Complex Hydraulic and Geothermal Model of the Komarno-Šturovo Pilot Area of the TRANSENERGY project

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Keywords: 3D modeling, geology, hydrogeology, groundwater flow

ABSTRACT

The Komarno-Šturovo (Komárom-Párkány) Pilot Area of the Transenergy Project is situated in the north-eastern part of the Transdanubian Range in Hungary and its basinal part in Slovakia. The groundwater bodies are divided by national boundaries and are in focus of International Commission for the Protection of the Danube River (ICPDR).

The large karstwater-aquifer contains of mainly Upper-Triassic limestones and dolomites (Dachstein Limestone, Main-dolomite) affected by bauxite (Fenyőfő) and coal mining (Dorog, Mány, Tatabánya, Balinka, Dudar) and its growing dewatering since the 1950's. Due to the intensive water extraction the water table significantly decreased and cold and/or warm springs disappeared (Tata-, Dunaalmás-, Esztergom springs) or the yields reduced (Budapest thermal springs, the Patince spring/well lost its artesian characteristic) along the whole Transdanubian Range since the 1960's. After the mine-closures the water abstraction of the mines decreased or stopped (somewhere replaced by drinking water supply, e.g. Tata) the karstwater level started to increase and springs reappeared and their yields increased: the Csokonai spring reappeared in 1999, the Fényes-spings in 2002.

In the last few years this increasing in the water levels sets a lot of new problems. How does regenerate the karst-flow system? Can the system totally regenerate? Is it possible that the current utilizations develop their services? Shall new investments get permissions? What will be the effects of the developments and/or new investments?

A complex 3D hydraulic and geothermal model based on geological, hydrogeological and geothermic data from both countries is looking for answers to the questions above. The regeneration of the discharge zones, the present and future utilizations can be determined by the help of transient flow and geothermal modelling the refilling of the system.

1. INTRODUCTION

In the first step a steady state model was made in the Komárno – Štúrovo pilot area of the Transenergy project. The modelling was focused on the karst aquifer of the Triassic limestones and dolomites in the NE part of the Transdanubian regional karst flow system.

The actuality of the modelling is the recovering karst system throughout the Transdanubian Range. From the beginning of the 1900's the karst system is affected by bauxite and coal mining, which became more intense in the 1950s: intense karst water abstractions started in the whole area (eg. Fenyőfő, Dudar, Kincsesbánya, Tatabánya, Mány, Dorog etc.). These water abstractions seriously impaired the natural karst flow system and caused regional, transboundary depressions in the Transdanubian Range. Several lukewarm (15-30°C) springs had dried up due to this activity.

After the mine closures the karst flow system started to regenerate and the beginning of the 2000's the hydraulic heads continuously rising (e.g. Tata, Tatabánya, Patince, etc.) and some of the springs reactivated (e.g. Dunaalmás, Tata, etc.). Under these conditions the historic spa utilizations took place in Tata, Esztergom, Štúrovo, Patince pretend larger production yields for the operation of the spas. Some old/new utilizations in the NW part of the pilot area also exist and used the thermal water for spa or agricultural targets. The main question is how the spa and agricultural utilizations can coordinate their operations and claims in a sustainable manner in this changing system.

3. GEOGRAPHIC SETTINGS

The Komarno-Šturovo (Komárom-Párkány) Pilot Area of the Transenergy Project is situated in the north-eastern part of the Transdanubian Range in Hungary and its basinal part in Slovakia. The groundwater bodies are divided by national boundaries and are in focus of International Commission for the Protection of the Danube River (ICPDR).

The borders of the pilot area fit the presence of the Triassic carbonate basement and the watershed of the carbonate aquifer. The south-eastern and eastern borders are the same as the south-eastern and eastern border of the Supra-regional model pilot area, then towards west, the northern border set along geological structure between the Mesozoic and metamorphic formations of the Veporic unit in Slovakia. In north-west the border is the boundary of the Triassic formations. Only the south-western part of the model boundary – between settlements of Ugod and Eplény – is artificial (Figure 1).

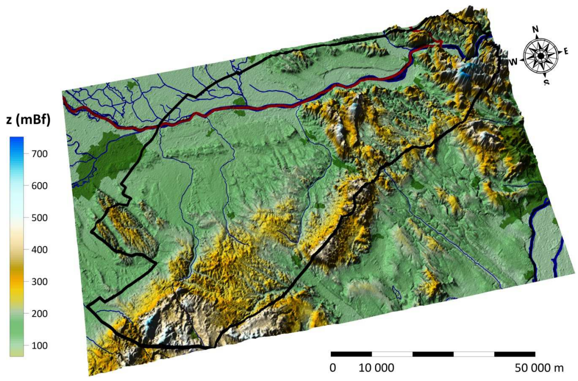

Figure 1. The area of the pilot model

4 GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS. GEOGRAPHIC SETTINGS

4.1 Geology

The Pre-Tertiary basement in the modelled area is build up shallow-water Middle to Upper Triassic platform carbonates (Main, or "Haupt" dolomite, Dachstein Limestone) focused by the hydrogeological modelling deposited on the passive margin of the Tethys ocean. This sequence has tectonic limit towards the Veporic crystalline unit and the Danube Lowland. The overlying rocks of the Triassic carbonates are pelagic Jurassic limestones, marls and cherty limestones with Lower Cretaceous clastic sequence in the Transdanubian Range and in the middle of the Slovakian part of the model area. In the western foreland of the Gerecse and Vértes Hills, the succession continued during the Middle and Late Albian with terrestrial clastics, shallow-water limestones and finally turned to open-marine marl. Figure 2-3 represents the basement formations and their surface on the pilot area.

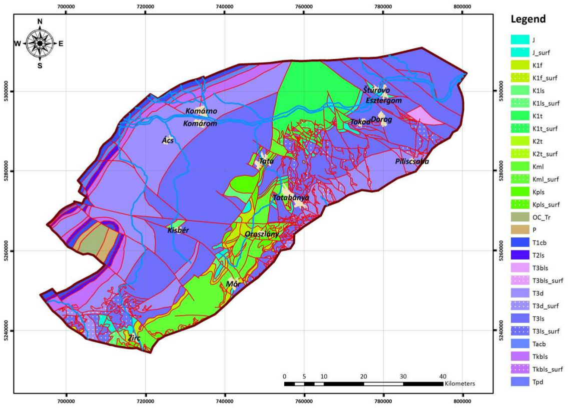

Figure 2. The geology of the Mesozoic basement of the pilot model

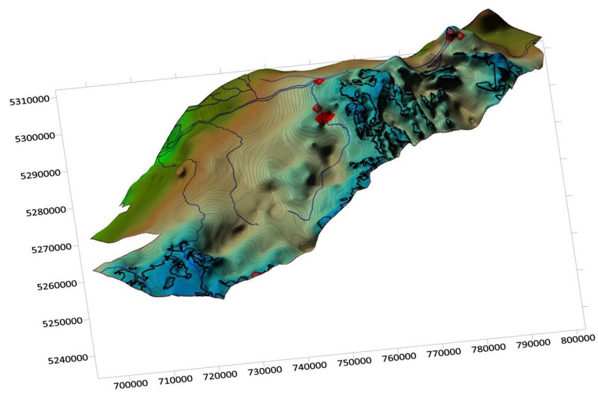

Figure 3. The surface of the mesozoic basement of the model area with the lukewarm springs in Hungary

The Mesozoic succession was deformed by Cretaceous (mainly Berriasian and Albian) deformation phases resulted in the nappe emplacement of the whole Transdanubian Range over other units. These processes followed by an extensive denudation period ended in the Middle Eocene which resulted in denudation surfaces and strong karstification in carbonates. In the Middle Eocene some karst-bauxite deposits were formed.

In the Middle Eocene a new basin formed named Hungarian Palaeogene Basin. Here the Eocene sequence started with continental deposits followed by neritic nummulitic limestones and bathyal (locally turbiditic) marls. The transgressive Eocene sequence has been extensively, the regressive sequence has been completely eroded in the area during an early Oligocene denudation event. In the western part of the area the Eocene covered by Oligocene fluvial formations. The basin was filled up by sandstones and siltstones during the late Oligocene.

The Neogene sedimentation started in the late Early Miocene in the western part of the Gerecse Hills resulted in fluvial-limnic successions with thin coal layers, while the subsidence of the Danube Basin started at the end of the Early and the beginning of Middle Miocene.

Karpatian and Badenian sediments exists in the eastern margin of the Danube basin, in the western foreland of the Gerecse consist of transgressive conglomerates, sandstones and volcanoclastics overlain by neritic calcareous clays, siltstones and subordinately sandstones. Terrestrial Miocene sediments occur only in the southern part of the pilot area.

The Sarmatian sediments deposited in shoreline shallow-marine environment: biogenic calcareous sediments and in the basin fine-siliciclastic sediments were deposited.

The Late Miocene lacustric and delta and fluvial sediments have small thickness along the Mesozoic outcrops of the Transdanubian Range, but towards the Danube Lowland in the Hungarian part and in the Slovakian part of the studied area are thicker.

In the northeastern part of the pilot area: in the Pilis, Visegrád Hills and Börzsöny Mountains the Neogene volcanic–volcanosedimentary rocks exist.

Quaternary is mostly represented by fluvial sediments, loess, and slope deposites (Maros et al, 2012).

4.2 Hydrogeology

The main and the most important aquifers in the pilot area are the Upper Triassic platform limestones and dolomites (Dachstein Limestone and Main Dolomite). The Middle Eocene denudation caused strong karstification in the more than 1500 meters thickness carbonate sequence. These well karstified conduits and fractures along the tectonic elements determine the groundwater (karst-water) flow system: due to the karstification the upper part of the system has higher permeability so the groundwater flow take place in this zone.

The topography of the karst aquifer also determines the natural groundwater flow: on the area of outcrops of the Upper Triassic rocks in the studied area (North-Bakony, Vértes, Gerecse, Pilis mountains) the precipitation infiltrate and along the karstified conduits the water flows towards the deeper regions. One part of the infiltrated cold water comes up near the recharge area as cold karst water but the rest of the recharge reaches greater depths, warmed up and enters the surface in lukewarm (~20 °C) karst springs along the margins of the mountains (Tata, Dunaalmás, Patince, Esztergom). A third part of the water warmed up more than 30 °C which also part of the flow system ended at natural discharge points, but smaller amount: these thermal karst water also produced by deep wells in the north-western part of the pilot area (near Bábolna, Ács, Komárom, Komárno the wells produce thermal water with 40-60 °C temperature).

The Upper Triassic carbonate aquifer uplift to shallow (app. 100 m) depth in Komárno high block. From a hydrogeothermal point of view, the area is divided into a high and marginal block (Remšik - Franko, et al. 1979; Franko, et. al. 1984; Remšik, et al. 1992). The Komárno high block has a fast water circulation and is considerably cooled (temperature is 20 – 22°C at a depth of 600 – 800 m, 24,5-26,5°C at 1100-1300 m, and around 40 °C at 3000m). The Komárno high block is encircled by the marginal block in the west, north and east and contains groundwater with a temperature exceeding 40°C.

The Transdanubian Range is affected by intensive groundwater abstraction connected to the coal and bauxite mines. These abstractions effected regional depressions and changes in the flow system in the whole region. Although the bauxite mining started in the early 1900’s, the most intense mining and the coupled dewatering started in the 1950’s and 1960’s. In the early period of the mining the cold springs were disappeared. From the 1950’s and 1960’s the lukewarm springs along the Transdanubian Range started to destroy. The spring yields reduced and after some years most of them were disappeared (Esztergom, Sárisáp, Dunaalmás, Tata, Patince). After the mine closures the karst flow system started to regenerate and the beginning of the 2000’s the hydraulic heads continuously rising (e.g. Tata, Tatabánya, Patince, etc.) and some of the springs reactivated (e.g. Dunaalmás, Tata, etc.) (Figure 4-5).

Figure 4. The regenerated (app. 2010) Lilla spring in Almásneszmély

Figure 5. Csokonai spring in Almásneszmély (regenerated around 2005)

The temperature and chemical composition of the lukewarm springs around the pilot area (Esztergom, Tata, Dunaalmás) serves good evidences of the uniformity and continuity of the whole karst system are. The regional depression caused by the mining also indicate an unified flow system.

5. MODEL OF THE AREA

In the first step of the modelling a steady state three dimensional groundwater and heat flow model was constructed, calibrated and used to describe and understand better the natural conditions of regional flow of the pilot area before the mining.

The groundwater flow and heat transport model was developed using the finite element model software FEFLOW 6.1.

5.1 Groundwater flow model

Model layering was based on conceptual hydrostratigraphy developed from the pilot-scale geological model (Figure 6).

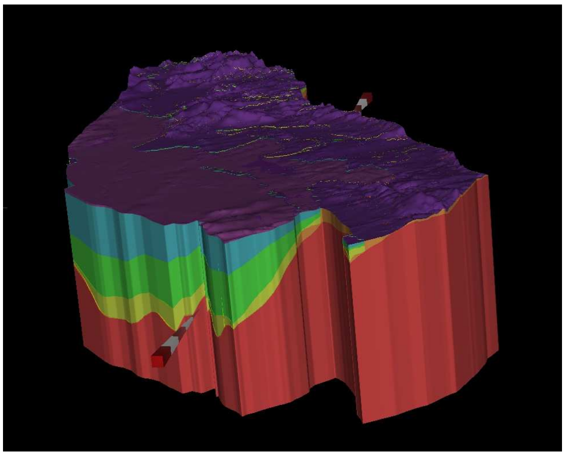

Figure 6. Model layering

During boundary condition determination we try to follow the rule to choose borders along “no-flow” boundaries. The SE model boundary is a watershed of the karst system. The northern model boundary and the NW border of the model have no flow boundary conditions. The SW and the NE boundary of the model is artificial, on the model layers of karstic aquifer we used fixed hydraulic head boundary conditions derived from the available hydraulic head maps of the Transdanubian karst system (Alföldi 2007).

The initial hydrogeological parameter values are based on well hydraulic tests, well measurements, literature data and previous observations and modelling experience (Tóth et al. 2012).

The parameter zones of the model layers are based on and determined, or assumed according to the hydrogeological characterization of the geological formations. In one layer to represent the different formations parameter change was used.

For the model calibration the initial values of parameters were derived from the supra regional TE model, literature and measured data and previous experience which were adjusted during the calibration process (Alföldi, 2007).

5.2 Geothermal model

The geothermal model of the area was based on the calibrated hydraulic model.

Uniform parameter distributions were used in the main hydrostratigraphic units. The same parameter zones were applied for thermal properties as for hydraulic properties. The main heat transport parameters are evaluated by measured and literature data and the supra regional Transenergy geothermal model (Lenkey et al., 2012, Remšik et al., 1992).

Calibration of geothermal parameters was based on temperature measurements in lukewarm springs (Tata, Almásneszmély, Esztergom) and thermal wells abstracted from the Triassic carbonate aquifer (Ács, Bábolna, Komárom, Komárno, Patince, Štúrovo, Esztergom).

5.3 Results of the model

Constructed regional model is simplified numerical representation of hydrogeological and geothermal characteristics of the pilot area and enable simulation of basic features of the geothermal system.

The open karst system is basically sensible for the climate parameters (direct relation between the surface and the deep subsurface region through the outcrops on the surface). Consequently the boundary conditions and the diffuse recharge on the top of the aquifer were the most sensitive parameters during the modelling of the hydraulic head distribution. (The head is less sensitive to the spatial distributions of hydraulic conductivity of the Mesozoic rocks due to the thick unified flow system.)

The recharge area of the deep karst system in Slovakia is situated in the area of outcropping carbonates in the Hungarian part of the modelled area. Subsurface water and heat flow has no limit along national borders. The simulated results are well reproduces this situation (Figure 7).

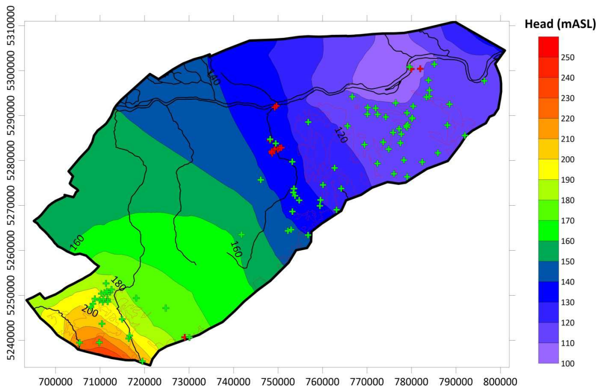

Figure 7. Simulated water table elevation of the karst aquifer

The temperature distribution of the Transdanubian karst flow system is mainly affected by forced heat convection. In the karstified dolomite and limestones the water can flow deep down the surface without any barrier: the recharged precipitation water cool down the system even at high depths. Due to the intensive flow system, this cooling effect can observed also far from the recharge areas (Figure 8).

As described above the heat distribution affected by the flow system, thus the heat is very sensible for the hydraulic features of the aquifer. During the calibration of the head and heat distribution we had to manage together these two parameters, which took more difficult the modelling and the calibration.

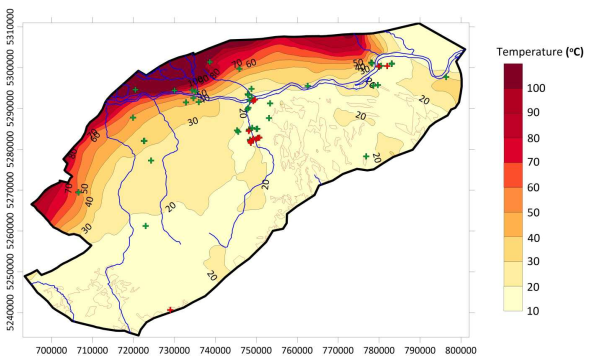

Figure 8. Simulated water temperature of the karst aquifer

6. CONCLUSIONS

The modelling of the Komárno – Štúrovo pilot area was focused on the karst aquifer of the Triassic limestones and dolomites in the NE part of the Transdanubian regional karst flow system. Due to the specific characteristics of the karst aquifer a finite element method was applied for the modelling: FEFLOW was used for the modelling of the karst system flow and coupled heat transport. Steady flow and steady heat flow were taken into account during the model simulations.

The constructed 12-layered numerical model simplified the complex geological and hydrogeological system and capable to simulate the steady state natural flow and heat transport processes before the intense mine water abstraction in the transboundary area.

The model presented the close connection between the water and heat flow: in the karst system the recharged precipitation from the area of the outcropping carbonates flows fast and to large depth in the karstified carbonate aquifer. This flow basically affects the heat transport in the area: a convective heat transport takes place in the karst system, thus the recharged water cooled down the system even at long range from the recharge area.

Although — based on this preliminary relatively good results, — the model would be able to prescribe properly the natural system, detailed hydrogeological data are needed from the period before the intense mine water abstractions to get better matching simulated values. However poor data of the “natural” system are available from this period, the further (transient) model period can serve reliable results for the flow system.

REFERENCES

Author, A. and Author, B.: Example of a conference paper, *Proceedings of the European Geothermal Congress 2007*, Unterhaching, Germany, (2007), paper #001, 1-6.

Author, A., Author, B., Author, C. and Author, D.: Example of a journal publication, *Journal*, **xx,** city, (year), 153-166.

Author, A.: Example of a book, *Publishers*, city, (year).

Author, A. and Author, B.: Example of a chapter in an edited book, in: Edited Book, Author, C. (Ed.), 153-166, *Publishers*, city, (year).

Alföldi, L., Kapolyi, L.: Bányászati karsztvízszint-süllyesztés a Dunántúli-középhegységben, Budapest, MTA Földrajztudományi Kutatóintézet (2007)

Atlas krajiny Slovenskej republiky. 1. vyd. Bratislava: Ministerstvo životného prostredia SR; Banská Bystrica: Slovenská agentúra životného prostredia, 2002, 344 s.

Hurter, S. & Haenel, R., Atlas of Geothermal Resources in Europe. - 93pp, 88 plates, ISBN 92-828-0999-4, CG-NA-17-811-EN-C; Luxemburg (Office for Official Publications of the European Communities) (2002)

Lenkey, L., Rajver, D., Švasta, J.: Summary Report „Geothermal Models at Supra-Regional Scale". Project TRANSENERGY internal report (2012)

Maros, G., et al.: Summary report of geological models. Available on 30.1.2013 at: http://transenergy-eu.geologie.ac.at/ (2012)

Remšik A., Franko, O., Bodiš D.: Geotermálne zdroje komárňanskej kryhy, Zapadne Karpaty, ser. Hydrogeológia a inžinierska geológia 10., Geologickȳ Ústav Dionȳza Štúra, Bratislava, 159-199 p. (1992)

Tóth, G., et al.: Summary report of the supra-regional hydrogeological model. Project TRANSENERGY internal report (2012)