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Hydrodinamic and heat transport modelling of the regional transboundary geothermal aquifers of Western Hungary

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ABSTRACT

The research area is situated in the transboundary region of Hungary, Slovakia, Austria, Slovenia and Croatia. The Upper Pannonian porous cold and thermal aquifer is affected each country, while the large karstwater-aquifer, contains of mainly Upper-Triassic carbonates, mainly situated in Hungary. The groundwater bodies are divided by national boundaries and are in focus of International Commission for the Protection of the Danube River (ICPDR).

For more than 50 years, more than 300 thermal wells utilize the thermal water from both kind of aquifers. So, in some parts of the research area the problem is the over-production, while in other parts of the area the refilling karst system causes uncontrolled water seepages on the surface. Next to the drinking water-, balneological- and agricultural water utilizations, there is increasing demand for the energy purpose of the thermal water, which may be confronted to the existed and/or domestic uses.

For the sustainable utilization and management regional hydrogeological and geothermal investigations are needed: the determination of the regional flow paths is the key for the sustainable and coordinated utilization.

The main questions are: what kind of flow systems situated in the porous and karst aquifers? How are the gravitational and geothermal forced systems linked? Which are the main flow directions? Are there conductive, convective and/or mixed flow systems in the geothermal system? How can we give answer for the geothermal anomalies? How can we utilize the changing systems in the future?

My PhD thesis is looking for the answers to the questions above with a complex 3D hydraulic and geothermal model based on geological, hydrogeological and geothermic data from each country.

1. INTRODUCTION

Hungary has great (thermal)water potential, compared to the European countries. The water has been used for over 140 years for different purposes: drinking water, balneological-, agricultural utilizations. With the increasing demand for the energy purposed abstractions, it may be confronted to the existed and/or domestic-, mainly in field of the high temperature utilizations. Because of this and the pressure drawdown, nowadays the sustainable utilization of the water – as natural resource – is an important and increasingly urgent problem. Along the state borders this problem is also a transboundary problem, where the effects of the water abstractions even can be observed across the borders.

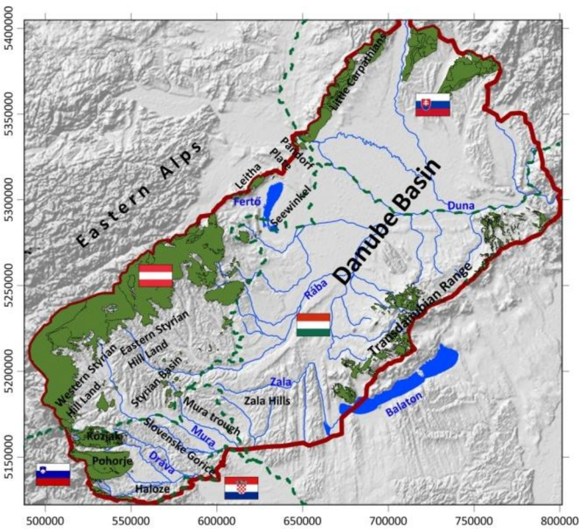

Figure 1. The studied area

From the problems mentioned above, and previous experience in (regional) and geothermal modelling (e.g. pilot area modelling of Transenergy project, etc.) pointed to the local investigations are not sufficient anymore for the sustainable utilization and management: regional hydrogeological and geothermal investigations are needed for the sustainable management.

By the help of the modelling and the investigations of the natural water and heat flow system, the geothermal utilizations and their effects on the other utilizations and/or the thermal aquifers in the area can be accurately planned. The impact areas of the utilizations can be delineated and the sustainable management of the geothermal utilizations can be planned for the (transboundary) aquifers.

2. GEOGRAPHIC, GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

Hungary is located in Middle-Eastern Europe, in the Carpathian Basin. The studied area is mainly situated in the western part of Hungary: the Zala Hills, the Transdanubian Range, the Danube Basin and their (basinal) continuation in Slovakia. In Austria the Pandorf Plate and Seewinkel, and towards south the Styrian Basin, in Slovenia the Mura and Drava Trough, Pohorje, Kozjak and Haloze, in small area of Croatia, the Mura Hills belong to the studied area (Figure 1).

Geological-hydrogeological conditions were taken into consideration during the outlining of the model area: the borders are natural regional watersheds of the Upper Pannonian porous and Mesozoic karst (cold and thermal) aquifers.

2.1 Geology

The Pre-Tertiary basement of the area mainly belongs to the ALCAPA (East Alpine–Central Western Carpathian–North Pannonian) major tectonic unit, characterized by complicated geological structure and tectonic systems (normal fault and strike slips structures), thrust sheets and nappes. One part of the basement is non-metamorphic, while the another part is affected by Alpine and older metamorphism (Maros et al., 2012).

The main tectonic unit of the area, the Transdanubian Range Unit, has tectonic borders and built up mainly Mesozoic platform carbonates (Main "Haupt" Dolomite and Dachstein Limestone). The synclinorium structure of the Transdanubian Range defines the extent of the geological formations: the Lower-Triassic carbonates take place on the marginal part of the synclinal, while the younger Cretaceous sediments are situated in the inner part of the structure (Haas et al., 2001) (Figure 2.a).

The Palaeogene sedimentation is limited to small areas: fine-grained sediments exists in the Transdanubian Range and Zala Hills (Hungary), in addition, Gosau sediments can be found mainly in patchy distribution in the Graz region, Slovenia and Slovakia.

During the Early- and Late-Miocene the sedimentation was linked to the extent of the Neogene basins (Danube Basin, Styrian Basin, Zala Hills, Mura and Drava Troughs). The sedimentation was compensated only in the Late Miocene/Pannonian.

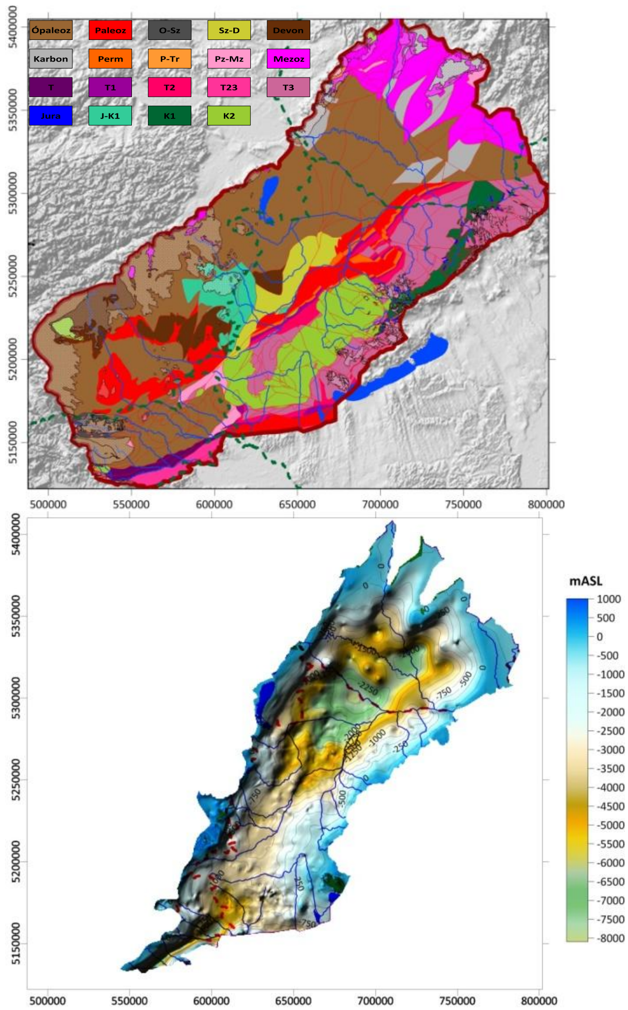

Figure 2. The geology of the Mesozoic basement of the studied area (2.a) and the bottom of the Upper Pannonian sediments in the model area (mASL) (2.b)

The Pannonian sedimentation was related to the infilling of the Lake Pannon. The deltafront was prograded mainly from NW to SE and in the first time coarse sediments, then turbidites, silts were deposited. During the Upper Pannonian thick beds of delta and alluvial plain sediments (Újfalu/Mura/Beladice, Zagyva, Nagyalföldi Formations) were deposited. (Figure 2.b) The overlying deposits of the Pannonian sediments are Pliocene fluvial deposits (Nagyalföld, Ptuj-Grad, Mura Formations).

The Quarternary sedimentation was related to the rivers in the lowlands, while eolian formations, talus and travertine were deposited in the hilly areas.

2.2 Hydrogeology

The main and most important regional aquifers in the NW Pannonian Basin are the Upper Pannonian porous aquifer (consists of sediments: Újfalui, Zagyva, Nagyalföld, Mura Ptuj-Grad Formations) and the karst aquifer of Upper Triassic platform limestones and dolomites (Dachstein Limestone and Main Dolomite).

Natural flow systems in the karst aquifer

The 1500-2000 m thick carbonate sequence of the Mesozoic carbonates were affected by strong karstification. The fractures, conduits and/or caves of the well karstified system determine the flow system: the upper part of the aquifer has high permeability and intensive karst-water flow takes place in this zone (Figure 3.a).

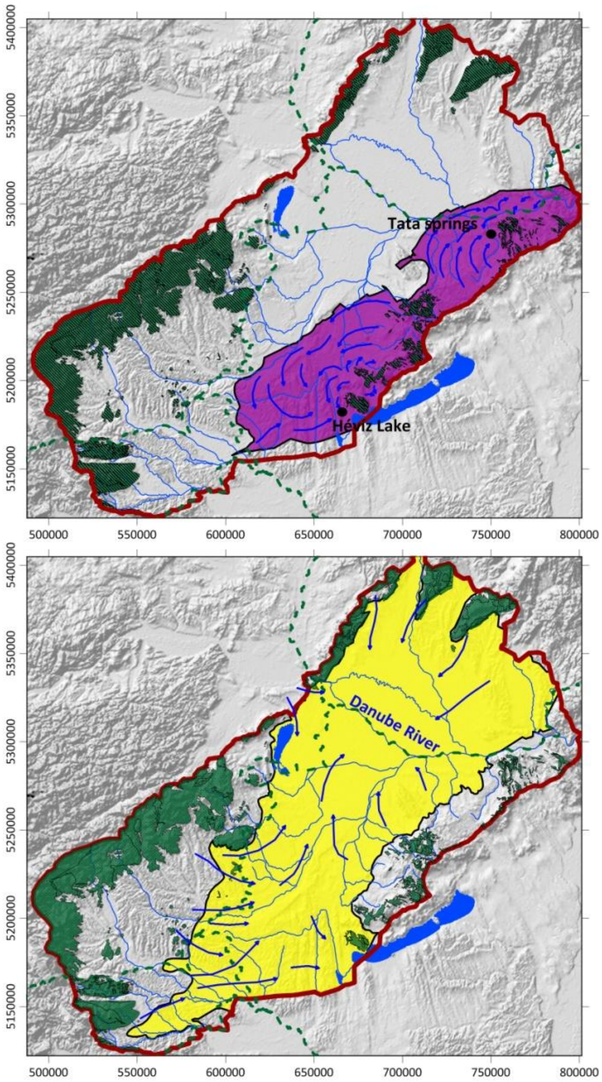

Figure 3. Natural flow systems of the Mesozoic karst aquifer (3.a) and of the Upper Pannonian porous aquifer (3.b) (basement outcrops with green colour)

The carbonates crop out on the high positioned area of the Trasndanubian Range, where the precipitation infiltrates and flows towards the deeper and confined part of the karst aquifer. In the SW-Bakony Mountains, in the deep, the water flows towards W and SW, then turns back to E, in the NE-Bakony Mountains the main flow direction is NE. The warmed up water enters the surface in karst springs situated in the marginal parts of the mountain. The main discharge zones of the karst aquifer are the Hévíz Lake, Tapolca- and Tapolcafő springs in the SW and in the NE part the Esztergom-, Patince-, Dunaalmás- and Tata lukewarm springs (Franko et al. 1995, Alföldi et al., 2007) (Figure 3.a).

During the 1950's and 1960's water abstractions related to the coal and bauxite mine, effected regional depressions and changes in the natural flow systems: the cold and lukewarm karst springs started to disappear. Only from the 2000's, many years after the mine closures, started the karst system to regenerate and some springs to reappear.

Natural flow systems of the porous aquifer

A very thick Upper Pannonian porous aquifer is situated in Western Hungary: Danube Basin - 1500-2000 m, Zala Hills and Mura-Dráva Basin - >1000 m. The aquifer mainly contains of sands and sandstones intercalated with clay and silts, which form numerous layers and lens thickening from the margins towards the inside of the basin. In the marginal part of the aquifer, the sand layers are thin and cannot be followed laterally for long distance, but in the inner part of the basin we can found more, thicker and laterally extensive sand/sandstone layers.

In the sedimentary basin exist a gravity-driven flow system and a deeper pressure-driven flow system. The shallow flow system is driven by the main river of the studied area, the Danube. The water in the porous sequence flows from the margin of the aquifer towards the inner part of the basin, towards the Danube (Erdélyi, 1971, Tóth et al., 2012). In the SE part of the area one part of the water flows – through the model boundary – to SE (Figure 3.b). The Upper Pannonian porous aquifer has close contact with the Quarternary unconfined aquifers and they form a uniform regional hydraulic system.

More than 200 wells were drilled on the porous aquifers and used their thermal water (T>20 °C) in the last 60-70 year.

3. MODEL DEVELOPMENT

To describe the natural, initial conditions of the cold and thermal flow systems of the studied area, in the first step of the modelling, a steady state 3D hydrodynamic model was developed by the help of FEFLOW 6.2 modelling code.

2.1 Model description

Model geometry and parameters

During the finite element mesh design the main cold, lukewarm and hot springs, thermal wells, main rivers, and tectonic element were taken into consideration. After the refinement around the springs, wells, rivers, main tectonic zones, the mesh consists of 923 000 finite element and 526 464 nodes. The total area of the constructed model is 42 040 km2, the total model volume is 432 185 km3. The top of the model is the topographical surface, the model basement is situated in -10 000 mASL.

For the vertical structure of the numerical model, the geological formations were merged into 9 larger units based on their stratigraphic and hydrogeological characteristics. These 8 hydrostratigraphic units are located in 9 layers (Figure 4) and horizontally pinches out, hence in one model layer more than one units can be found. The main hydrostratigraphic units, the Upper Pannonian porous and the Mesozoic carbonate units are represented the porous and karst aquifers.

The initial hydrogeological parameter values are based on well hydraulic tests and literature data. The parameter zones of the model layers are assumed according to the hydrogeological characterization of the geological formations.

Boundary conditions

The model horizontal boundaries follow the natural, regional watersheds: so they are "no flow" boundaries and only in a short sections (in SE and NW) are artificial. The SE and E model boundaries are also the regional watersheds of the karst system of the Transdanubian Range.

The higher elevated regions in the E part of the model area, where the carbonates crop out on the surface, are the main recharge areas of the karst aquifer. These zones were delineated by the help of the surface lithology and meteorological data.

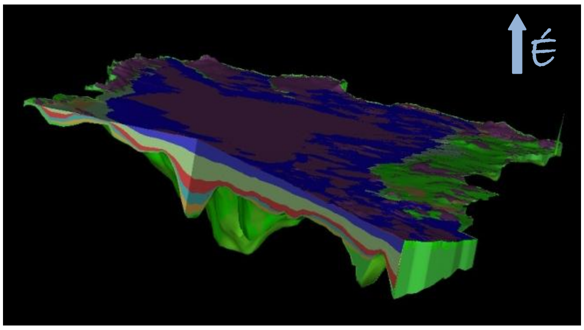

Figure 4. The main hydrostratigraphic units of the numerical model (figure basement=top of the Pretertiary basement)

The main rivers and their alluvium are the natural discharge zones of the porous system, while the main discharge areas of the karst system are the springs. Numerous (thermal) wells represent the artificial discharge points of both aquifer.

For the model calibration calculated groundwater tables, based on the well-, field data, and literature maps, were used.

4. MODEL RESULTS AND FURTHER TASKS

In this paper presented model results are preliminary and connected to the hydrodynamic modelling.

The following figures (Figure 5.a and b) show the modelled natural hydraulic head distribution both in the Mesozoic karst and Upper Pannonian porous aquifers. The modelled water flows closely follow the natural hydraulic potential existed in the karst and porous system. From the middle part of the aquifer, the infiltrated water flows towards W and SW (to Zala hills) then turns back to the direction of the Balaton and Hévíz Lake. In the NE part of the Bakony, the water flows to N-NE (to Slovakia), from the Vértes-Gerecse Hills, the karst water flows towards N, NE (Figure 6.a). The Figure 6.b shows the modelled hydraulic potential in the porous system. The main discharge area of the Danube River can be clearly identified.

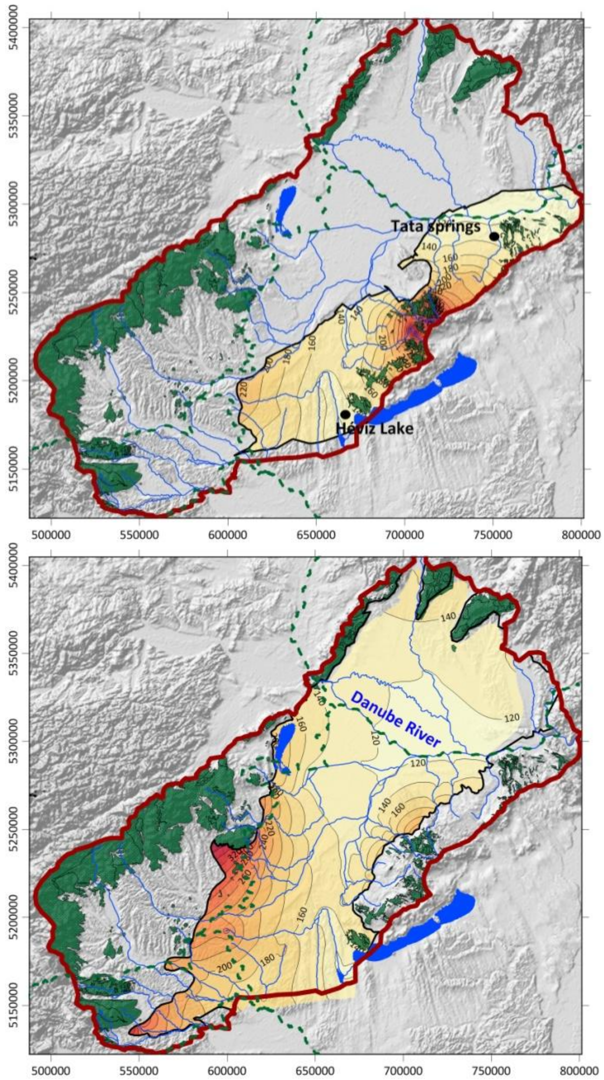

Figure 5. Simulated natural water table elevation (mASL) of the karst aquifer (5.a) and of the Upper Pannonian porous aquifer (5.b) (basement on top with green colour)

The numerical modelling consists of three steps. In the first step a hydrodynamic model was constructed. In the last year of the phD studies, the next task, after the calibration, the hydraulic model transformation into geothermal model.

The geothermal settings of the modelled area is very complicated. In the karst aquifer two geothermal system can be separated. In both system the infiltrated precipitation can cooled down the system even at long range from the recharge areas. The system is mainly affected by forced heat convection. In the NE-Bakony, the water can't reach as high as temperatures in the SW part of the system, thus in the area of the Zala

Hills we can found higher water temperatures. The thicker, deeper and more extensive aquifer has larger heat convection systems (Gáspár et al., 2013, Joháné, 2009).

In the third step, by the help of the model (knowing the water and heat flow system) the geothermal utilizations and their effects on the other utilizations and/or the thermal aquifers in the area can be accurately planned.

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