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Detailed cross-border monitoring and reporting assessment of pilot areas

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6.3.2 Detailed cross-border monitoring and reporting assessment of pilot areas

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1 Introduction

TRANSENERGY targets the enhanced and sustainable utilization of hydrogeothermal resources, where the carrying medium of subsurface heat is groundwater. Therefore management and monitoring issues are two-folded: on one hand they are strongly linked to the related questions of groundwater management, and as such are rather focussing on the fulfilment of environmental targets (sustainable satisfaction of water demands without causing long-lasting qualitative and quantitative changes in the aquifers). On the other hand measurements have to provide reliable data on energy contribution of geothermal installations, such as mass flow and temperature, which require different concepts and other types of parameters to be measured.

The concepts and parameters to be measured, as well as basic principles of reporting requirements were summarized in the report 6.3.1. “Catalogue of monitoring and reporting measures”. Based on those standards, as well as a detailed knowledge of the pilot areas coming from their hydrogeological and geothermal modelling this report aims to exhibit the future prospects on a harmonized bilateral monitoring and reporting strategy of hydrogeothermal reservoirs in trans-boundary zones of the pilot areas of TRANSENERGY. Detailed plans were established for each pilot area where intensive use of thermal water exists, or effects of thermal water extractions exceed the national boundaries.

Legal Frameworks and Guidelines for monitoring and reporting

The legal framework of trans-boundary monitoring was overviewed as the part of 'Methodology for joint groundwater management' (Prestor et al 2012). In addition to the common international regulations and recommendations, each country has its own rules on groundwater monitoring (including thermal water monitoring). The different national features are highlighted here again, because they had to be considered during the elaboration of harmonized monitoring plans for the pilot areas.

1.1 Austria

The concerns of groundwater monitoring are regulated by the Austrian federal water act (WRG 1959, BGBl 1959/215, last amendment 2011) and by the national water management plan (NGP 2009). So far only one hydrogeothermal reservoir has been included to the NGP 2009, however this reservoir composed of Jurassic Limestones (»Malmkarst«) and showing trans-boundary flow systems is located outside the Transenergy project region at the border region between Austria and Germany (Code: GK100157, Name: »Thermalgrundwasser«). Nevertheless it can be seen as a good practice example for already existing harmonized trans-boundary monitoring and reporting procedures between Austria and Germany (Prestor et al 2012).

In Austria practical guidelines and recommendations on groundwater management and monitoring in general are given by the Austrian Association for Water and Waste Management (Österreichischer Wasser- und Abfallwirtschaftsverband – OEWAV). The guideline »Regelblatt 215 – »Nutzung und

Schutz von Thermalwasservorkommen«; ÖWAV, 2010) contains recommended surveys and monitoring strategies for hydrogeothermal utilizations, both for balneological use (no reinjection) as well as for energetic purposes (reinjection of used thermal water). It varies between the different stages of development of hydrogeothermal utilizations, as well as between qualitative and quantitative monitoring strategies.

2.2. Slovakia

In Slovakia national water management already started in 1954 (National Water Management Plan – NWMP). It was adapted several times (e.g. 1975 for a more detailed Guiding Water Management Plan for the Slovakian territory of former Czechoslovakia) until the transposition of the EU Water Framework Directive (WFD) was accomplished.

Following the WFD several geothermal water bodies (temperature > 15°C) have been classified. One of these bodies is situated in the Vienna Basin pilot area (Code: SK300030FK). This thermal water body is represented by Triassic carbonates of the basement of the Vienna Basin. Furthermore a Neogene sedimentary reservoir associated to Eggenburgian sediments is also comprehended by this thermal water body. Although it is not believed, that there is a significant interflow between these two hydrogeothermal structures they are legally treated as one body, which directly terminates at the national border between Slovakia and Austria. This groundwater body comprises the hydrogeothermal plays [1a, 1b], [2] and [4] on Slovakian territory (see also chapter 2.1.1). However, this groundwater body associated to the WFD is not harmonized to the Austrian NGP 2009 yet.

The water management sector is legally regulated by the Act No. 575/2001 Coll., the Section of Water under the Ministry of Environment is the competent authority. Under the governance and controlling of the Water Section, the Slovak Hydrometeorological Institute (SHMI) is the responsible authority for the coordination and the implementation of groundwater monitoring. In relation to thermal water, the quantity of utilized water, temperature (not regularly) are reported by the user to SHMI monthly. The Government Resolution No. 7/2000 and No. 664/2000 approved procedures for monitoring and related information systems, which also include the Partial Monitoring System – Water (PMS) relevant for the monitoring of thermal water. Amongst others the PMS is aiming to fulfil the requirements for international conventions and treaties.

Monitoring of thermal water for balneological and healing purposes is governed by the Ministry of Health based on §4 Act 538/2005 Coll. The range of monitored physical, chemical and biological parameters, both for basic analyses and extended analyses are governed by Decree 100/2006 Coll.

2.3. Slovenia

Current groundwater management is implemented by the Water Act (ZV-1: Official Gazette RS, No. 67/2002) and by the Decree on Danube and Adriatic Sea River Basins Management Plan (Official Gazette RS, No. 61/2011). The River basin management plan is implemented for the 1st management period 2009-2015 following the Water Framework Directive.

The groundwater monitoring systems in Slovenia rely on different reporting levels.

The top level is so called “national” groundwater monitoring for the characterization, status and risk assessment of groundwater bodies in Slovenia”. This system is operated and evaluated by

Environmental Agency of Slovenia (ARSO) under the umbrella of Ministry of the Environment and Spatial Planning of the Republic of Slovenia (MOP). This monitoring includes the *quantitative* monitoring systems, such as observing groundwater levels in karstic, fissured and intergranular porosity aquifers and spring discharge. This monitoring system also includes regular *quality* measurements for the chemical (quality) status assessment. The national River Basin Management Plan monitoring network was reported to the European Commission on March 22, 2007.

The sub-systems of the national monitoring system includes measurements and observations performed by water rights holders, subjects liable for the environmental impact monitoring and Public Health Institute of Republic of Slovenia.

Other monitoring sub-systems of quantitative and qualitative status of groundwater are performed by the individual municipal local governments and periodical surveys performed by government bodies, scientific institutes and other organizations.

Most data from the sub-system of the “national” groundwater monitoring” are also collected, managed and evaluated by ARSO. Only waterworks collect manage and distribute the observation data by themselves.

The actual “top level” national monitoring system in Slovenia does not include its “own” deep observation wells to monitor thermal groundwater status. The monitoring of thermal water should rely on the monitoring of water rights holders. Because actually the concessions of existing users are not yet granted, this monitoring is effectively not yet operational. The level of monitoring is significantly different from user to user and still not managed on an integrated way.

The recommendation for common monitoring system requirements for every individual concessionaire was already prepared. This recommendation has to be considered in the user’s proposal of his monitoring design. The monitoring design has to be approved by Concession Provider and agreed by the concession contract.

Nevertheless, the monitoring system relying only on concessionaires’ measurements and reports wouldn’t be enough, especially if no wells in the direct impact of neighbouring active abstraction are observed. For this reason some observation wells should be selected for the national monitoring that would serve to control the regional water level and water flow directions and the trends. An upgrade of national top level monitoring network is under preparation. This advanced network would also include deep thermal wells sufficiently far away from actual abstraction sites to monitor background and boundary conditions of the regional thermal water system. This kind of monitoring wells would be of extremely importance for trans-boundary management, especially, if the observation well would be designed and/or equipped and maintained in the cooperation by the neighbouring countries, using best practices examples and the most advanced technology.

2.4. Hungary

The groundwater monitoring system consists of two sub-systems in Hungary. One of them is the so called aerial monitoring that is under the auspices of the state and local governments and it’s density and detail is proportional to the rate of the public interest.

The aerial monitoring system includes the following elements:

- monitoring systems continuously operated by governmental organizations under the auspices of the Minister of Rural Development (e.g. Regional Directorates for Environmental Protection and Water Management). These include the *quantitative* monitoring systems, such as observing unconfined and confined groundwater, karstic and thermal water pressures and water levels, spring monitoring systems, monitoring regarding the quantity and quality of surface waters related to groundwater bodies. These monitoring systems also include regular measurements regarding to the *quality*, and monitoring systems implemented for special observations of a certain area including strategic water reserves.

- other monitoring systems continuously operated by other state organizations (e.g. groundwater level monitoring system operated by the Geological Institute of Hungary (after April 1, 2012 the Geological and Geophysical Institute of Hungary), Soil Protection Information and Monitoring System operated by the plant and soil protection services, maintained by the Ministry of Rural Development).

- monitoring of quantitative and qualitative status of groundwater in the public administration area of the settlement performed by the municipal local governments

- periodical surveys performed by government bodies, scientific institutes and organizations and expedition surveys.

The other sub-system of the national monitoring system includes measurements and observations performed by *environmental users*. Measurements performed by waterworks, monitoring in connection with operation of industrial firms, waste deposition, and drinking water reserves, mineral- and medical water usage, and activities related to water resource protection are ranked under the environmental impact monitoring. According to a special regulation remediation monitoring systems in contaminated, permanently damaged areas and measurements performed in the surroundings of emission sources and polluted areas are also part of the environment impact monitoring.

For the assessment of the status of groundwater bodies, related to the provisions of the Water Framework Directive, all elements of aerial monitoring performed by the state, and environmental impact monitoring performed by the users are necessary. The monitoring assessing the status comprises not only the classical quantitative and qualitative observations, but data related to the use of the subsurface / groundwater aquifers whether they cover natural elements (e.g. groundwater dependant ecosystems), or man-made processes (e.g. sludge deposition).

As the reporting to the European Commission does not require all individual data, therefore representative monitoring stations were determined for groundwater bodies, trans-boundary aquifers and protected areas. The national monitoring report was sent to the European Commission on March 22, 2007, altogether 3,500 monitoring stations and observations were listed, which officially form part of the EU-WFD monitoring program. The monitoring program of the River Basin Management Plans was also established in this document. The document is a legal obligation towards the EU for the performance of the monitoring program.

The EU-WFD monitoring program is performed by the 12 Regional Directorates for Environmental Protection and Water Management, the 10 Regional Inspectorates for Environment, Nature and Water, the Geological Institute of Hungary (after April 1, 2012 the Geological and Geophysical Institute of Hungary) and the selected users. The selected users (waterworks, spas, etc.) have to perform measurements on their own wells (except for those situations, when they were previously measured by the Inspectorates). Data collection and control is the task of National Institute for Environment.

As the conclusion of the above chapter it is obviously that neither deep trans-boundary groundwater bodies, nor their management strategies including monitoring are harmonized between partners' countries. The first steps of this harmonization should happen on pilot areas scale.

Creating the monitoring plans of pilot areas the first step was making an overview on the geothermal reservoirs and existing hydrogeothermal utilizations. The next step was describing the actual status-quo concerning monitoring and reporting issues. Evaluating the present situation the transboundary monitoring plan was created and suggestions for further monitoring points were done on each pilot areas.

2 Monitoring plan of pilot areas

2.1 Vienna Basin

2.1.1 Overview on the selected geothermal reservoirs (plays)

The existing relevant hydrogeothermal reservoirs in the Vienna Basin have been described at Bottig et al (2013). In total 6 different hydrogeothermal structures (plays) have been identified, of which 5 are located trans- or near-boundary. Although the Vienna Basin has not been developed yet for hydrogeothermal energy production, it offers great chances for future utilization (see also Figure 1). However, this region was and still is heavily used for hydrocarbon production and therefore possible utilization conflicts should not be disregarded at future monitoring and reporting strategies. The subsequent Table 1 summarizes main characteristics of the identified hydrogeothermal structures.

Table 1:Summary of selected characteristics of the identified hydrogeothermal structures

Pos	Name	Description	Average depth interval (top, base: m.b.s)	Existing utilization
1a	Tirolic Nappes	Fractured reservoir at the basement of the Vienna Basin. Connate waters showing locally overpressured conditions at high salinities.	645 - 3394	No
1b	Iuvavic Nappes	Fractured reservoir at the basement of the Vienna Basin. Connate waters showing locally overpressured conditions at high salinities.	1730 - 3260	No
2	Deltafront Sediments	Porous reservoir at sedimentary fillings. Connate waters at hydrostatic pressure. At marginal basin areas (SK) recharge possible.	1021 - 1187	No
3	Aderklaa Conglomerate	Double porosity reservoir at sedimentary fillings. Locally depressured conditions due intense hydrocarbon exploitation in the past. This reservoir is locally used for injection of formation water by the hydrocarbon industry	1972 - 2132	Yes (hydrocarbon industry)
4	Central Alpine & Tatric Carbonates	Fractured reservoirs at basement of the Vienna Basin. Active recharge as well as trans-boundary hydrodynamic circulation systems existing.	2145 - 4489	Yes (balneology)

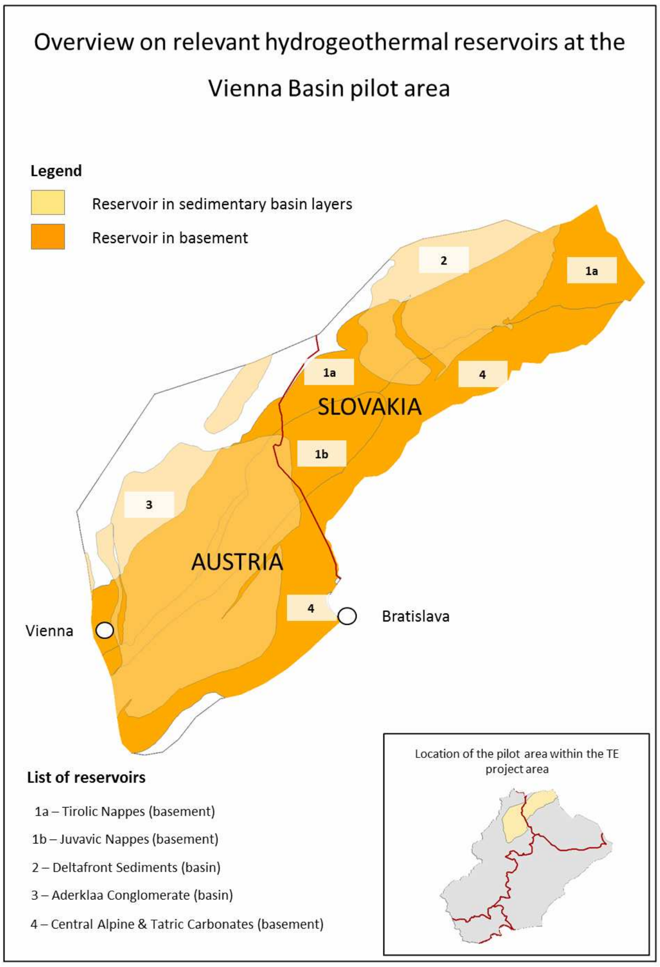

Figure 1: Overview on the identified relevant hydrogeothermal reservoirs at the Vienna Basin pilot area.

2.1.2 Overview on the existing hydrogeothermal utilizations

So far hydrogeothermal utilization is limited to Central Alpine & Tatric Carbonate reservoirs [hydrogeothermal structure nr. 4] at the eastern margin of the pilot area. At three locations in Austria (see below) a total yield of around 60 l/s is partly used for balneological purposes (**Table 2**).

Table 2: Summary of existing hydrogeothermal utilization in the Vienna Basin pilot area.

Location	Water extract	Total Yield	Outflow temperature	Use
Leithaprodersdorf	1 trapped spring	<5 l/s	~20°C	Not Used
Mannersdorf	1 trapped spring	<5 l/s	~25°C	Balneological Use
Bad Deutsch Altenburg	3 wells	~50 l/s	20°C – 27°C	Balneological Use

It is assumed, that the Central Alpine & Tatric Carbonates hydrogeothermal structure is representing a trans-boundary flow hydrodynamic thermal water system. Evidence is given in deep wells and hydrocarbon drillings showing clear aberrant geothermal conditions (see also cross section at Figure **2**). At the above mentioned hydrodynamic system utilization is limited to balneological use due to moderate thermal water temperatures and moderate yields.

The other hydrogeothermal structures at the Vienna Basin pilot area have not been developed yet for hydrogeothermal utilization. However, a recent hydrogeothermal project for heating purposes with a maximum installed capacity of 40 MW_{th} is currently on hold due to a non-successful exploration well.

Nevertheless most of the above listed structures have been exploited for hydrocarbons in the past. Above all the so called Aderklaa Conglomerate structure [3] is locally showing depressurized conditions due to hydrocarbon exploitation and is furthermore used for reinjection of waste formation waters by the hydrocarbon industry. Although the hydrocarbon exploitation in the Vienna Basin is continuously decreasing in the Vienna Basin possible utilization conflicts aspect have to be considered in a future monitoring and reporting procedure.

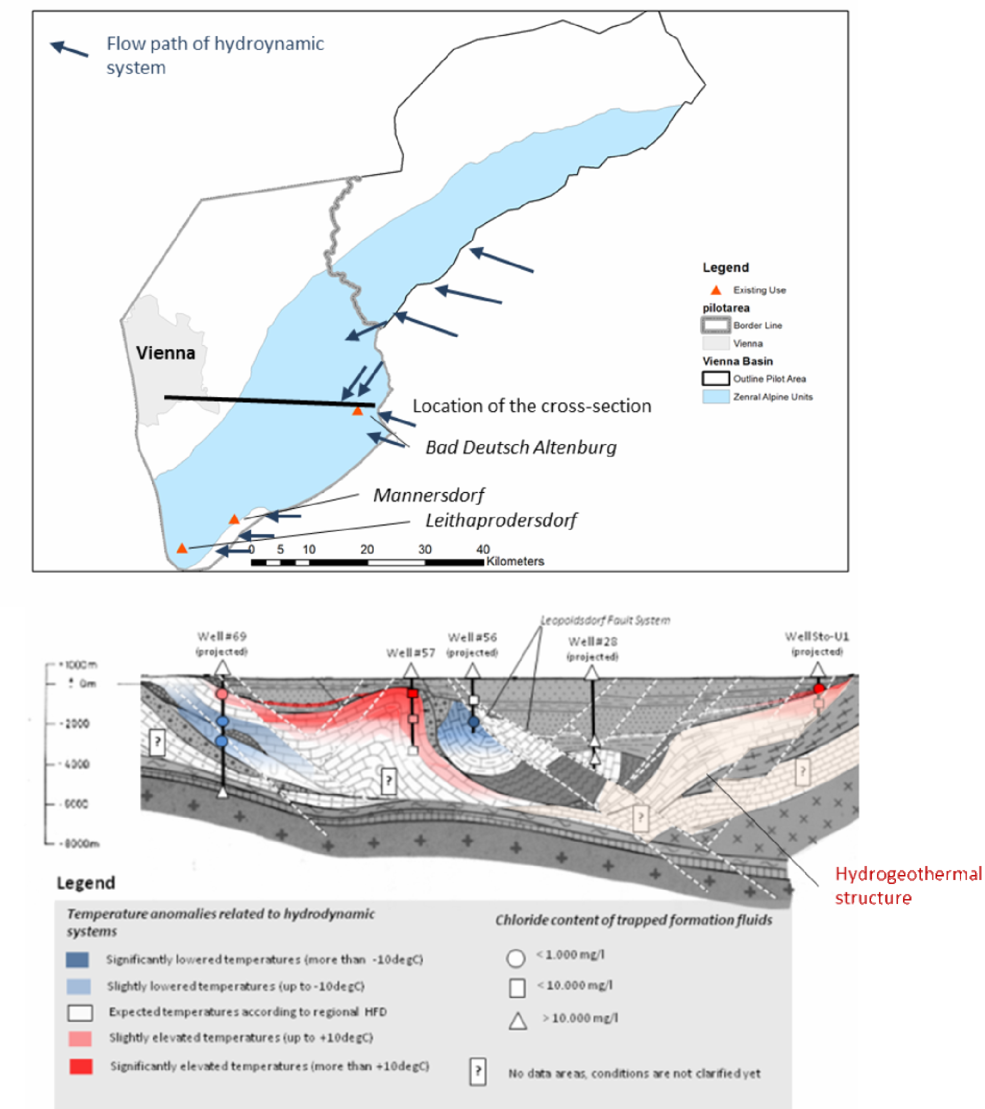

Figure 2: The Central Alpine & Tatric Carbonates hydrogeothermal structure

2.1.3 The actual status-quo concerning monitoring and reporting issues

Concerning the trans-boundary exploitation of hydrocarbons in the pilot area a bilateral Commission has already been founded in the late 1960s between Czechoslovakia (now Slovakia and Czech Republic) and Austria. Although exclusively coordinating hydrocarabon this commission and its procedures may have an impact on a future monitoring and reporting for hydrogeothermal use in the pilot area for the following reasons:

i. Most of the identified geothermal structures in the pilot area coincides with regions of hydrocarbon exploitation. At some structures hydrocarbon exploitation has been executed in the past or is still undergoing.

ii. The existing reporting procedures are adapted for deep buried reservoirs. Similar characteristics are given at most of the identified hydrogeothermal structures.

In the Vienna Basin pilot area no bilateral hydrogeothermal monitoring nor reporting procedures have been implemented yet, as there is no need to do so in them moment due to lacking utilizations. This will change as soon as the first hydrogeothermal utilizations are installed at trans-boundary reservoirs near the Austrian – Slovakian border.

In contrast bilateral commissions for harmonized bilateral exploitation of hydrocarbons (HC) consisting of Austrian and Slovakian members do exist since the late 1960s. The bilateral reservoir management of trans-boundary hydrocarbon reservoirs is therefore basing on bilateral reporting of HC production.

2.1.4 Trans-boundary monitoring of Vienna Basin

According to the different levels of general monitoring concept (Prestor and Lapanje 2012) The identified hydrogeothermal plays [1] to [3] are currently still at monitoring level 1 , that means no hydrogeothermal utilization is currently installed. Hydrogeothermal play [4] can be classified at level 2 (Moderate utilization, no interference or regional scale changes), as except for Bad Deutsch Altenburg only minor utilizations for balneological purposes are installed and neither interferences nor regional scale changes of the quality or quantity of the used thermal waters have been observed. However, as the Central Alpine & Tatric Carbonate hydrogeothermal play [4] is assumed to represent a trans-national hydrodynamic system a bilateral baseline monitoring focussing on the existing utilizations (active monitoring, as well as observation of natural discharges as far as available) as well as on the recharge of the hydrodynamic system is needed but not implemented yet.

Presently in the trans-boundary zone of the Vienna Basin pilot area an active monitoring should only be applied on hydrogeothermal play [4].

In the current utilization at the identified hydrogeothermal plays in the Vienna Basin Passive monitoring is not of importance.

2.2 Danube Basin

2.2.1 Overview on the selected geothermal reservoirs

The crystalline basement has no significant influence on the groundwater flow system. They have fissure-type permeability. They differ in stratigraphy, but the main features are the same. Usually they can be characterize with intensive heterogeneity, decreasing fissure aperture closing downwards causing the decreasing of permeability, and improved hydraulic conductivity due to tectonic effects.

Except the Mesozoic aquifer system of the Danube Range only some smaller blocks of carboniferous basement aquifers appears.

The Levice block is located in the Northeastern part of Danube Basin. It composed of Mesozoic rocks of the higher nappes, is locally underlain by the remnants of the Mesozoic envelope of the crystalline complex (Fusan et al. 1979). This surface of the Mesozoic dips first smoothly and then more steeply westwards. It has only westward continuation. The aquifer layer is formed by mainly Triassic dolomites together with the basal Badenian clastic sediments. The temperature of the water is 69-80 °C, and it has the mineralization reaches around 19 g/l.

The Dubnic depression is a special type of basement aquifers. It is filled mainly with Miocene sediments underlain by crystalline shists and granitoids of the Veporicum. The aquifer formed by basal Badenian clastics (conglomerates, sandstone) at a depth between 1000-2000 meters. It represents a closed reservoir, with temperature of 52-75 °C, and mineralization ranges from 10-30 g/l.

The *Komarno block* extends between Komárno and Štúrovo. Altough it represents an important basement reservoir of Danube Basin; it is also part the main reservoir of Komarno-Sturovo pilot area. So this reservoir is discussed in the Komarom area.

The Miocene aquifers are connected in every case to the basement aquifers, especially to highs of the basement and form a single flow system. They are represented by Badenian or Sarmatian sands and limestones. They content fossil waters with high salinity.

The main reservoir of Danube Basin represents the Upper Pannonian formation. The dish-like shape and brachysynclinal structure of this depression, located between the towns of Bratislava and Komárno/Komárom, is filled with Quaternary, Rumanian, Dacian, Pontian and Pannonian sediments. Quaternary and Rumanian sediments are represented by gravels and sands, while the other stages by alternations of clays and sandy clays with sands and sandstones. The topmost boundary of this geothermal water reservoir is at a depth of 1,000 m, while the bottom is represented by a relatively impermeable aquiclude (clay), which deepens from its periphery to its centre and reaches a depth of 3,400 m in the central part of the depression. It contains thermal waters 42–92 °C warm which are bound mainly to sands to sandstones aquifers. The aquifer layers of the central part in the thermal water system outcrop at the edges of the depression.

2.2.2 Overview on the existing hydrogeothermal utilizations

The utilization of the geothermal water is spread throughout the whole pilot area on Slovak and Hungarian side and partly on Austrian side. The utilization of geothermal water is performed by pumping and natural overflow form wells. The average yield of utilized geothermal water on Hungarian side of the Danube basin pilot area is 51 349 m^3/year and on Slovak side 87 631 m^3/year (as reported for the purposes of Work Package 3 of this project). There is only one utilization with smaller amount of exploited thermal water in Frauenkirchen at the Austrian part of Danube Basin area.

2.2.3 The actual status-quo concerning monitoring and reporting issues

Analysis of the geothermal water use in geothermal water bodies was prepared for purposes of the National Report (NR), which is prepared in accordance with the reporting requirements of the Water Framework Directive (Bartková et al., 2005).

The main objective of the monitoring subsystem is to provide quantitative indicators of groundwater (in springs and wells), to observe changes in yields, temperature, groundwater level regime (continuous or with weekly steps) for the purpose of processing reports, studies and expertise.

Geothermal water user is required to perform monitoring of the geothermal source. The conditions for monitoring (parameters to be measured and frequency of measurement) are stated in permission for water exploitation by Regional Environmental Office. The measured parameters include yield of source (well, spring), temperature of water, well head pressure. The permission can include the request for measurements of chemical components to assess the change in chemistry of the water by water user/observer. The following measurements are performed by the users: manual measurement, Measurements are taken by probe too: (automatic measuring equipment): recorded automatically at regular, intervals - water level (m), pressure on the well head (MPa), yield at source (l/s), state of the flow meter, water temperature (° C), pH, specific electrical conductivity (µS/cm).

In the area of the TRANSENERGY project only well FGČ-1 in Čilistov is monitored by the Inspectorate of Spas and Springs by the above mentioned methods.

2.2.4 Trans-boundary monitoring of Danube Basin

For monitoring areas delineation the following criteria have been chosen as the most indicative: expected temperature and pressure decrease due to pumping of thermal waters, and high transboundary water flow. Accordingly, the following three monitoring areas have been selected, based on the results of steady state geothermal models of Danube basin pilot area:

- Area 1 Mosonmagyaróvár – Lipót – Šamorín,
- Area 2 Gyõr – Veľký Meder,
- Area 3 Komarom-Sturovo

Area 3 mostly belongs to Komarom pilot area,so the detailed monitoring is discussed in Chapter 2.3.

Both areas 1 and 2 exhibit considerable long term decrease of temperature as well as groundwater pressure due to pumping in existing thermal wells. These effects extend partly across Hungarian-Slovak state border (Figure 3).

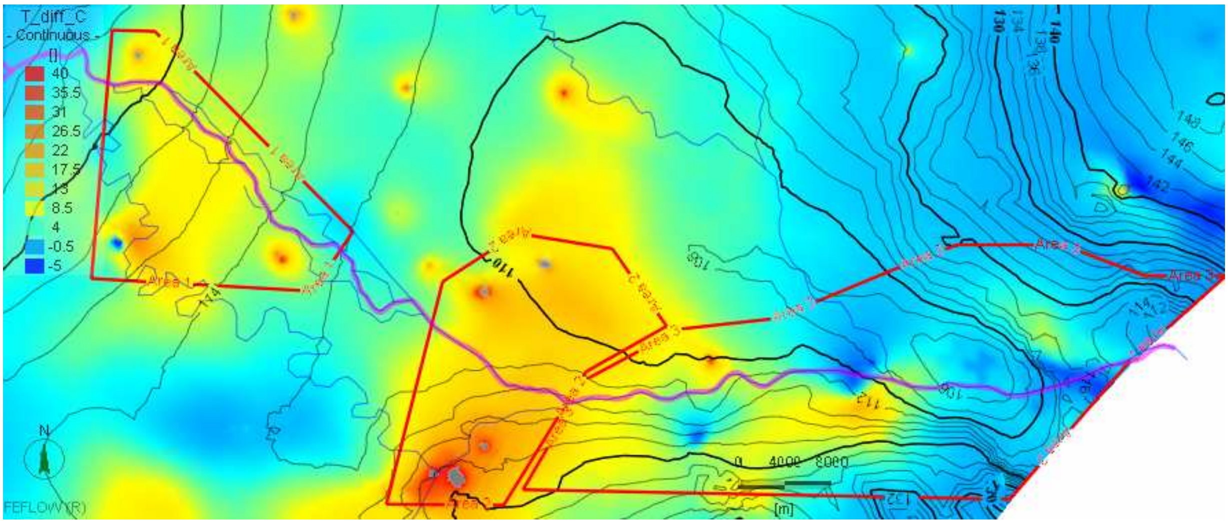

Figure 3: Map of hypothetic decrease of temperature due to infinite pumping (color) and piezometric head contours at the base of upper Pannonian at natural state (black, m a.s.l.) overlain with proposed monitoring areas (red).

Because incomparably lower trans-boundary water and energy flow in geothermal aquifers was observed along the Austrian state boundary, no monitoring areas are proposed there.

2.2.4.1 Area 1

In this particular area, thermal waters are bound to upper Pannonian aquifer, extending over large region on both sides of the border river Danube at depths from 1000 to 2500 m. Thermal waters are utilized by a number wells, almost solely for recreational purposes. Proposed monitoring boreholes are highlighted on (Figure 4).

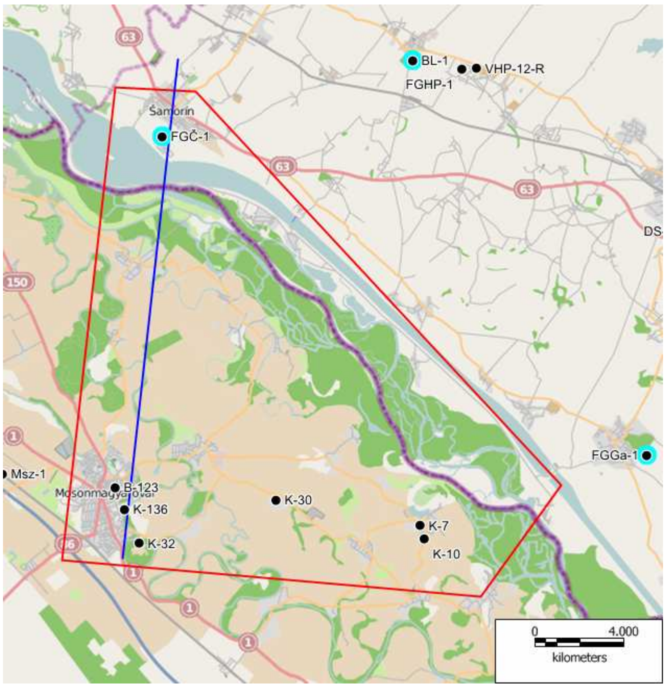

Figure 4: Proposed extend of monitoring Area 1 Mosonmagyaróvár – Lipót – Šamorín (310 km^2), with geothermal boreholes and cross-section line (blue).

Although no pressure or temperature changes had been observed at former monitoring well BL-1 Boheľov, it cannot be excluded that as utilization continues, adverse effects may emerge. As geothermal model of Danube basin showed, future decrease of temperature as well as pressure in the vicinity of pumping wells may be expected (

Figure 5).

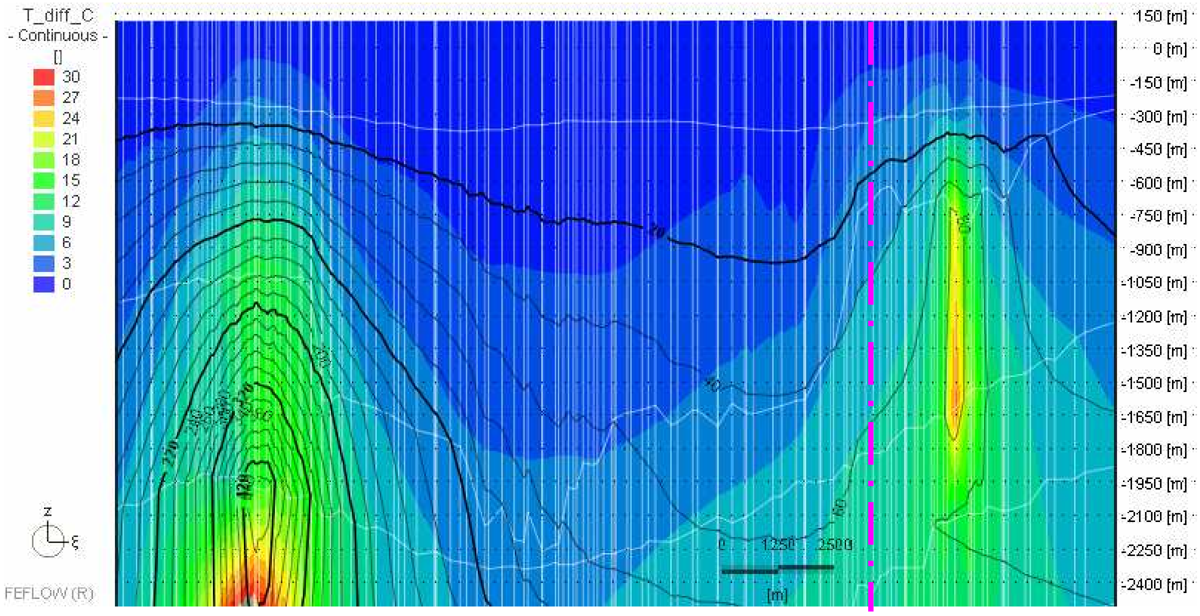

Figure 5: South-to-north cross-section (Mosonmagyaróvár –Šamorín) with effect of infinite pumping on temperature (colour) and pressure (black contours, kPa).
Dashed line is state border projected to depth.

It is advisable to set up at least two new monitoring wells between Mosonmagyaróvár and Šamorín, and use existing currently non operated wells FGČ-1, BL-1 and FGGa-1 too. Monitored parameters should include well head pressure and reservoir temperature as a minimum, sampled on weekly basis. Continuous monitoring of groundwater heads and temperatures are recommended in Lipót K-7 or K-10 when they are out of order.

Overview of thermal groundwater utilization in monitoring Area 1 is shown in Table 3.

Table 3: Overview of thermal groundwater utilization in monitoring Area 1

Name	Depth	Formation	Water temp. [℃]	Water utilization [m^3/year]			Water use	Monitoring
				2007	2008	2009		
FGČ-1	2500	Ivánka formation	54	89 310.0	84 990.0	180 813.0	bathing and swimming (including balneology)	no monitoring
Moson-magyaróvár B-123	2000	Újfalu Sandstone Formation	75	395 295.0	395 280.0	320 105.0	industrial water	continuous data
Moson-magyaróvár K-136	2000	Újfalu Sandstone Formation	78	215 827.0	249 978.0	200 020.0		annual data
Mosonmagyaróvár K136.	1994.9	Zagyva Formation	60	0.0	0.0	0.0	bathing and swimming (including balneology)	no monitoring
Lipót K-10	1806	Somló and Tihany Formation	61	85 387.0	99 377.0	158 103.0		annual data
Máriakálnok K-32	1182.6	Upper Pannonian sand	50.1	0.0	0.0	0.0	bathing and swimming (including balneology)	no monitoring
Lipót K-7	2206.5	Újfalu Sandstone	64	47 071.0	30 145.0	39 340.0		annual data

		Formation							

2.2.4.2 Area 2

Groundwater of upper Pannonian thermal aquifer between Győr and Veľký Meder is harvested for bathing at many sites (Figure 6). This considerable amount of water pumped (>200 000 m^3 per year) may cause deterioration of water quality, quantity and temperature (Figure 7). This raises importance of common groundwater management based on good monitoring data (Table 4).

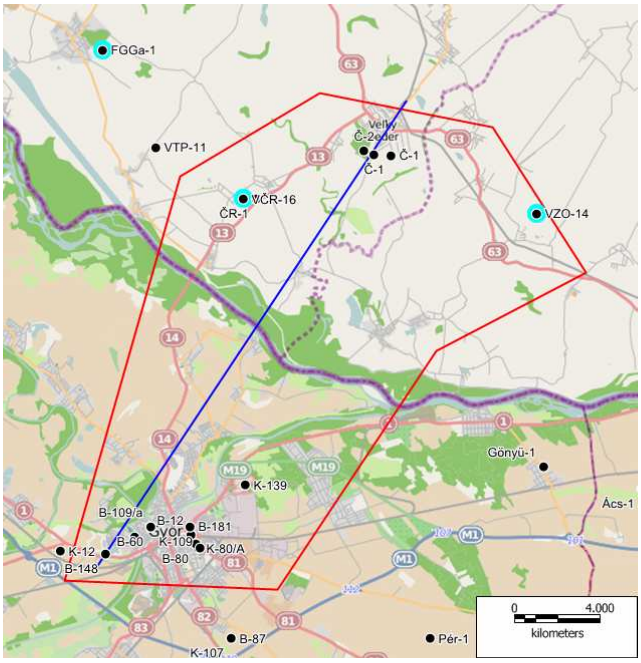

Figure 6 Proposed extend of monitoring Area 2 Gyõr – Veľký Meder (315 km^2), with geothermal boreholes and cross-section line (blue).

Proposed monitoring boreholes are highlighted.

Existing, but currently unused wells VZO-14 and VČR-16 can be easily converted into monitoring boreholes. Area close to river Danube, uncovered by deep hydrogeological boreholes, is of major importance for setting up another two monitoring boreholes.

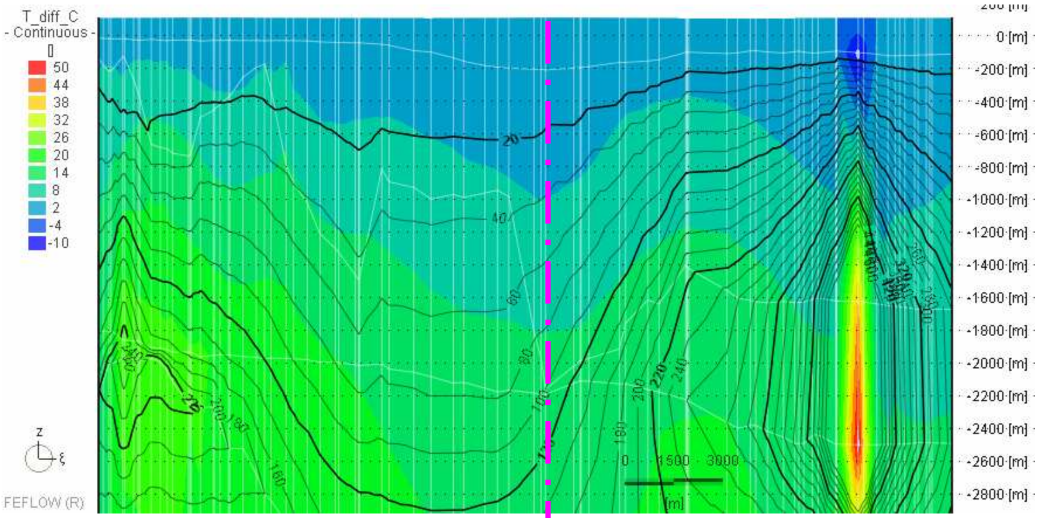

Figure 7: South-west-to-north-east cross-section (Gyõr – Veľký Meder) with effect of infinite pumping on temperature (colour) and pressure (black contours, kPa).
Dashed line is state border projected to depth.

Table 4 Overview of thermal groundwater utilization in monitoring Area 2

Name	Depth	Formation	Water temp. [℃]	Water utilization [m^3/year]			Water use	Monitoring
				2007	2008	2009		
Gyõr B-12/A	367.8	Zagyva Formation	22	8 281.0	3 500.0	3 500.0	bathing and swimming (including balneology)	no monitoring
Gyõr K-139	466	Somló and Tihany Formation	24	507 874.0	6 980.0	6 635.0		monthly data
Gyõr B-181	398.5	Somló and Tihany Formation	23.2	471 951.0	407 920.0	273 032.0	bathing and swimming (including balneology)	monthly data
Gyõr B-60	1998	Újfalu Sandstone Formation	66	160 594.0	21 630.0	186 788.0		annual data
Gyõr K-80/A	0	Somló and Tihany Formation	29	14 423.0	22 735.0	2 356.0	bathing and swimming (including balneology)	monthly data
Gyõr B-87/a	360	Somló and Tihany Formation	21	17 833.0	0.0	23 489.0	bathing and swimming (including balneology)	monthly data
ČR-1	2513	Beladice formation	80.5	86 600.0	85 000.0	838 000.0	bathing and swimming (including balneology)	no monitoring
VČR-16	1800	Beladice formation	62	0.0	0.0	0.0	bathing and swimming (including balneology)	no data

Name	Depth	Formation	Water temp. [℃]	Water utilization [m³/year]			Water use	Monitoring
				2007	2008	2009		
Č-1	2502	Beladice formation	69	0.0	170 820.0	145 498.0	bathing and swimming (including balneology)	no monitoring
Č-2	1503	Beladice formation	53	410 057.0	363 067.0	354 151.0	bathing and swimming (including balneology)	no monitoring
Abda K-12	1850	Újfalu Sandstone Formation	65	110 000.0	110 000.0	30 381.0		monthly data
Gyõr B-148	2034	Újfalu Sandstone Formation	68	242 768.0	23 338.0	253 748.0		monthly data
Gyõr B-81	2004	Újfalu Sandstone Formation	69	92 725.0	20 341.0	175 886.0	bathing and swimming (including balneology)	monthly data
Gyõr K-109	551	Somló and Tihany Formation	27	0.0	0.0	0.0	bathing and swimming (including balneology)	no monitoring

2.3 Komarno pilot area

2.3.1 Overview on the selected geothermal reservoirs

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 mostly take place in this zone (Figure 8).

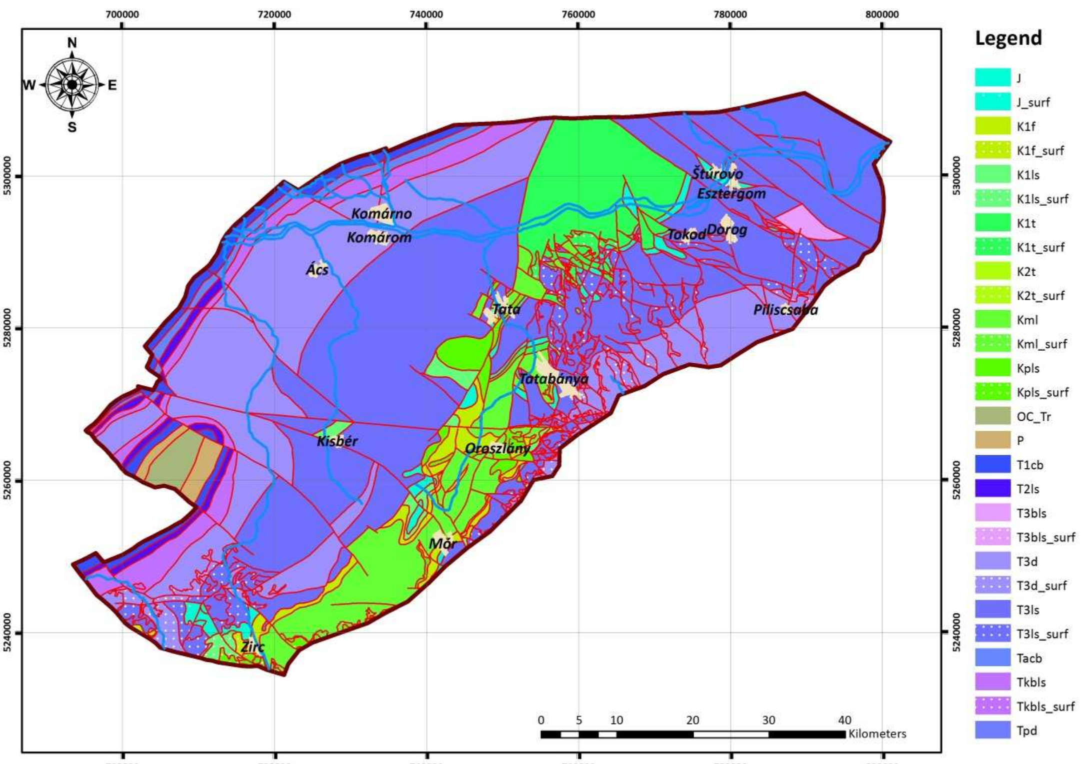

Figure 8: The geology of the Mesozoic basement of the pilot model
(the common legend of the geological model was applied, Maros et al 2012)

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.

2.3.2 Overview on the existing hydrogeothermal utilizations

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 coal and 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 vanish. 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.).

The thermal water wells of the region are used mainly for balneological purposes in Komarom, Patince, Esztergom and Sturovo. **Hiba! A hivatkozási forrás nem található.** contains the list of thermal wells which are illustrated on **Hiba! A hivatkozási forrás nem található.** .

Table 5: Overview of thermal groundwater utilization in Komarom area

Name	Depth [m]	Formation	Water temp. [°C]	Water utilization [m^3/year]			Water use	Monitoring
				2007	2008	2009		
Komárom K-21	1263	Szépvölgy Limestone Formation	60	267 906.0	429 061.0	402 623.0	bathing and swimming (including balneology)	annual data
M-2	1060	Ivánka formation	42	10 000.0	10 000.0	10 274.0	other	no monitoring
FGK-1	1970	Ivánka formation	45	0.0	0.0	0.0	other	no monitoring
SB-2	160	Dachstein limestone	26.7	16 261.0	159 993.0	202 570.0	other	no monitoring
SB-3	170	Dachstein limestone	26.4	20 100.0	0.0	0.0	other	no monitoring
VZO-13	1650	Beladice formation	56	95 840.0	129 170.0	105 290.0	bathing and swimming (including balneology)	no monitoring
Ács K-67	1848	Lajta Limestone Formation	70	36 792.0	36 792.0	77 916.0	drinking water	no monitoring
Almásneszmély K-10	390	Lower Jurassic Limestone	22	12 300.0	12 850.0	12 250.0	agricultural use	annual data
Almásneszmély K-4	140.7	Dachstein Limestone Formation	24	160 832.0	140 910.0	144 909.0	bathing and swimming (including balneology)	monthly data

Name	Depth [m]	Formation	Water temp. [℃]	Water utilization [m^3/year]			Water use	Monitoring
				2007	2008	2009		
Tata K-28/a	565	Dachstein Limestone Formation	23	0.0	0.0	0.0	bathing and swimming (including balneology)	monthly data
Tata K-31	204	Szák Claylymarl Formation	21	16 830.0	14 937.0	16 710.0	bathing and swimming (including balneology)	annual data
Tata K-35	201	Környe Limestone Formation	22	68 664.0	45 424.0	38 593.0		monthly data
Tata K-61	495.5	Dachstein Limestone Formation	21.8	4 082.0	0.0	0.0		monthly data
SB-1	226.5	Dachstein limestone	26.7	0.0	0.0		industrial water	no monitoring
Tata K-63	941.8	Dachstein Limestone Formation	21	0.0	0.0	0.0	drinking water	no monitoring
Tata K-39	326	Dachstein Limestone Formation	22	0.0	0.0	0.0		no monitoring
Almásneszmély K-9	254	Dachstein Limestone Formation	24	62 813.0	66 158.0	66 421.0		monthly data
Komárom K-109	1251	Szépvölgy and Tokod Formations	37	0.0	0.0	146 000.0		monthly data
Tata K-34	400	Dachstein Limestone Formation	22	6 082.0	5 554.0	8 040.0	drinking water	monthly data
Bábolna K-53	1274	Pusztamiskei, Bádeni, Hauptdolomite Formation	52	0.0	0.0	0.0	out of order	no monitoring
Komárom B-62	1286	Baden, Lajta Limestone, Csatka Formations	41	0.0	0.0		bathing and swimming (including balneology)	no monitoring

Name	Depth [m]	Formation	Water temp. [℃]	Water utilization [m³/year]			Water use	Monitoring
				2007	2008	2009		
Tata B-47	70	Jurassic limestone	20.5	0.0	0.0	0.0	bathing and swimming (including balneology)	continuous data
Tata B-48	60	Dachstein Limestone Formation	20.3	0.0	0.0	0.0	bathing and swimming (including balneology)	continuous data
Dunaalmás K-12	142.5	Upper Pannonian Sand	22	550.0	550.0	550.0	drinking water	monthly data
Dunaalmás K-15	166.5	Upper Pannonian sand and Jurassic limestone	24	0.0	500.0	500.0	bathing and swimming (including balneology)	no monitoring
Esztergom B-46	296	Dachstein limestone	27					
Esztergom B-86	97.8	Dachstein limestone	27.8	365	365	365		
Esztergom K-107	184.6	Dachstein limestone	30.5	912500	912500	912500		
Esztergom K-108	147.4	Dachstein limestone	30.7	912500	912500	912500		
Sturovo FGS-1	128	Dachstein limestone	37.9	433367	387704	414256		
Sturovo OPKS	96.7	Dachstein limestone	38.9	24762	24094	25803		

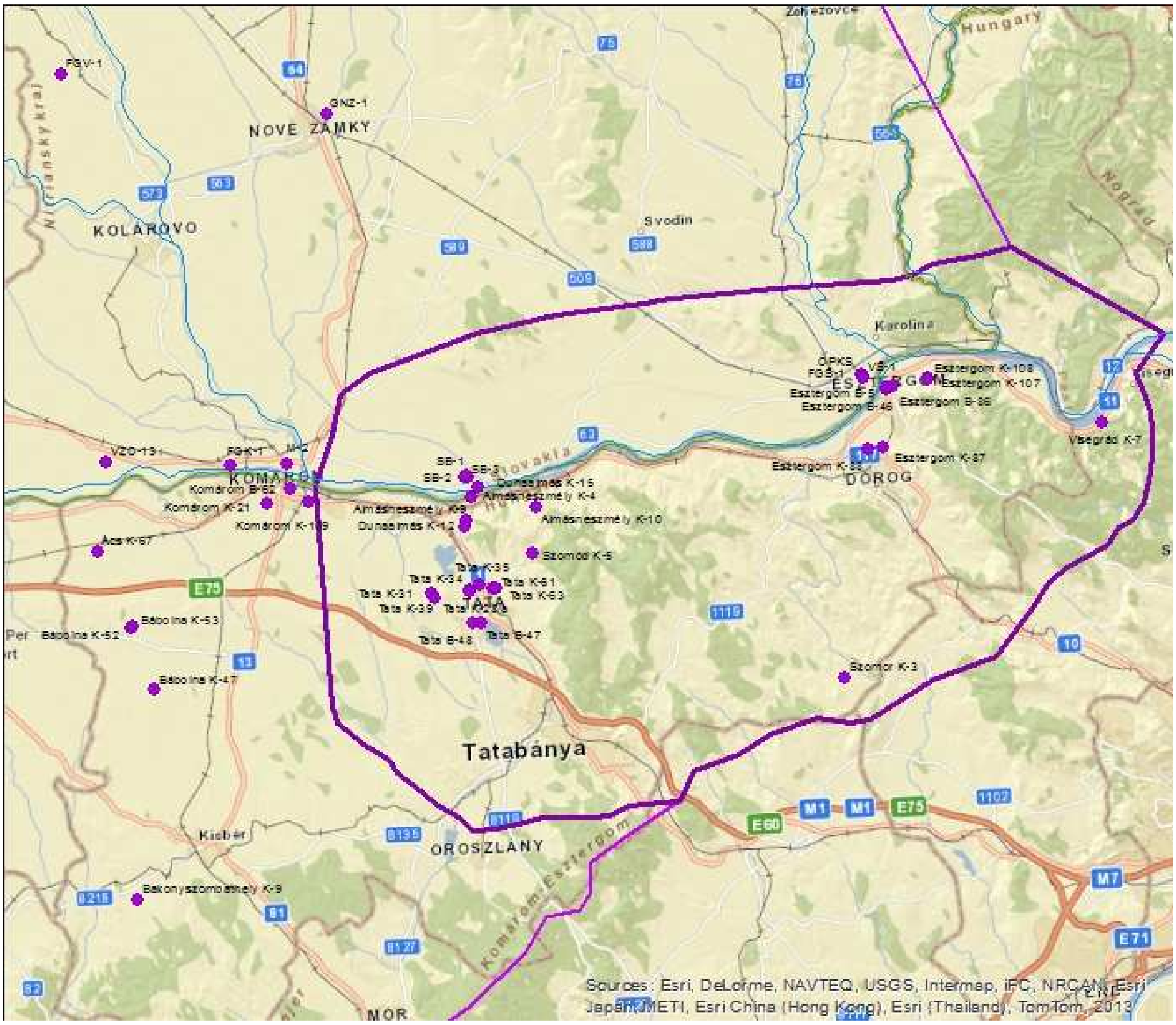

Figure 9: Thermal wells (above 20 ºC) in Komarom pilot area

2.3.3 The actual status-quo concerning monitoring and reporting issues

As it was mention in Chapter.2.2 (Danube Basin) the users are required to perform monitoring of the geothermal source in both countries. The conditions for monitoring (parameters to be measured and frequency of measurement) are stated in permission for water exploitation by Regional Environmental Office. The measured parameters include yield of source (well, spring), temperature of water, well head pressure. The permission can include the request for measurements of chemical components to assess the change in chemistry of the water by water user/observer.

There are some monitoring points (spring at Sárisáp and EK-1 karst monitoring well at Esztergom) measured in Hungary in the trans-boundary zone.

2.3.4 Trans-boundary monitoring of Komarno area

Springs, monitoring wells and as well as operating thermal wells are planning in the trans-boundary monitoring of Komarno area. Due to finishing of mining dewatering, karst water reappears in springs in the pilot area. Several springs are recommended to monitor: Mala-sping in Esztergom, Lilla- and

Csokonai-spring in Dunaalmás, and Fényes-spring in Tata. Mala-spring located at the Mala-tunnel where there is possibility to make continuous measurements of discharge of the spring, temperature and conductivity. Measuring the other springs need to create measuring objects. Sárisáp spring is involved in the recent monitoring, so further measurements are required in the future too (**Hiba! A hivatkozási forrás nem található.**).

The EK-1 monitoring well is operated by MFGI (Hungarian Geological and Geophysical Institute). The well is equipped with data logger and GSM transmitter (**Hiba! A hivatkozási forrás nem található.**). Further monitoring wells are proposed to configure at Bábolna, where K-52 and K-53 wells are out of order. Continuous measurement of karst water level and groundwater head in the Miocene aquifer is planed with data logger in these wells. For better monitoring of changes of geothermal field, existing and currently non-operating wells FGK-1, M-3, PGT-11, GTM-1, VZO-14 and VŠE (highlighted on Figure 10) should be equipped with pressure/head transducers, temperature and electrical conductivity probes. Monitoring should be performed on daily basis. Active monitoring is expected in the operating thermal wells (**Table 5**). The proposed monitoring points are shown in Figure 10.

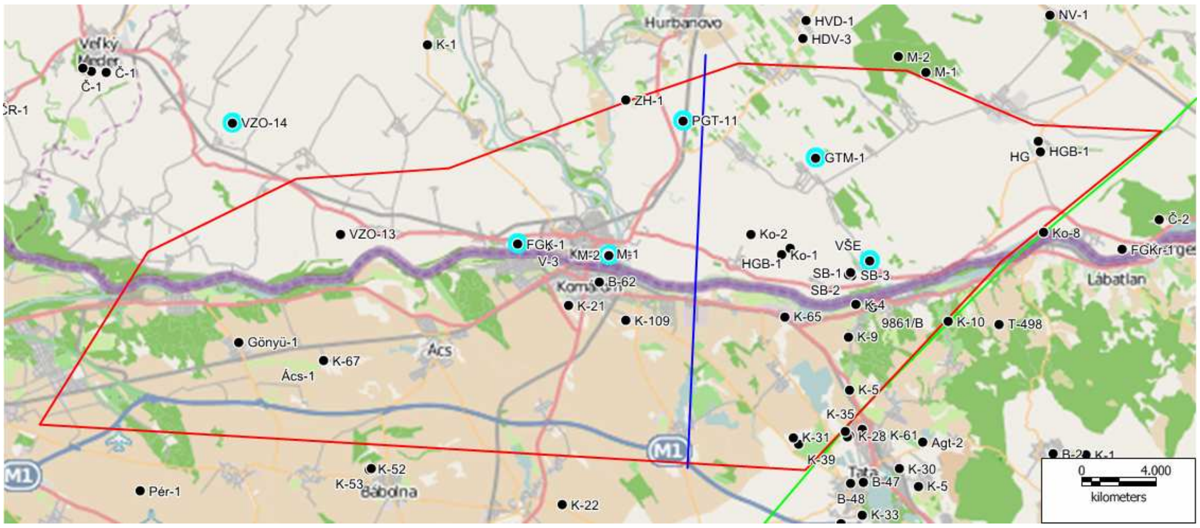

Figure 10 Proposed monitoring points of Komarom pilot area

2.4 Lutzmannsburg-Zsira pilot area

2.4.1 Overview on the selected geothermal reservoirs

There are three different reservoirs existing in the Lutzmannsburg-Zsira pilot area: Devonian Dolomite, Miocene porous and Upper-Pannonian porous reservoirs. The reservoirs related to different geological formations, which results big differences in thermal water andn reservoir characteristics.

The Devonian Dolomite Formation is a special type of basement reservoirs. It can be characterized as a fractured aquifer, with high permeability. The permeability originates from multiple tectonic stresses, the reactivation of structural elements, and possible karstification during exposed periods. In the basement reservoir temperature varies between 80-110 °C at 2500 m depth. The temperature of thermal water exceeds a level of 60°C in a depth of 1000 meters.

There are two types of Miocene reservoirs. One consists of siliciclastic shallow water sediments as porous aquifer. The other is shallow marine deposited biogenic limestones and siliciclastic limestone with double porosity. The Miocene layers have hydrogeological importance only in basin marginal position, or where they are deposited directly on the basement and are connected to the basement reservoirs. Due to marginal position this reservoir has got lower temperature, 30 °C in 700 m.

The Upper Pannonian sandy layers represent one of the most important aquifers. Alternating with silty layers their permeability varies within a wide range. They have important role both as a cold drinking water supply and as a thermal water resource. The maximum temperature reached in the reservoir is 53.5°C at the region of Sárvár.

2.4.2 Overview on the existing hydrogeothermal utilizations

Extensive groundwater extractions existed in the region for several decades, both from the cold and the thermal water aquifers. Famous spas (Lutzmannsburg Spa and Bük Spa) situated both in Austria and Hungary within 15 km distance. Due to intensive thermal water utilization significant drop occurred in groundwater heads of the Miocene aquifers. The thermal water in Lutzmannsburg derived from Miocene porous aquifer layers. The main reservoir of Bük Spa is the Devonian Dolomite (, but Upper Pannonian aquifer layers are also used (together 1695 m^3/d). There are some Upper Pannonian thermal water utilization in the pilot area at Szeleste (273 m^3/d), Szombathely, Sárvár (500 m^3/d).

The thermal wells illustrated in Figure 12.: Proposed monitoring points in Lutzmannsburg-Zsira pilot area and data of the wells are shown in **Table 6**.

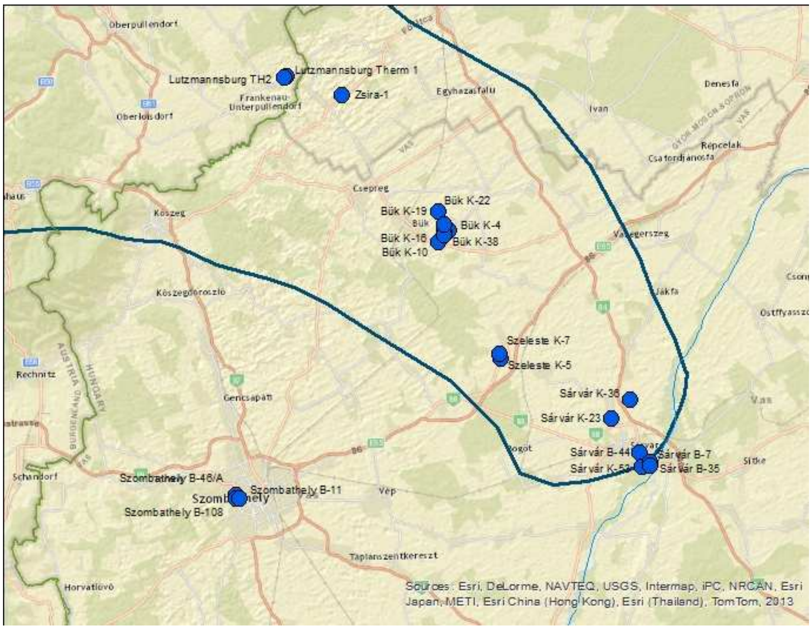

Figure 11: Thermal wells of Lutzmannsburg-Zsira pilot area

Table 6: Overview of thermal groundwater utilization in Lutzmannsburg-Zsira area

Name	Depth [m]	Formation	Water temp. [°C]	Water use	Monitoring
Lutzmannsburg Th-1	960	Karpatian Sand	32.6	balneology	half year
Lutzmannsburg Th-2	813	Karpatian Sand	33	balneology	half year
Bük K-4	1282	Bük Dolomite Formation	58	balneology	yearly
Bük K-10	1100	Bük Dolomite Formation	58	balneology	yearly
Bük K-16	782	Újfalu Sandstone Formation	42	balneology	yearly
Bük K-19	630	Somló and Tihany Formation	39	balneology	no monitoring
Bük K-22	718	Újfalu Sandstone Formation	38.5	balneology	yearly
Bük K-38	900	Somló and Tihany Formation	44,5	balneology	yearly
Szeleste K-7	800	Újfalu Sandstone Formation	36	balneology	
Szeleste K-5	1258	Újfalu Sandstone Formation	49,5	balneology	
Szombathely B-108	639	Somló and Tihany Formation	34.2	balneology	yearly
Szombathely B-46/A	700	Somló and Tihany Formation	37	balneology	yearly
Sárvár B-35	1293	Zagyva Formation	44	balneology	yearly
Sárvár B-44	1300	Újfalu Sandstone Formation	48	balneology	no monitoring
Sárvár B-7	998,5	Újfalu Sandstone Formation	44	belneology	yearly

Name	Depth [m]	Formation	Water temp. [°C]	Water use	Monitoring
Sárvár K-53	1050	Újfalu Sandstone Formation	46	balneology	yearly

2.4.3 *The actual status-quo concerning monitoring and reporting issues*

Active monitoring is executed in both countries. Monitoring includes qualitative and quantitative measurements of thermal water in every operating wells. The most important wells are Lutzmannsburg Thermal-1 and Thermal-2, Bük K-4, Bük K-10 and Bük K-16 (**Figure 12.: Proposed monitoring points in Lutzmannsburg-Zsira pilot area**.).

There are only a few monitoring points for passive monitoring in the trans-boundary zone. The actually measured Zsira-1 well is equipped with data logger and GSM unit to serve continuous information about groundwater head changes of Miocene layers. There are some other monitoring wells (Csepreg K-7 and Csepreg K-13) where the groundwater head of Upper-Pannonian aquifers are measured in different depth. These observations must be continued in the future to get enough information to trans-boundary monitoring.

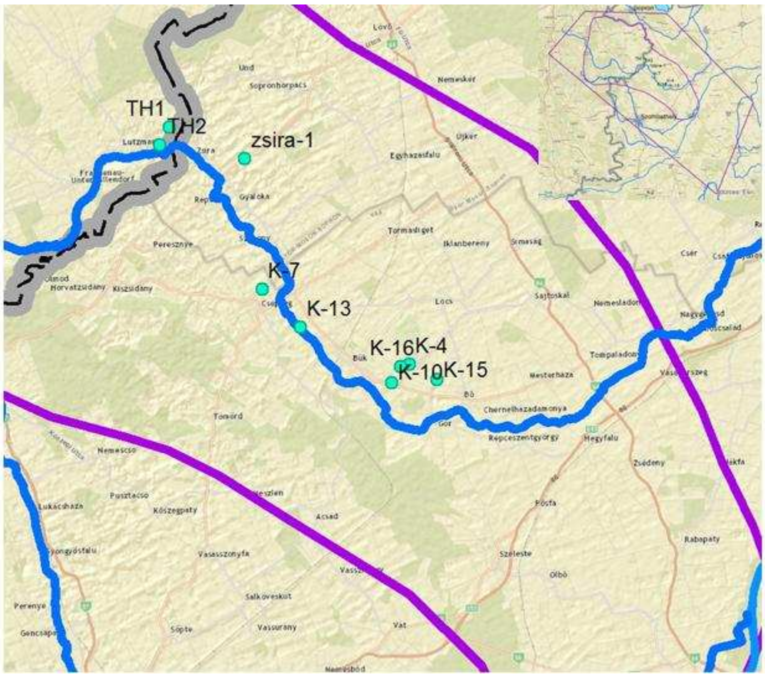

Figure 12.: Proposed monitoring points in Lutzmannsburg-Zsira pilot area

2.4.4 *Trans-boundary monitoring of Lutzmannsburg-Zsira area*

The present measurements of active monitoring must be continued to serve information of utility and changes of the parameters of reservoir. Well log measurements (temperature- and inflow log measurements) are proposed in every 5 years to control the thermal and technical status of the well.

The continuous measurements are needed in the future too in the existing monitoring wells.

Additional measurements are required about the basement reservoir of Devoniain Dolomite. The monitoring well Csepreg K-15 originally was deepened more than 1000 meters reaching to the basement. Recently the well is only 300 m deep, and it is proposed to reconstruct to be able to measure the karstwater head again (**Hiba! A hivatkozási forrás nem található.**).

One well of the two Lutzmansburg thermal wells is alternately operating, while the other is set to standby. It is proposed to make continouos groundwater head measurements with data logger in the well which is currently out of order.

2.5 Bad-Radkersburg-Hodos pilot area

2.5.1 Overview on the selected geothermal reservoirs

Two geological units were delineated in the Bad Radkersburg – Hodoš pilot area: Neogene sediments and Pre-Neogene basement, the latter consisting of carbonate and metamorphic rocks. Geological description of the region can be found in the report on supra-regional geological model (Maros et al., 2012).

The focus of the monitoring and reporting assessment is the Pre-Neogene basement aquifer in the Mesozoic carbonate and Paleozoic fissured metamorphic rocks along the Raba fault zone. This aquifer is situated in the narrow and deep Radgona – Vas tectonic half-graben developed along the Rába fault system in SWS – ENE direction, and south of the South Burgenland Swell.

The shape of the pilot area follows this major fault system on both (northern and southern) sides. According to our working hypothesis the South Burgenland swell represents a hydraulic barrier for the Radkersburg area (Jennersdorf TH1 and Güssing 1 wells). The metamorphic rocks on the Murska Sobota High act similarly. The western border of the area follows the surface water divide between the Drava and Pesnica Rivers.

In the south-eastern part of the area, in Slovenia, the metamorphic rocks prevail in the basement. Carbonate rocks can be found only in tectonic patches. Beyond the Bajan fault in Hungary, towards the east, the Mesozoic carbonate rocks occur in a wider range as a part of the Transdanubian Range (Table 7).

The main utilization can be found in the transboundary zone between Austria and Slovenia, and there are favourable but unexploited possibilities in Hungary. In Bad Radkersburg (A) there is a thermal spa in the vicinity of state border with Slovenia. In 2008, a research borehole was drilled in Korovci (SI) in the vicinity of state border intended to capture the same aquifer in a distance of less than 5 km from Bad Radkersburg spa is causing trans-boundary tensions between the two countries.

In Benedikt, 11 km SWS from Bad Radkersburg, a borehole was drilled into the Raba fault zone fissured metamorphic rocks in 2004. We assume that the recharge mechanism is comparable with Bad Radkersburg and Korovci area (Figure 13.

In the Neogene sediments and sedimentary rocks above the basement no important thermal aquifers were identified, but according to logging results some thermal water bearing layers exist.

Table 7:Summary of selected characteristics of the identified hydrogeothermal structure

Pos	Name	Description	Average depth interval (top, base: m.b.s)	Existing utilization
4	Mezozoic and Paleozoic rock in the Pre-neogene basement	Fractured reservoir in basement of the Bad Radkersburg – Vas tectonic halftrench. Trans-boundary hydrodynamic circulation systems existing.	700 - 4600	Yes (balneology, energy)

Figure 13: Overview on the Bad Radkersburg - Hodoš pilot area with the location of utilisation sites.

2.5.2 Overview on the existing hydrogeothermal utilizations

The main utilization in the area takes place in Benedikt and in the trans-boundary zone between Austria and Slovenia. In Bad Radkersburg (A) there is a thermal spa in the vicinity of state border with Slovenia.

So far recent hydrogeothermal utilization in the pilot area is limited to Mesozoic and Paleozoic rock in the Pre-Neogene basement at the south – western margin of the pilot area. At two locations in Slovenia and one location in Austria (**Table 8**) a total yield of around 27 l/s is used partly for balneological purposes and partly for energy purposes now, for another 20 l/s the system has to be upgraded with the reinjection well.

Table 8: Summary of existing hydrogeothermal utilization in the Bad Radkersburg - Hodoš pilot area.

Location	Water extract	Total Yield	Outflow temperature	Use
Bad Radkersburg (AT)	2 wells	22,2 l/s	~78°C	Balneological and Energy Use
Benedikt v Slov. Goricah (SI)	1 well	5 l/s	72 °C	Energy use
Korovci (SI)	1 well	~20 l/s	80 °C	Not in use

Because both Bad Radkersburg and Korovci are situated at the state border, it is obviously, that the Bad Radkersburg - Hodoš hydrogeothermal structure is representing a trans-boundary flow hydrodynamic thermal water system.

2.5.3 The actual status-quo concerning monitoring and reporting issues

The actual “top level” national monitoring system in Slovenia does not include its “own” deep observation wells to monitor thermal groundwater status. The monitoring of thermal water should rely on the monitoring of water rights holders. Because actually the concessions of existing users are not yet granted, this monitoring is effectively not yet operational. The level of monitoring is significantly different from user to user and still not managed on an integrated way.

No passive monitoring is present in the area.

In the Bad Radkersburg – Hodoš pilot area no bilateral monitoring or reporting procedures have been implemented yet. In bilateral SI-AT ‘’Mura’’ commission on water management this issue is raised for several years, but no conclusions for bilateral monitoring and reporting are made yet. Nevertheless the common survey of the pumping test in Korovci in 2009 was performed (Kraljić et al., 2009; Vižintin et al., 2009; Schmidt, 2010).

2.5.4 Trans-boundary monitoring of Bad-Radkersburg-Hodoš area

The concept how to establish a possible harmonized monitoring at the Bad Radkersburg - Hodoš pilot area between Slovenia, Austria and Hungary is discussed here. A possible legal basis of a joint initiative will not be discussed in this report. Review of the existing monitoring sites. The density of wells reaching the Pre-Neogene fracture aquifer in Mesozoic and Paleozoic is very scarce. Because of the great depth to the aquifer is it not convenient to build up new monitoring network system, especially in HU part, where the thickness to the aquifer exceeds 4000 m (Figure 14). We recommend including in the monitoring grid existing production or non-operating thermal wells. Thus we selected 3 production wells, one non-operating thermal well and one monitoring well; 3 observation wells are from Slovenian part, 2 from Austrian part and none of them from Hungarian part of Bad Radkersburg – Hodoš thermal aquifer. In Figure 2 locations of two nearest existing wells in Hungary, NK-2 and K-2, show that they are not a part of Bad Radkersburg – Hodoš geothermal aquifer, but that they are part of Hungarian GWB Thermal karst. Therefore, boreholes BK-2 and K-2 are not suitable as observation wells for this geothermal aquifer.

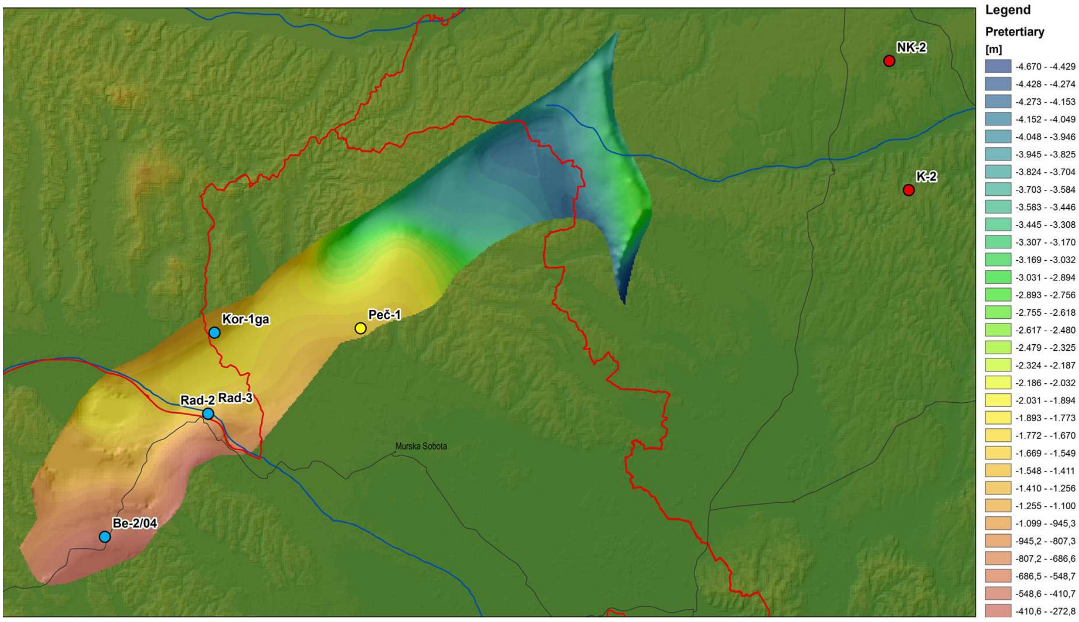

Figure 14: Depth to the Pre-Neogene geothermal aquifer in Mesozoic – Paleozoic fractured aquifer

For the purpose of the modelling of expected future influence of the geothermal water utilization on Bad Radkersburg – Hodoš thermal aquifer status, the abstraction monitoring at utilisation sites should be collected to the common database annually.

The general monitoring and data management concept chosen is presented in the subsequent table 2. It consists in 3 levels of utilization approach (no, moderate, intense), which is linked to specific measuring/monitoring and data management activities (Table 9).

The identified hydrogeothermal aquifer is currently classifies at level 2, as utilizations for balneological and energy purposes don’t show neither interferences nor regional scale changes of the quality or quantity of the used thermal waters yet. However, as the Mesozoic and Palaeozoic fractured aquifer in Pre-Neogene basement represent a trans-national hydrodynamic system a bilateral baseline monitoring focussing on the existing utilizations (operative monitoring,) as well as on the recharge of the hydrodynamic system is needed but not implemented yet (**Figure 15**).

Table 9: General monitoring concept for Bad-Radkersburg pilot area

Level of Utilization (Exploitation)	Data Acquisition (Surveys / Monitoring)	Data Management
1 – No utilization	Closed aquifers: Interpretation of existing exploration data (baseline estimation) Open systems: baseline monitoring	Bilateral numeric, regional scale steady state models for identified hydrogeothermal plays; reporting of resources; bilateral database
2 – Moderate utilization, no interference or regional scale changes	Interpretation of exploration data Operative Monitoring	Bilateral database of baseline and production data; evaluated and calibrated bilateral numerical models for allowance and permissions
3 – Intense utilization, interferences and regional scale changes evident	Operative Monitoring Passive Monitoring Evaluation of existing permission based on numerical modelling	Bilateral database of passive monitoring; evaluation of numerical models for history matching ➔ adaption of models; evaluatiuon of existing utilizations based on adapted numerical models;

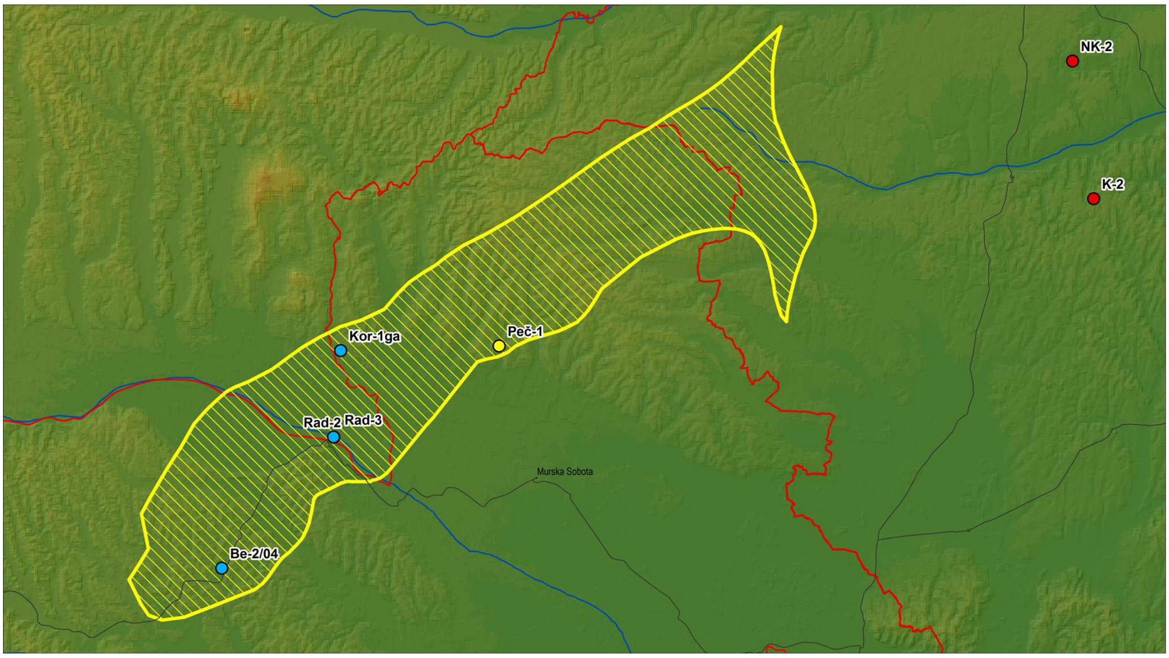

Figure 15. Proposed joint Bad Radkersburg - Hodoš monitoring network.

Proposed monitoring boreholes on Slovenian part of Bad Radkersburg – Hodoš thermal aquifer monitoring network are: Be-2 (operational monitoring), Kor-1gα (observative monitoring) and Peč-1 (observative monitoring).

Proposed monitoring boreholes on Austrian part of Bad Radkersburg – Hodoš thermal aquifer monitoring network are: Rad-2 (operational monitoring) and Rad-3a (operational monitoring).

2.5.4.1 Baseline Monitoring (Baseline Estimation)

Baseline monitoring also comprehends baseline estimation and intends to summarize the initial (or steady state) hydraulic, thermal and hydrochemical conditions in the hydrogeothermal aquifer. In case of open loop hydrodynamic plays baseline monitoring should also focus on the estimation of recharge and discharge. The subsequent (**Table 10**) gives an overview on aimed parameters to be investigated at the Bad Radkersburg - Hodoš pilot area for baseline monitoring:

Table 10: Main parameters of baseline monitoring

Parameter group	Parameter (Minimum resolution in space)
Reservoir characteristics	Temperature (x,y,z) Pressure (x,y) Hydraulic Gradient (x,y) Thermal rock parameters (x) Hydraulic Rock Parameters (x,y)
Hydrochemistry	Main Ions (x) Salinity (x,y) Isotopes (x)
Recharge, Discharge	Infiltration Rate (x,y) Discharge Rate (x,y)

Note: »x« stands for scalar characteristic values

The baseline monitoring / estimation can also be compiled of reported explorative data by users. In order to guarantee a harmonized data-acquisition a bilateral explorative catalogue of measurements should be implemented in the national licensing and permitting procedures. Protocol for data exchange should be approved by Permanent Bilateral Slovenian – Austrian ''Mura'' commission for Water Management.

2.5.4.2 Operative Monitoring (production)

Operative monitoring can be separated into (1) Qualitative Monitoring and (2) Quantitative Monitoring. The operative monitoring should be performed by users based on the protocol given in the report Catalogue of monitoring and reporting measures (Prestor et al., 2103). We propose that the operative monitoring is applied to the boreholes Rad-2 and Rad-3a in Bad Radkersburg and Be-2 in Benedikt v Slovenskih Goricah. The exact monitoring program should be agreed between users and competent public authorities.

2.5.4.3 Passive Monitoring (observative monitoring)

It has to be kept in mind, that depth to the Bad Radkersburg – Hodoš reservoir is more than 2000 meters below surface in most of the area. Pure observation wells have to be financed by public authorities and therefore not likely to be realized for the above mentioned reservoir depths. Synergies for cost reduction may in turn be given at:

(a) Abandoned hydrocarbon wells

(b) Non-prospective exploration drillings (hydrogeothermal, hydrocarbons).

The data-acquisition, maintenance of both well and monitoring probes as well as the list of main monitoring parameters has to be realized by public authorities and associated agencies / institutes. All quantitative monitoring should be realized by automatic devices. The Slovenian candidates for the observative monitoring are wells Pe-1 in Pečarovci and Kor-1gα in Korovci.

3 Conclusions

In the frame of TRANSENERGY project proposals for trans-boundary monitoring systems in the trans-boundary zones of five pilot areas have been prepared. The international regulations and recommendations and the best practice of trans-boundary monitoring (Malm-aquifer in the border region of Bavaria-Upper Austria (D-AUT) and trans-boundary monitoring plan of T-JAM project) and results of the steady state pilot models were considered.

In the monitoring plan three different levels were distinguished. Baseline monitoring supply information the natural changes of hydrogeothermal systems. Active monitoring is based on the measurements taking in production (injection) wells by the users. Passive monitoring represents the regional changes caused by thermal water withdrawals. These measurements must be managed by the regional authorities. Due to intense costs associated to the installation of monitoring wells, further observation points of thermal waters will only be implemented at non successive or abandoned wells.

Monitoring programs have to be specifically designed for each geothermal reservoir because of their individual characteristics, and planed measurements included both qualitative and quantitative parameters.

The monitored parameters in different monitoring levels have determined and monitoring points in the trans-boundary zone of the pilot areas were selected.

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