European Geothermal Congress 2013
Pisa, Italy, 3-7 June 2013

Integrated geoscientific modelling of the TRANSENERGY project area

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Keywords: geological model, groundwater flow system, geothermal potential, geothermal reservoir, transboundary groundwater bodies.

ABSTRACT

During the every day management of thermal-water systems, a tool is needed to provide the decision makers with information about the future responses of the system to the effects of various interactions, as well as about available hydrogeothermal resources. This tool can be based on the results of different models.

At the frame of TRANSENERGY project series of conceptual and numerical models were built on each other. They handled the project area in a uniform system approach. It had given an overview on the large-scale geological, hydrogeological and thermal characteristics of thermal water flow systems in the western part of the Pannonian Basin

The developed models describe the groundwater flow and geothermal system behaviour and its possible changes and serve as a basis for sustainable trans-boundary thermal water- and energy management.

1. INTRODUCTION

Natural resources, such as geothermal energy, and its main carrying medium are deep groundwaters along regional flow paths, are strongly linked to geological structures that do not stop at state borders. Therefore only a trans-boundary approach and the establishment of a joint, multi-national management system may handle the assessment of geothermal energy and the limits of use in a region, irrespective of political state borders. This is especially true for trans-boundary aquifers, where water extraction at a national level without cross-border harmonized management strategies may cause negative impacts (depletion or overexploitation) leading to unnecessary economic and political tensions between countries.

Geothermal resource assessment was carried out by various geological, hydrogeological and geothermal models at the TRANSENERGY project area situated on the western part of the Pannonian Basin, and Vienna Basin along the border regions of Austria, Slovakia, Slovenia and Hungary. The different types of models are interconnected and build on each other.

The *geological model* outlined geometry of the formations for the hydrogeological models. The main geological units with similar hydrogeological characteristics define hydrostratigraphical units, which are one of the key inputs into the hydrogeological models.

The *hydrogeological model* described the cold and thermal water flow system. Hydrogeological models serve as the basis of prediction the effects of hydrological changes in the aquifer. Hydrogeological models were calibrated and verified by hydrogeochemical models. The hydrogeochemical model (as part of the hydrogeological model) helped to recognize and understand the ongoing processes in the thermal water reservoir systems.

The *geothermal model* expressed the temperature distribution in 3D and its possible alterations because of the advection/convetion processes. The geothermal model developed based on the geological model as a pure conductive model, and than was compared the results of the flow system.

2. GEOGRAPHICAL SETTING

The TRANSENERGY project area is situated in the trans-boundary region of Austria, Slovakia, Slovenia and Hungary. This part of the Pannonian Basin is surrounded by the eastern margin of the Alps, the western margin of Carpathians, the Trans-Danubian Midmountains and the Slovenske Gorice. Between these mountains there are lowland regions separated with hilly territories and smaller inselbergs (island-hills) (Figure 1).

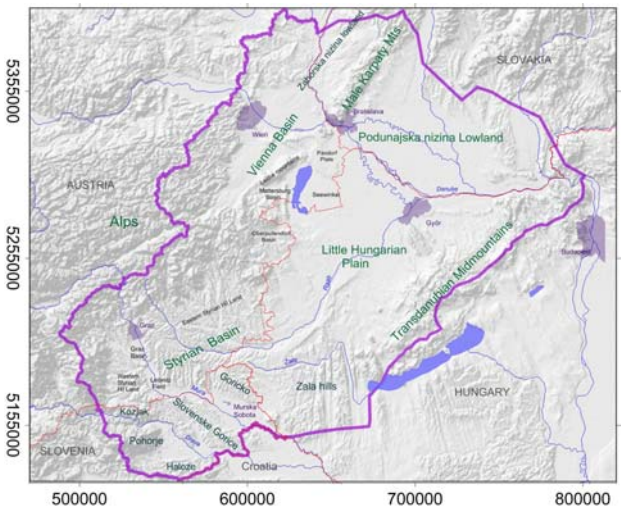

Figure 1. Geographical settings of the project area

The Austrian part of the TRANSENERGY project region comprises the eastern margin of the Alps and its intra-mountain basins. The two most important geological basins of this region are the Styrian Basin in the southwest and the Vienna Basin in the northeast.

The Slovakian continuation of the Vienna Basin is the Zahorska nizina Lowland. Eastward it is separated from the Podunajska nizina Lowland by the Male Karpaty mountains. Podunajska nizina Lowland is bordered by the western margin of the Carpathian Mountains on the northern and eastern side. Towards the south the Lowland continues to the Little Hungarian Plain in Hungary.

The Little Hungarian Plain is situated in the north-western part of the Hungarian project area. South-eastward it is bordered with the Trans-Danubian Mid-mountains, has and its continuation in the basement of Zala Hills.

This hilly region is continuing towards Slovenia, in the Goricko. The central part of the project area in Slovenia is Slovenske Gorice. On the western part it is bordered by Kozjak, Pohorje and Halože hilly areas. In the Slovenian part os the investigated area the Drava, Ptuj, Ormož and the Mura fields are situated.

3. GEOLOGICAL MODEL

Geological model (Maros et al. 2012) serves as the geometrical framework and determines the lithological composition for the hydrogeological and geothermal models through a 3D model, visualised by different maps and cross-sections. Geological model provides basic information for determining the rock-attribute set of a given point in space, on the basis of which hydrogeological and geothermal models run.

Hydrogeological models require not only the hydrostratigraphical units, but surfaces which border them (various geological depth-contour maps). The constructed maps represent the interface of these geological units. In general we compiled the lower surfaces what we call base map. The base map plots formations below the given geological age and the topographic position of the formations below sea level. There were constructed basement map for each hydrostratigraphical units were. On the basis of geological surfaces different lithological and worm-eye maps were constructed too.

A so called supra-regional geological model were constructed for the entire region, containing elevation and geological formations, by a "nick-name": flying carpets. (Fig.2.), which means that instead of a voxel model, surfaces encompass the surface space grid and geological database information (Maros et al. 2012).

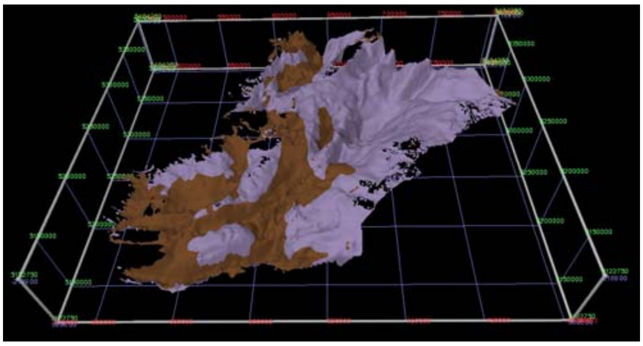

Figure 2. Pre-Cenozoic and the Pre-Neogene horizons

Three cross-sections were constructed which are more or less perpendicular to the main tectonic structures. These sections illustrate complex geological structure (with different napes, thrust sheets, strike slip structures and normal fault systems) of the West-Pannonian Basin.

One of the most important task within geological modelling was the harmonization. To develop the harmonized legend, the scale of the maps and sections, and the agreement with a common symbol system was essential.

4. HYDROGEOLOGICAL MODEL

The aim of the hydrogeological model is to give an overview on the large-scale hydrogeological processes of thermal water flow systems in the western part of the Pannonian Basin. Thus, the connection among the main groundwater bodies (that sometimes have very different geological-hydrogeological characteristics) can be determined.

4.1 Developing numeric model

A steady state three dimensional groundwater flow model was constructed, calibrated, and used to describe regional flow of the project area. The modelling was performed by finite-difference Visual

MODFLOW, which is a graphical interface of the worldwide standard modelling code MODFLOW.

The first step in the modelling process is the construction of a conceptual model consisting of a set of assumptions that verbally describe the system's composition, the ongoing processes that take place in it, the mechanisms that govern them, and the relevant medium properties. The conceptual model was based upon the detailed hydrogeological and hydrochemical characterisation of the model area (Tóth et al. 2012).

The hydraulic and thermal systems of the NW Pannonian Basin consist of two main and separate groundwater flow systems, the porous system and the basement system. The more or less separate Neogen sub-basins of the NW Pannonian Basin are filled with porous sediments in great thickness. Some part of these porous sequences are important thermal water aquifers. Despite of the different hydrogeological characteristics and conductivities of the layers, the whole Neogene porous system forms a uniform hydraulic system, in which separate, sometimes several hundred meter thick aquifer and aquitard layers alter.

The basement formations consist of metamorphic crystalline and carbonate rocks. Basically the crystalline rocks cannot be considered as real aquifers, but the fissures of the rocks can have higher conductivity, especially in the upper weathered zone. The most important thermal water aquifers of the basement are the carbonate formations. Sometimes they can be characterized as fissured aquifers, but usually they were karstified during different stages of geological history.

These two systems (porous and fissured or karstic basement) are separated by thick lower Pannonian and Miocene aquitard formations, and therefore form independent thermal water systems. These systems needed different approach in the modelling, so two different models were developed, however they have been merged together at the end of the modelling work. Having the same model grid the physical merging of the two models was a simple task adding the basement layer to the porous model. All the applied boundary conditions and calibration elements were used in the merged model.

Developing the model started with simple, (horizontal) 2D version and gradually (step by step) became to a more complicated 3D model version. This kind of model developing ensures the reliability of the model in every phase.

4,2 Results of the hydrogeological numeric model

The major outputs of the Supra Regional model are the following:

- computed shallow groundwater table, confined cold and thermal water heads in the porous parts, karst and fissured water table and thermal karst water heads (Fig. 3 and 4);
- computed flow lines, groundwater velocities and directions in 3D,
- computed discharge at the major springs and at other discharge objects (rivers, seepage faces),
- computed and aggregated drawdown of the production wells,
- computed budgets of the major delineated groundwater bodies, including trans-boundary water transfers.

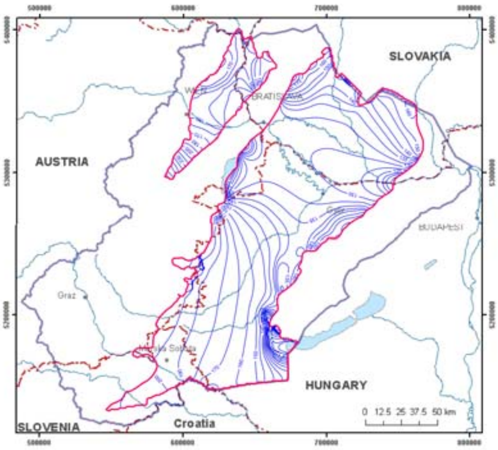

Figure 3. Head values in the thermal water aquifer komplex of the Upper Pannonian

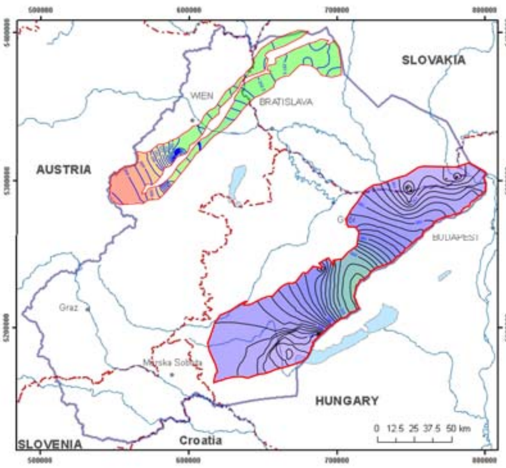

Figure 4. Head values in the karst aquifers of the basement

It is clearly shown in Fig. 3. and 4., that the major thermal water flows through the national borders. The budget of these trans-boundary zones are calculated for the model.

Table 1. demonstrates the possible water transfers between the cold and thermal groundwater bodies. It also gives information on the trans-boundary budgets. Similar tables can be produced for the present state abstractions, or any reasonable scenarios. The model can be used this way also for the trans-boundary management purpose.

Table 1. Zone budget of the transboundary areas (values are in m3/d)

		To								
		Cold unconfined (14)	AT Cold confined Pa2 (11)	AT thermal Pa2 (10)	SK Cold confined Pa2 (7)	SK thermal Pa2 (6)	SLO Cold confined Pa2 (8)	SLO thermal Pa2 (12)	HU Cold confined Pa2 (4)	HU thermal Pa2 (5)
From	Cold unconfined (14)		**24180**		**63250**		**15330**		**101410**	
	AT Cold confined Pa2 (11)	**10840**		**1570**	**390**	**2**	**910**		**22320**	**390**
	AT thermal Pa2 (10)		**2480**						**60**	**1960**
	SK Cold confined Pa2 (7)	**73620**	**150**			**16960**			**610**	**100**
	SK thermal Pa2 (6)	**180**			**20510**				**130**	**8560**
	SLO Cold confined Pa2 (8)	**14540**	**460**					**11690**	**9800**	**440**
	SLO thermal Pa2 (12)						**8360**			**6650**
	HU Cold confined Pa2 (4)	**144660**	**6570**	**90**	**3410**	**60**	**9170**	**1**		**30470**
	HU thermal Pa2 (5)	**330**	**170**	**2690**	**170**	**2560**	**550**	**2720**	**36700**	

Scenarios of different rate of pumping in the existing thermal water wells in the partner countries were examined. Results clearly showed, that production in each region has trans-boundary consequences. The computed drawdown of all productions of second half of the last decade are shown in Fig.5. The regional values are rarely larger than 8 m, mainly in the Slovenian part and around the Zalakaros spa (SW-Hungary). One of the more realistic scenario is supposing 5 times higher production at each present utilization area in the future the regional drawdown is larger than 20-30 meters. It means the depressions would be much larger at the given production wells (>50-100 m). The results highlighted to the limitation of thermal water utilization without re-injection in this region.

5. GEOTHERMAL MODEL

One of the goals of the geothermal modelling was to present an overview of the geothermal conditions for the entire project area in order to enhance the awareness and understanding about existing resources. Furthermore geothermal boundary conditions could be determined for regional scale geothermal models within the project area. Based on that, the geothermal potentials and resources within the area could be estimated to allow a sustainable (and balanced) utilization of the existing hydrogeothermal resources.

The geothermal regime of the supra-regional model is represented by means of temperature maps for several depths as well as by a surface heat flow density map. By using continuous thermal logs, bottom-hole-temperature (BHT) and drill-stem-test (DST) data obtained from wells, it was possible to estimate the geothermal regime. In addition to the in situ-data, outflowing water temperatures were included in the thermal processing.

The geothermal model expressed the thermal potential of the project area. 3D temperature distribution is presented on temperature maps of 1000, 2500 and 5000 m depth. Different horizons of 50°C, 100°C and 150 °C isotherm surfaces, and the temperature map of the Pre-Tertiary basement formation (Fig. 5) were created as well as surface heat flow density map. The values of heat in place and specific identified resources related to different rock formations (Neogene sediments and upper 50 m of the Pre-Tertiary basement) were determined. The significant regions with convective heat flow were identified by comparing the conductive geothermal model and the groundwater flow model (Goetzl et al 2012).

3. CONCLUSIONS

Integrated geoscientific modelling was carried out at the trans-boundary zone of the TREANSENERGY project.

The models were developed on the basis of harmonized geological data, maps and constructed geological surfaces of four countries, Austria, Hungary, Slovakia, and Slovenia. Harmonizing all the available geological information from the different countries new geological maps and series of geological horizons were created to serve as the frame of the hydrogeological and thermal models.

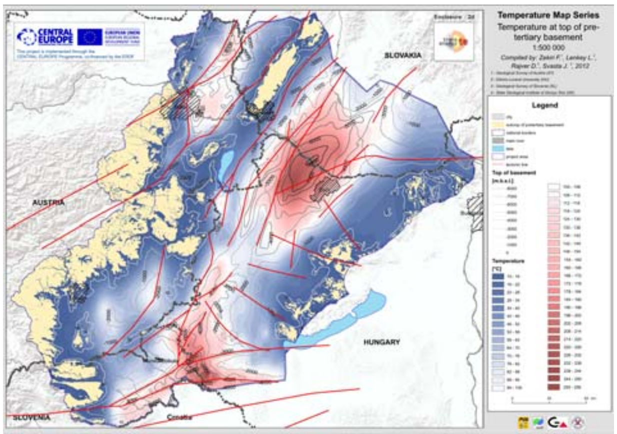

Figure 5. Temperature at top of Pre-Tertiary basement

The hydrogeological model is a unique flow model both in scale and regarding its the transboundary character. It is based on a special theory of combining the upper porous and the lower basement model of the fractured-karstified formations.

In the steady state groundwater flow model three different conditions were simulated: condition without groundwater abstraction, condition with current abstraction and condition with the abstraction five times greater than current pumping volumes at the studied area. The results of the different model scenarios showed that some of the national utilizations have trans-boundary consequences and they have significant trans-boundary effects together. Furthermore, the results showed the limitation of thermal water abstractions.

The joint interpolation and modelling of harmonized geothermal data led to a compilation of geothermal maps in scale of 1:500.000, which cover the entire Western Pannonian Basin and its adjacent areas for the first time The quality and significance of the elaborated heat flow density and temperature maps reflect the data situation of 2010. By applying easily applicable, well documented approaches the existing maps can be updated in future without great effort.

The elaborated geothermal potential maps and balances only allow taking a first look on the available geothermal resources and actual degree of exploitation at the project area, irrespective to known or estimated geothermal plays and reservoirs. However, the achieved results imply, that only a very small amount of the available believed geothermal resources is already utilized (<1%) and therefore, hydrogeothermal utilization is able to play an important role in the future energy supply in the TRANSENERGY project area.

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