjection well up to the end of 2024, used within a doublet for heating of the Lendava town (Valančius et al. 2023). Two more were drilled for this purpose - the first one in Moravske Toplice from 1993 was transformed into a production well in 2000, and the second one drilled in Murska Sobota in 2013 was never connected to the grid.

Exploratory monitoring identified declining trends in piezometric groundwater levels between 2009 and 2015, indicating a high risk of over-exploitation (Rman et al. 2024). This was followed by an official ban for new thermal water abstractions until the negative trend is mitigated by the Water Management Plan in 2015 and in all following periods. Recently, new reinjection wells were drilled: the one in Moravske Toplice in 2023 will be connected to the grid probably at the end of 2025 while reinjection wells in Dobrovnik are in use since the end of 2024.

METHODS

Reinjection wells as parts of doublets or triplets are promoted as one of main solutions for preventing over-exploitation of aquifers with low recharge and high development pressures. As there are various geological, technical and operational issues related to the proper position, design and management of reinjection wells in unconsolidated sandy aquifers, and we have observed improvement of hydraulic condition without extensive or additional reinjection in Slovenia, we **argue that good joint management and control of the exploitation can, to some extent, replace the need for new reinjection wells**.

To support our assumption, we have presented the development of the management systems in Slovenia, pointed out the newly developed guidelines to support planning of new reinjection wells, current research on main barriers preventing successful reinjection in loose sandstone, and compared:

- Annual abstraction of thermal water from the regional and transboundary Upper Pannonian aquifer in north-eastern Slovenia
- Groundwater levels in observation wells in north-eastern Slovenia, controlled by GeoZS
- Simulated trends in regional groundwater levels if abstraction continues as current or is increased to reach the amounts granted in concessions, using FEFLOW software.

RESULTS

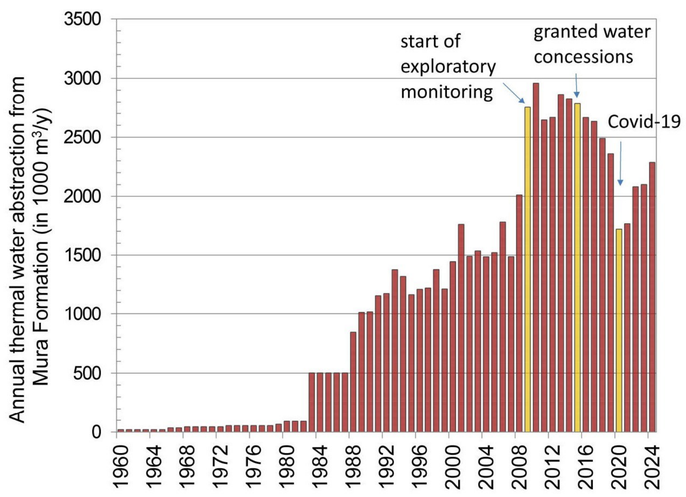


Figure 1: Annual abstraction of thermal water until 2024

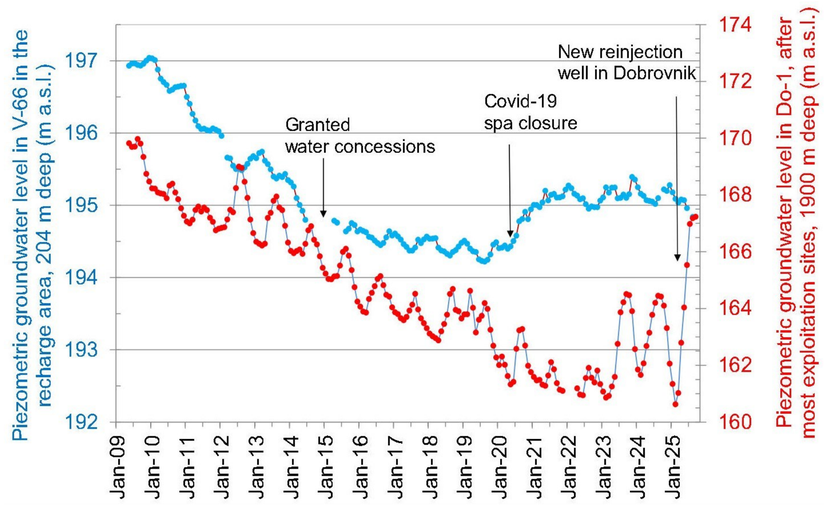


Figure 2: Groundwater level trends in 2 observation wells in 2009-2025

Unified monitoring conditions (optimization) and reporting form
3-year monitoring programme has to be approved by ARSO
Continuous hourly measurements of p/GWL, T, Q at each well
On-line daily data transmission to ARSO
Regular step tests (1st, 3rd, every 6th year)
Regular chemical and isotopic analyses
Thermal efficiency > 70%
Observation wells in critical areas
Annual evaluation of reports by ARSO
Annual numerical modelling of aquifer's state

Figure 3: Monitoring requirements in the concession decrees according to the Water Act

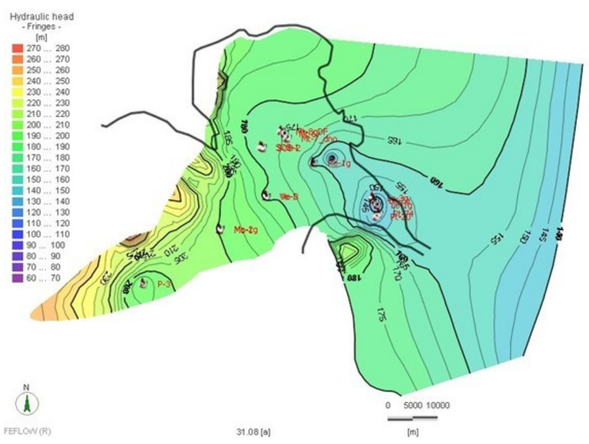


Figure 4: Simulated groundwater levels in 2040 (abstraction as in 2023m 2.2 mio m^3/y)

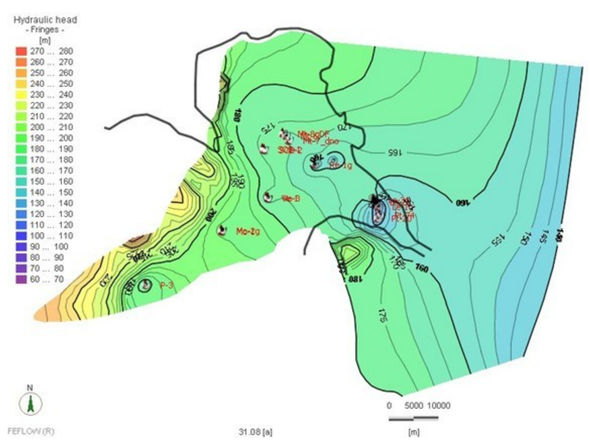


Figure 5: Simulated groundwater levels in 2040 (abstraction as in granted concessions, 2.5 mio m^3/y)

Criteria	Appropriate reinjection well
Purpose	Clear aim
Security	No risk for environment and people
Technical	Assessment of well integrity
Hydraulics	Tested and known hydro- and geothermal parameters
Leakage risk	Assessment of well integrity
Water quality	<20% difference, assessed risk of corrosion & scaling
System operation	Known operation plan, monitoring
Injection rate	Reasonable well: 40-60% return Moderate well: 60-80% return Good well: >80% return
Annual amount	Reinjection well: >80% production Reworked well: >40% production

Figure 6: Current guidelines for reinjection wells in Slovenia

DISCUSSION

Following a strict operational monitoring control since 2015, when the most concession contracts according to the Water Act were signed in Slovenia, the regional abstraction has reduced and groundwater levels stabilized. During the COVID-19 years (2020-2021), several spas were closed, reducing the regional abstraction to 1.8 mio m^3/y which stabilized or increased groundwater levels. In 2024, abstraction reached pre-covid amounts (>2.3 mio m^3/y), which again affected the levels and often turning the trend toward the decrease. The most evident effect of a new reinjection well is observed in Do-1 observation well (Fig.2) where groundwater levels after half year of reinjection about 2 km away returned to pre-2015 ones, which is very favourable.

CONCLUSION

Based on observed dependency of regional groundwater levels and abstraction, and numerical simulation, we estimate the available amount of thermal water in the Mura Formation for exploitation without reinjection to cca 2 million m^3 per year. All additional development needs are available only using the doublets or triplets, with reinjecting waste thermal water. We have proven that detailed and ongoing management can improve the water balance, however, this approach is limited by physical aquifer properties. For additional needs, reinjection remains a necessary measure for good aquifer management, and can be better developed using already published guidelines (INFO-GEOTHERMAL project results).

Acknowledgements

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REFERENCES

Rman, N., Gál, N., Marcin, D. et al.: Potentials of transboundary thermal water resources in the western part of the Pannonian basin, Geothermics, 55, 88-98, (2015), https://doi.org/10.1016/j.geothermics.2015.01.013

Rman, N., Lenuța Bălan, L., Bobovečki, I. et al.: Geothermal sources and utilization practice in six countries along the southern part of the Pannonian basin, *Environmental Earth Sciences,* 79:1, (2020), https://doi.org/10.1007/s12665-019-8746-6

Rman, N., Lapanje, A., Rajver, D. et al. 2024: Booklet on energy efficient use of geothermal resources and their development, 37 pp., ISBN 978-961-6498-81-4, https://kdb.api.gic.geo-zs.si/api/v1/documents/138/pdf/DC%204_1%20Knjizica%20o%20energetsko%20ucinkoviti%20rabi%20geotermalnih%20virov%20in%20njihovem%20razvoju.pdf

Tóth, G., Rman, N., Rotár-Szalkai, Á. et al.: Transboundary fresh and thermal groundwater flows in the west part of the Pannonian Basin, *Renewable and Sustainable Energy Reviews*, 57, 439-454, (2016), https://doi.org/10.1016/j.rser.2015.12.021

Valančius , R., Černeckienė, J., Jurelionis, A., Analysis of the Wider Potential for Heat Pump and Geothermal Energy Integration in Traditional Systems and Grids , Energetika, 69:1, 49–64, (2023), https://doi.org/10.6001/energetika.2023.69.1.4