Future hydrogeothermal resource management and mitigation of utilization conflicts based on numerical modelling in the frame of the Central Europe project Transenergy

Gregor Goetzl[1], Stefan Hoyer[1], Magdalena Bottig[1], Fatime Zekiri[1], Jaromír Švasta[2], Ivan Baráth[2], and Radovan Černák[2]

[1] Geological Survey of Austria, Neulinggasse 38 A-1030 Vienna, Austria

[2] State geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava 11, Slovakia

gregor.goetzl@geologie.ac.at

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ABSTRACT

The Vienna Basin, located at the trans-boundary region of Austria and Slovakia also including the capital city of Austria, Vienna, is well developed for hydrocarbon production. However, hydrogeothermal utilization has not been applied yet except for several minor scale balneological uses. As the Vienna Basin offers great opportunities for future geothermal use, resource assessment based on 3D numerical modelling and 2D Raster analyses have been performed in the framework of the project Transenergy.

Following a multiplet calculation scheme proposed by Gringarten (1978) so called total "Inferred Resources" (Deibert, 2010) in the range of 350GW_{th} have been assessed for 5 hydrogeothermal structures in the Vienna Basin. In contrast at least 230MWth have already been proved at water inflow at hydrocarbon exploration wells located at the identified hydrogeothermal plays ("Measured Resources"). In a next processing step the "Probable Reserves" will be estimated for the Vienna Basin. This term represents the fraction of hydrogeothermal resources, which can presently be recovered in an economical feasible way.

The achieved results represent a first bilaterally harmonized step towards a possible future trans-national management of near- and trans-boundary hydrogeothermal reservoirs.

1. INTRODUCTION

1.1 Nomenclature

In the following paper the term "hydrogeothermal" covers aspects associated to naturally existing thermal water bodies and aquifers as well as the utilization of thermal waters in a geothermal doublet. This term does not include heat-pump supported geothermal applications at shallow groundwater bodies.

The reporting of hydrogeothermal resources follows the Canadian Geothermal Code for Public Reporting (Deibert, 2010). In this context the term "hydrogeothermal play" is used for a subsurface formations and tectonic nappes which consist of at least one thermal aquifer.

1.2 Current situation and motivation of the study

The Vienna Basin, situated in the trans-boundary region of Eastern Austria and Western Slovakia, offers home to more than 2 million habitants also covering Vienna, the capital city of Austria. It is a region of still on-going economic and industrial development showing a strong trans-national character as part of the so called "Centrope Region".

The Vienna Basin represents one of the most relevant sedimentary basins in central Europe for hydrocarbon exploitation. As a consequence of various oil and gas reservoirs located at both sedimentary layers as well as at fractured and fissured basement rocks the Vienna Basin has been well explored during the last 70 years both on Austrian and Slovakian territory covering more than 2500 deep drillings.

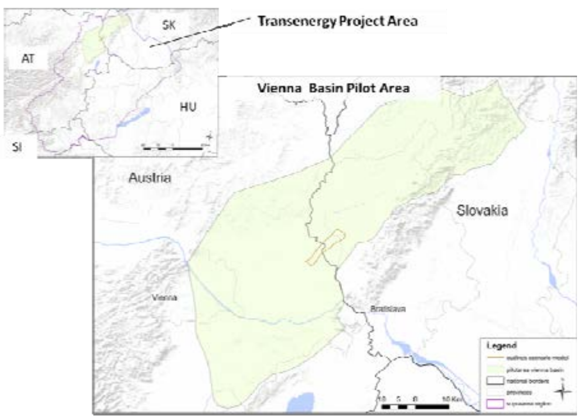

Figure 1: Location of the Vienna Basin Area at the Transenergy project area.

In contrast to this hydrogeothermal utilization has not been developed in the Vienna Basin although relevant resources are evident. However, actively circulating thermal aquifers are already used for balneological purposes at the south-western and south-eastern margin areas of the Vienna Basin in Austria (see also Fig. 2).

In a recent study already installed total thermal capacities for balneological use in the range of around $30MW_{th}$ (referring to average groundwater temperature) have been summarized for the southern Vienna Basin (Goetzl et al, 2012). In contrast to this hydrogeothermal resources for energy supply in the range of at least $300MW_{th}$ to $500MW_{th}$ are estimated for the central and northern parts of the Vienna Basin (Goldbrunner, 2010).

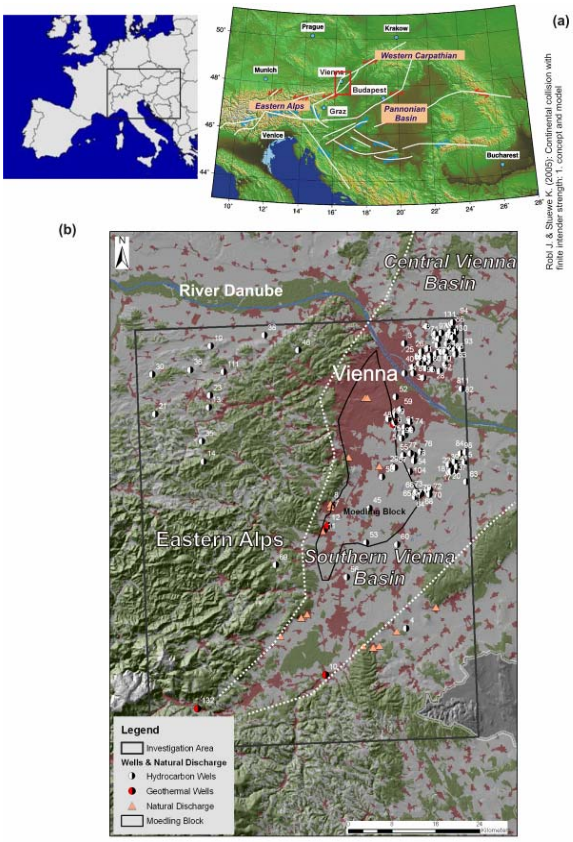

Figure 2: Location of thermal water wells and natural thermal springs at the southern Vienna Basin (taken from Goetzl et al, 2010).

Until now the main barriers for developing hydrogeothermal utilization in the Vienna Basin are related to the intense exploitation of hydrocarbons in this region. However, as the peak of hydrocarbon production in the Vienna Basin is believed to be continuously rising. In this context recently the first major geothermal project has been launched at the city of Vienna ("Geothermie Wien Aspern", see also Goldbrunner & Goetzl, 2013).

However, as hydrocarbon exploitation is still active and various relevant hydrogeothermal reservoirs are located trans-boundary, future geothermal utilization should base on profound water management, which should fulfil the following demands in order to avoid conflicts: (1) Bilateral harmonization and (2) considering hydrocarbon production. State of the art management of hydrogeothermal resources should in turn base on numerical 3D modelling in order to predict future impacts of current use.

1.3 Aims of objectives of Transenergy in the Vienna Basin pilot area

The project „TRANSENERGY – Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia" (2010 – 2013) aims to provide implementation tools based on a firm geoscientific basis for enhanced and sustainable use of geothermal resources linked to CEU Program, Area of Intervention 3.1. (developing a high quality environment by managing and protecting natural resources).

In collaboration of the geological surveys of Austria, Hungary, Slovakia and Slovenia various trans-national databases and models have been elaborated for the western Pannonian Basin and its adjacent areas in order to support harmonized future management of hydrogeothermal resources (see also Fig.1).

Within the Transenergy project area several pilot areas have been selected for applying the chosen approaches and methods in a more detailed and practical way. All pilot areas are affected by different scientific questions and aims, which have been approached by harmonized numerical modelling techniques. In this context the Vienna Basin pilot area is representing a region without existing large scale hydrogeothermal utilization but offering great future possibilities as well as potential utilization conflicts. For that reason the main objectives in the application of numerical modelling are represented by:

i. Estimating hydrogeothermal resources at relevant reservoirs

ii. mapping the initial steady state conditions (baseline estimation) at the selected reservoirs

iii. compiling the present data situation in 3D models (data containers)

iv. providing numerical models associated to different reservoirs for future permission and monitoring procedures.

The achieved models, prepared by the Geological Survey of Austria and bilaterally provided to Austria and Slovakia, illustrate the basis of a possible joint thermal water management in the future. This extended abstract focuses on the assessment of resources. An outlook on future practical applications of the elaborated models is given in chapter 6.

2. HYDROGEOTHERMAL SETTINGS IN THE VIENNA BASIN PILOT AREA

2.1 Geological Background

The Vienna Basin is representing an intra-mountainous pull-apart basin, located at the transition zone between the Eastern Alps and the Western Carpathians (see also Fig. 2). Showing the shape of a spindle its major strike direction is oriented southwest to northeast (Wessely 2006).

As a consequence of several different stages of sedimentation cycles and Alpine thrusting the Vienna Basin consists of three autochthonous and allochthonous floors (Brix and Schultz, 1993). The tectogenetic evolution of the Vienna Basin commenced in middle Jurassic times leading to the development of a synsedimentary rift basin (Pre Vienna Basin). Its further tectonic and sedimentary history from late Jurassic until Oligocene follows the Northern Alpine Molasse Basin and is representing the basal autochthonous floor.

In early Miocene stage tensional forces due to Alpine and Carpathian thrusting lead to the evolution of a piggy-back basin on the top of the Alpine and Carpathian nappes (Proto-Vienna Basin).

The final and actual tectonic and sedimentary stage is related to the pull-apart mechanism and the subsidence of the Alpine and Carpathian nappes (allochthonous second floor of the Vienna Basin) leading to the deposition of Neogene sediments (Neo- Vienna Basin) from Eggenburgian to Ottnangian age (early Miocene) on. The Neogene basin fillings are representing the third, autochthonous floor of the Vienna Basin.

The (Neo-) Vienna Basin is divided into several high-zones (e.g. Moedling Block, Mistelbach Block) and depression zones (e.g. Zistersdorf Depression and Schwechat Depression) separated by major normal faults (e.g. Leopoldsdorf Fault Zone) and by the Vienna Basin transform fault. Whereas the high-zones are predominately located at the margin areas, depression zones are located at the central parts of the Vienna Basin. At the major depocenters Neogene sedimentary fillings reach thicknesses of up to 5000 meters.

2.2 Hydrogeological settings

In general the Vienna Basin is affected by hydrodynamic convection systems as well as by stagnant, connate aquifers. Following the overall concept by Wessely (1983) the relevant hydrodynamic systems are located at those marginal areas of the Vienna Basin, which are hydraulically connected to outcropping carbonates associated to the Northern Calcerous Alps and the Little Carpathians (see also Fig. 3).

Most of the Vienna Basin pilot area is covered by connate reservoirs, which are separated from the hydrodynamic systems at the basin margins by either great normal fault zones (e.g. Leopoldsdorf Fault System) or by geological borders. At connate reservoirs the increase of salinity with depth varies between 12g(Cl)/km and 35g(Cl)/km reaching values up to 120g(Cl)/l.

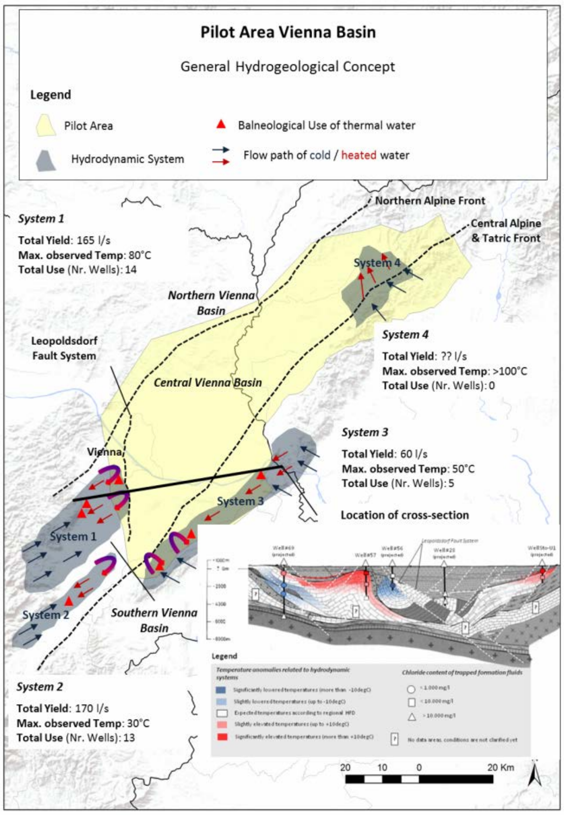

Figure 3: General hydrogeological concept of the Vienna Basin pilot area. Red coloured regions at the cross-section represent zones of elevated subsurface temperatures due to convection. Blue coloured areas correlate with areas of lowered temperatures.

The pressure conditions vary between hydrostatic- to slightly overpressured (excess pressure conditions up to 50 bars at depths of around 3000 meters). In contrast the actively recharged hydrodynamic systems at the marginal areas show significantly lowered mineral contents (down to <1g/l at depths of 3000 meters) at hydrostatic to slightly overpressured pressure conditions due to thermo-lift.

2.3 Geothermal settings

The geothermal conditions at the Vienna Basin are influenced by both the supra-regional scale crustal build-up and local to regional scale convective processes. Whilst the average observed terrestrial heatflow density (HFD) is at the level of 70mW/m², its range varies between <50mW/m² and 100mW/m² (see also Fig. 4).

Gradually enhanced geothermal conditions are observed towards the Pannonian Basin south-eastwards of the Vienna Basin due to reduced lithospheric thickness. In contrast lowered HFD values have been observed towards the south-western margin of the Vienna Basin influenced by Alpine thrusting in combination with massive inflow or meteoric waters at permeable carbonates of the Northern Calcareous Alps.

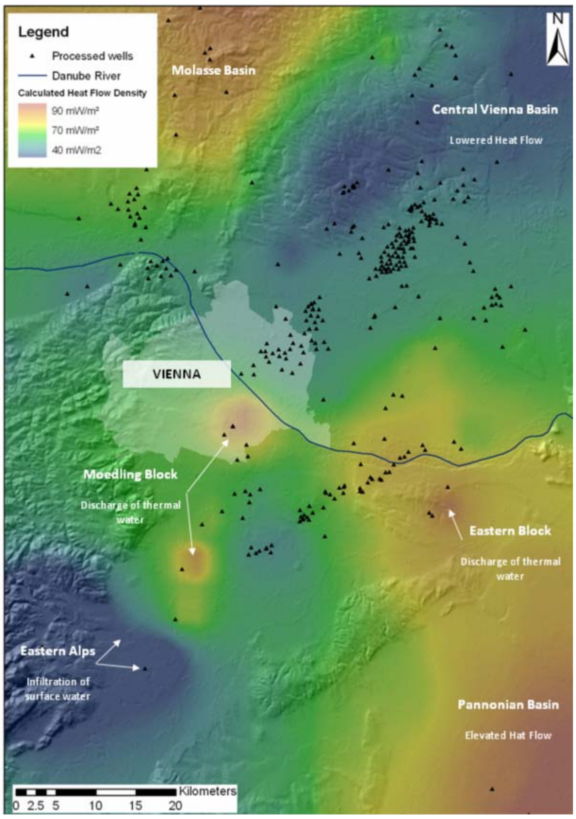

Figure 4: HFD map of the central and southern Vienna Basin region (taken from Goetzl, 2010).

In addition reduced HFD values are also observed at the great depocenters at the central and northern Vienna Basin as a consequence of rapid sedimentation of cold surface sediments. The long-scale geothermal settings are overprinted by local to regional scale geothermal anomalies caused by hydrodynamic convection systems at the southern and eastern marginal areas as shown at the cross-section at Fig. 3 as well as at Fig. 4, respectively.

2.4 Relevant hydrogeothermal plays

Relevant hydrogeothermal plays have been identified based on the following criteria: (i) Near- or cross-border location, (ii) minor use for hydrocarbon exploitation in order to avoid utilization conflicts and (iii) hydrogeothermal utilization already exists or is to be expected in the near future.

In total 5 relevant structures have been identified in the Vienna Basin pilot area, which are located at floor 3 (Neogene sedimentary deposits) and floor 2 (allochthonous Alpine and Carpathian basement rocks). The stratigraphic and geographic location of the selected hydrogeothermal plays is shown in Fig. 5 and listed in Table 1.

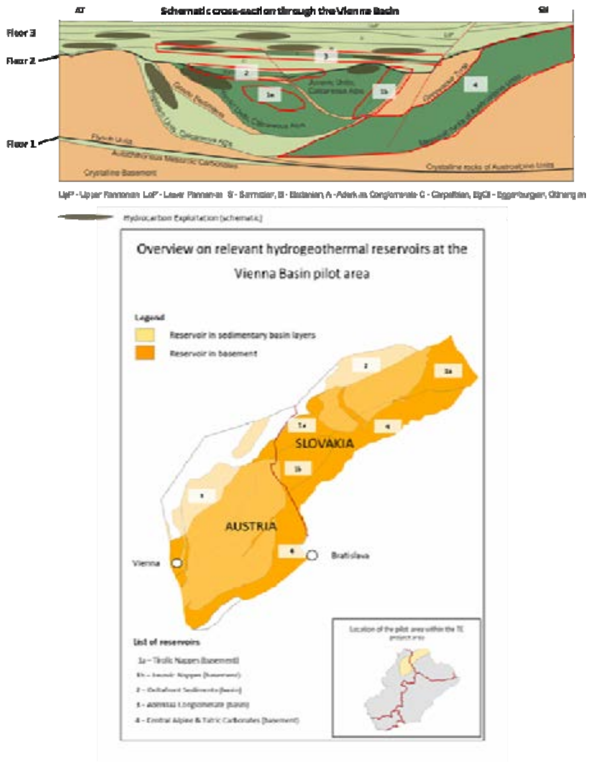

Figure 5: Overview on the selected relevant hydrogeothermal plays in the Vienna Basin pilot area.

Table 1: List of selected hydrogeothermal plays.

ID	Name	Description
1a	*Tirolic Nappes*	Upper Austroalpine Units (basement), fractured reservoir (Dolomite & Limestone), connate water, slightly overpressured
1b	*Juvavic Nappes*	Upper Austroalpine Units (basement), fractured reservoir (dolomite & limestone), connate water, hydrostatic pressure
2	*Deltafront Sediments*	Neogene basin fillings, porous reservoir (sandstone), connate water, hydrostatic pressure
3	*Aderklaa Conglomerate*	Neogene basin fillings, porous reservoir (conglomerates), connate water, underpressured due to hydrocarbon exploitation
4	*Central Alpine & Tatric Carbonates*	Fractured basement rocks (dolomites and sandstones), partly active recharge, existing utilizations (balneology)

Except for hydrogeothermal play 4 (Central Alpine & Tatric Units) no hydrogeothermal use has been yet installed at the Vienna Basin pilot area. Nevertheless, due to the existing relevant hydrogeothermal resources and favourable geographical position of the hydrogeothermal plays in the vicinity of the capital cities of Vienna and Bratislava future hydrogeothermal use for energetic purposes has to be expected.

3. METHODOLOGY AND APPROACH

3.1 Data background

Due to the strict data policy of the Austrian hydrocarbon industry, it was generally hard to get access to reservoir- and production data. The same situation has to be reported for Slovakia. Nevertheless, the achieved models basically found on published data and data from the archives of the involved geological surveys.

The geometrical model of the identified hydrogeothermal plays was derived from published structural maps at scale 1:200.000 (e.g. Kroell, 1993), re-evaluated by formation tops at hydrocarbon wells and various published geological cross-sections (e.g Wessely, 2006). No seismic exploration data have been used for the build-up of the geometrical models due to a restricted data-access.

The thermal and hydrogeological input data for characterizing the identified hydrogeothermal plays have been partly gained from previous studies (Goetzl et al, 2010) and from field reports from the hydrocarbon industry, which were available at the geological surveys. In addition boundary conditions concerning the basal heat flux have been derived from the supra-regional scale data models previously established in the frame of the project Transenergy (Goetzl et al, 2012).

Thermal and hydraulic rock parameters have also been gained from printed field reports available at the involved geological surveys. Thermal rock parameters have additionally been measured on drilling cores at previous studies (see also Goetzl et al, 2010). Due to a low density of available input data quite simple and generalized reservoir models (main statistical characteristics) had to be used.

3.2 Applied workflow

Considering the objectives of the studies at the Vienna Basin pilot area the following workflow has been chosen after identifying the most relevant hydrogeothermal plays: (1) Build-up of the geometrical models; (2) Petrophysical characterization of the identified hydrogeothermal plays (thermal- and hydraulic rock parameters); (3) Regional scale thermal modelling covering the entire pilot area; (4) Assessment of hydrogeothermal resources based on 2D raster analyses. In the following, the main working steps will be presented in brief:

Geological Modelling

The conceptual geological legend for the Vienna Basin pilot area consists of 14 geological units, whereat 7 units are associated to the Neogene Basin Filling and the remaining units to the Pre-Neogene basement (see also Fig. 5).

The geometrical modelling was performed using the software packages ArcGIS™ for data preparation and GOCAD™ for the modelling itself. All models solely rely on published literature data. As the resulting geometrical models are covering both Austrian and Slovakian territories, harmonization of input data had to be performed locally. Trans-boundary structural maps (e.g. Kroell, 1993) as well as trans-boundary cross-section (e.g. Wessely, 2006) have in turn been used for the harmonization of input data.

The export of the achieved geometrical layer-models for the later numerical modelling was basing on ASCII 3D datasets for the allocation of material parameters and CAD data-formats.

Petrophysical characterization of reservoirs

The petrophysical characterization of the identified hydrogeothermal plays covers the following rock parameters: (i) Thermal conductivity (solid matrix), (ii) heat capacity (solid matrix), (iii) total porosity, (iv) bulk density, (v) hydraulic permeability, (vi) density of the subsurface waters.

Except for the parameters (i) and (ii) all petrophysical input data have been gained from archive data related to hydrocarbon exploration wells. In turn the thermal rock parameters have been gained from several previous studies performed by the Geological Survey of Austria. As a consequence of a quite heterogeneous and scattered distribution of most petrophysical input data only uniform significant values (average values and standard deviation) have been assigned to the individual model units assuming isotropic and homogenous reservoir conditions.

Regional scale numerical modelling

The numerical modelling at a regional scale resolution covering the entire pilot areas was aimed to calculate the subsurface temperatures as an input for the latter estimation of hydrothermal resources. The achieved model covers an area of approx. 127 km x 50 km at a vertical extend of 15 km. The modelling itself was performed using the software package Comsol Multiphysics™, which uses finite-element algorithms for the simulation of coupled physical transport processes.

The elaborated numerical mesh consisted of 3.4 million tetrahedrons ranging between 0.5 km and 10 km (side length).

As heat transport by conduction had been considered as the only thermal transport process, the applied boundary conditions cover an elevation dependent surface temperature as well as constant basal heat flux.

The assignment of material parameters was performed by 3D interpolation of input data, which had previously been allocated to a 3D grid of the geometrical build-up exported from GOCAD™.

The simulation was performed steady-state in several cycles for refitting of boundary conditions and material parameters. In this context the achieved numerical models have been iteratively calibrated with 775 measured borehole temperatures (DST datasets) gained at 236 wells.

Assessment of hydrogeothermal resources

The assessment of hydrogeothermal resources mainly follows the terminology of the "The Canadian Geothermal Code for Public Reporting" (Deibert et al, 2010) also including the theoretical potential (Heat in Place). The general resource assessment scheme is shown in Fig. 6.

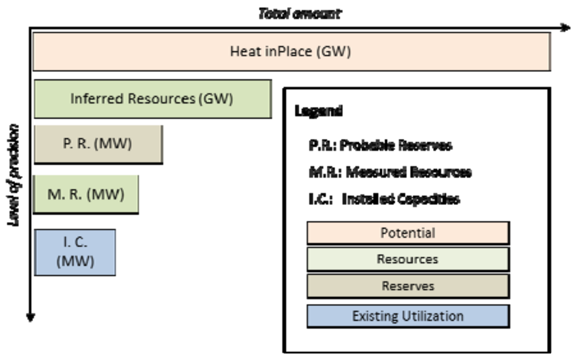

Figure 6: Resource-scheme applied for the Vienna Basin resource assessment.

The calculation of the Heat in Place follows general calculation schemes (e.g. Hurtig et al, 1991), whereas the total porosity as well as the gross thickness were used in the chosen approach. The geometrical as well as thermal input parameters have directly been taken form the regional scale numerical model.

The calculation of hydrogeothermal resources and reserves associated to the identified hydrogeothermal plays was performed by applying 2D raster analyses based on the software packages Esri ArcGIS™ and Golden Software Surfer™.

According to Deibert et al. (2010) the term "*Inferred Resources*" describes estimated hydrogeothermal resources at a low level of accuracy based on generalized assumptions of the reservoir conditions. Our approach towards the calculation of Inferred Resources follows a multiplet calculation scheme of the Heat Recovery Factor published by Gringarten (1978). Based on an optimization of the distance between the wells of an individual dublet (*D*) and its yield (*Q*) optimized multiplet schemes have been calculated for the individual hydrogeothermal plays.

$$D = \sqrt{\frac{\rho_w \cdot c_w}{\rho_a \cdot c_a}\,\frac{Q\,\Delta t}{h}\,\frac{\pi}{3}} \qquad [1]$$

$$Q = \frac{2\pi T s}{\ln\frac{D}{r_w}} \qquad [2]$$

$\rho_w \cdot c_w$… Volumetric heat capacity of the thermal fluid [J/(m³·K)]

$\rho_a \cdot c_a$… Bulk volumetric heat capacity of the aquifer [J/(m³·K)]

Δt… Operational lifetime of the hydrogeothermal utilization [s]

h… Thickness of the aquifer [m]

T… Transmissivity [m²/s]

s… maximum allowed drawdown [m]

r_w… Radius of the well.

The calculation of Inferred Resources is basing on the following general settings: Technical reference Temperature (temperature of the injected fuid): 55°C; operational lifetime: 50 years (full annual operation); radius of the wells: $9^{5/8}$ inch; maximum drawdown: 200m.

The combination of equations [1] and [2] delivers the distance between the wells as well as the optimized yield of an individual hydrogeothermal dublet projected on the 2D raster, which characterizes the investigated hydrogeothermal play. In order to avoid non-realistic solutions of equations [2] a maximum allowed yield of 100l/s (0.1m³/s) was set as a constraint. Summarizing the energetic output of the derived multiplet scheme leads to the estimation of the Inferred Resources as well as to the Heat Recovery Factor.

The term "*Measured Resources*" is dedicated to a high level of confidence, proved by direct measurements in drillings. In this context the thermal energy in place was calculated based on investigated water inflow at hydrocarbon exploration wells located at the individual hydrogeothermal plays (open-hole tests and casing tests). As the maximum yield observed during a hydraulic test in hydrocarbon wells does not represent the thermal capacity of an aquifer due to reduced casing- and bit diameters used at these wells and the relatively short duration of the hydraulic tests the measured hydrogeothermal resources was calculated using a pessimistic volumetric approach as described in equation [3].

$$H_{[]} = \Phi_{eff} \cdot (c_p \cdot \rho)_w \cdot (T_{Res} - T_{Ref}) \cdot h \cdot r^2 \cdot \pi \qquad [3]$$

Φ_{eff}… Effective porosity [-]

T_{Res}… Measured reservoir temperature [°C]

T_{Ref}… Technical reference temperature (injection temperature = 55°C) r… radius of hydraulic influence according to the results of the hydraulic test [m].

According to Deibert (2010) the term "*Probable Reserves*" covers the thermal energy in place which can be recovered for commercial production. In our approach the Probable Reserves will be calculated by filtering the surface of a hydrogeothermal play with undedicated surface space leading to a Spatial Recovery Factor [0% - 100%], which can be combined with the Inferred resources.

The already "*Installed Capacities*" are calculated based on perennially averaged extraction rates following the EGC or IGA country update calculation schemes. Doing so the technical reference temperature is set to (a) the average injection temperature in case of a dublet use or (b) to the annual surface temperature in case of a singlet use (e.g. for balneological purposes).

4. RESULTS

The presented results will focus on the achieved numerical model (3D distribution of subsurface temperatures) as well as on the assessment of hydrogeothermal resources.

4.1 Regional scale numerical model

As described in chapter 3.2 the elaborated regional scale numerical model is founding on quite simple and generalized assumptions made for the subsurface characteristics, which have been iteratively modified in order to fit to measured subsurface DST data.

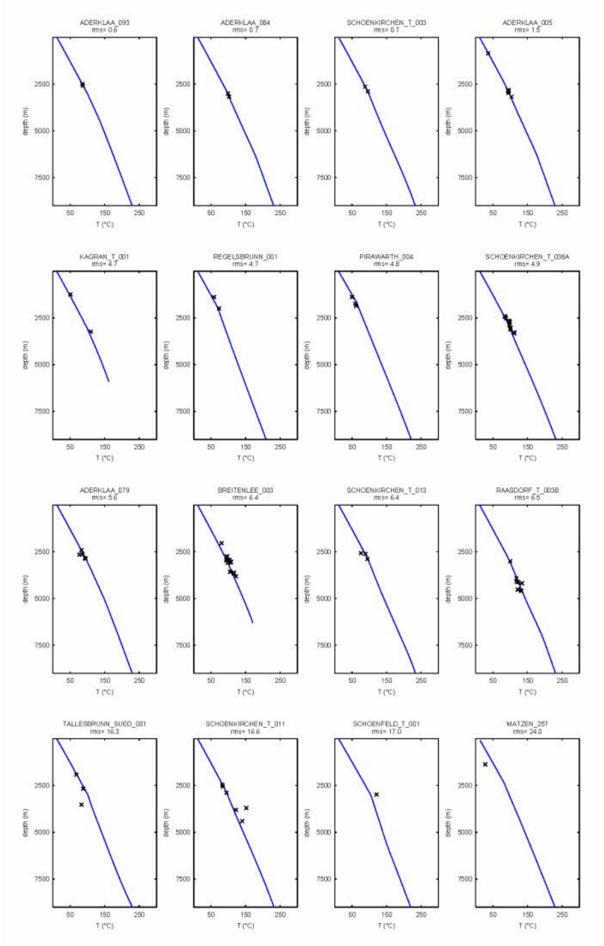

Figure 7: Fitting of the final numerical model on measured DST datasets.

However, as shown at Fig. 7 the general fitting of the achieved pure conductive thermal model to 775 measured subsurface temperatures is quite satisfying showing a mean deviation between modelled and observed temperatures of 0.02(±6.8)K or an absolute deviation of 6.13(±5.6)K, respectively. As a consequence of neglecting convective heat transport major residuals have been observed at wells showing a strong influence of hydrodynamic convection.

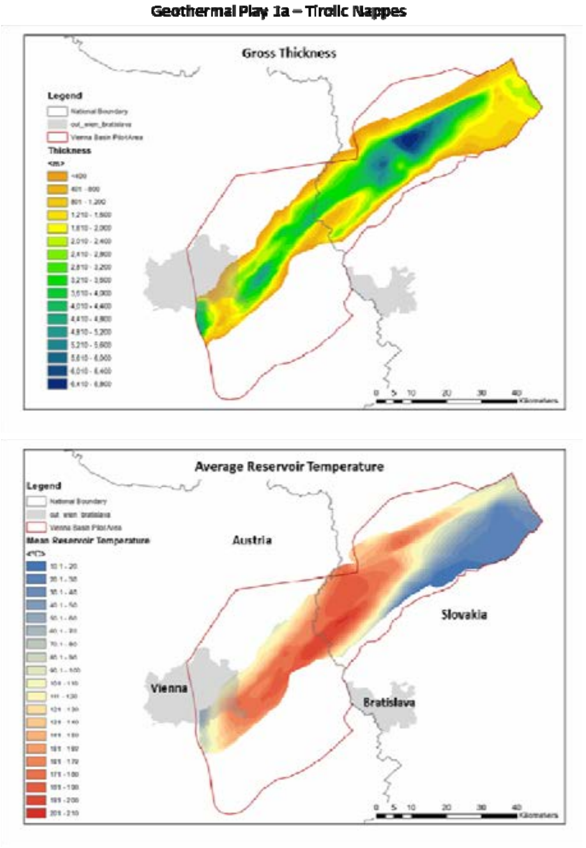

Figure 8: Gross thickness (above) and mean reservoir temperature (below) of the Tirolic Nappes hydrogeothermal play.

As indicated in Fig.8 the Tirolic Nappes hydrogeothermal play represents one of the most promising structures at the Vienna Basin pilot area, as it is showing average reservoir temperatures of up to more than 200°C as well as gross thicknesses of up to more than 6.500 meters. Furthermore the eastern districts of the capital city Vienna are also underlay by this hydrogeothermal play at reservoir temperatures above 100°C. Nevertheless, this structure is also used for hydrocarbon exploitation at some areas both located on Austrian and Slovakian territory. Taken this into account the most promising part of the Tirolic Nappes play is located at the border region between Austria and Slovakia as hydrocarbon exploitation is absent there.

4.2 Resource Assessment

Based on the above described approach the hydrogeothermal resources have been assessed for the identified 5 hydrogeothermal plays in the Vienna Basin pilot area taking into account gross volumes. The results are presented in the subsequent tables Table 2 to Table 4:

Table 2: Characteristics of the identified hydrogeothermal plays.

Hydrogeothermal Play	Gross-volume (km³)	ØT$_{Res}$ (°C)	ØTrans-missivities (m²/s)
1-a Tirolic Nappes	4426	117.8	$1.48 \cdot 10^{-3}$
1-b Juvavic Nappes	901	128.6	$3.766 \cdot 10^{-4}$
2 – Deltafront Sediments	124	58.2	$1.413 \cdot 10^{-2}$
3 – Aderklaa Conglomerates	249	79.8	$3.338 \cdot 10^{-4}$
4 – Central Alpine & Tatric Carbonates	3220	134.4	$5.537 \cdot 10^{-2}$

Table 3: Hydrogeothermal potential and resources.

Hydrogeothermal Play	HIP[1] (GW$_{th}$)	HF[2] (%)	Inferred Resources (GW$_{th}$)
1-a Tirolic Nappes	532	33.17	176
1-b Juvavic Nappes	118	33.14	39
2 – Deltafront Sediments	0.693	32.94	0.228
3 – Aderklaa Conglomerates	12.3	33.05	4.1
4 – Central Alpine & Tatric Carbonates	416	33.17	134

[1]Heat in Place referred to an injection temperature of 55°C and an operational lifetime of 50 years (full duty).

[2]Heat Recovery Factor.

Table 4: Measured resources and installed capacities.

Hydrogeothermal Play	Measured Resources[3] (MW$_{th}$)	Wells[4]	Installed Capacities (MW$_{th}$)
1-a Tirolic Nappes	180.711	134	0
1-b Juvavic Nappes	34.595	28	0
2 – Deltafront Sediments	5.846	251	0
3 – Aderklaa Conglomerates	11.699	271	0
4 – Central Alpine & Tatric Carbonates	0.289	6	4.9[5]

[3]Based on Austrian hydrocarbon exploration wells.

[4]Number of wells tapping the hydrogeothermal play (only Austrian data available).

[5]Installed capacities refer to annual surface temperature.

Considering an ideal multiplet scheme without spatial restrictions on the surface the calculated Heat Recovery Factor is almost invariant at a level of around 33%. This in turn leads to Inferred Resources of up to 180GW_{th} referring to an injection temperature of 55°C. The greatest Inferred Resources have been assessed for the carbonates of the Pre-Neogene basement (hydrogeothermal plays 1a, 1b and 4) due to high reservoir temperatures and considerable gross volumes. In contrast it has to be pointed out, that large parts of these plays are located at great depths of more than 5000 meters below surface and therefore may currently not be developed in an economically feasible way. The identified hydrogeothermal plays located at Neogene sediments (2 and 3) are showing Inferred Resources at a range several orders lower than those in the basement (0.693 – 12.3 GW_{th}). This is caused by (a) lower reservoir temperatures and (b) lower gross thicknesses.

In total, Inferred Hydrogeothermal Resources in the range of 350GW_{th} have been assessed for 5 hydrogeothermal plays in the Vienna Basin pilot area. These huge but hypothetical resources at a low level of accuracy are contrasted by Measured Resources assessed at hydrocarbon exploration wells in the range of 230MWth (0.6‰ of Inferred Resources). It has to be remarked, that the assessment of Measured Resources was following a rather pessimistic approach (see also chapter 3.2) and is basing at a low number of exploration wells in some hydrogeothermal play (e.g. play “4 – Central Alpine & Tatric Units).

The assessment of Probable Reserves is currently still going on and will be realized by means of filtering of Inferred Resources according to the topographic situation (available open space). In order to present a rough estimation of Probable Reserves an average amount of open space in the range of 5% is assumed. This leads to total Probable Reserves in the range of 18GW_{th}. Further reduction of the Probable Reserves is given by considering maximum utilization depths (economical constraint). This will above all tackle the Reserves assessed for the basement hydrogeothermal plays.

5. CONCLUSIONS

The elaborated geothermal models and the resulting assessment of hydrogeothermal resources are representing a first trans-national approach towards a joint future data- and resource management strategy for the Vienna Basin. As the achieved outcomes represent the actual data-situation in the pilot area, which are affected by a strict data policy by the hydrocarbon industry, the achieved level of accuracy and respectively confidence is still quite low. In this context, the assessed Inferred Resources are believed to lead to overestimations due to accounting gross-volumes. In contrast the Measured Resources are assumed to be underestimating due to fact, that (a) Slovakian exploration wells are missing in the assessment and (b) the chosen approach for assessment can be seen as quite pessimistic and conservative.

The applied multiplet-scheme approach by Gringarten (1978) in order to calculate the Inferred Resources is hardly affected by the Transmissivities of the investigated plays leading to more or less constant Heat Recovery Factors. For instance, low Transmissivities at a reservoir lead to reduced maximum yields considering a maximum drawdown at the production well and in opposite to this also lead to a reduced minimum distance between the two wells of a hydrogeothermal dublet. This fact in turn results in a quite constant Heat Recovery Factor. By setting constraints for high Transmissivities (e.g. maximum yield per dublet) and low Transmissivities (minimum required yield per dublet) unrealistic outputs can be avoided.

The achieved assessment scheme based on 2D raster calculations is suitable to be also applied on more detailed level of assessment (higher density of input data) and can easily be changed in case of up-dated input data. However, the geometrical as well as thermal and hydraulic input data for the 2D raster calculations should be provided by 3D numerical modelling as this approach provides a better accuracy than 3D interpolation of input data.

6. OUTLOOK ON FUTURE RESOURCE MANAGEMENT IN THE VIENNA BASIN

The achieved numerical models and assessed hydrogeothermal resources at the Vienna Basin pilot area are referring to regional scale geological models and generalized reservoir characteristics. However, in the framework or the project Transenergy a general scheme has been developed which can be used in future for a bilateral hydrogeothermal management in the Vienna Basin. In order to enhance the level of accuracy and confidence the following tasks have to be fulfilled in subsequent studies: (i) Geometrical modelling of individual, promising structures within hydrogeothermal plays, (ii) elaboration of more sophisticated petrophysical reservoir models (e.g. anisotropy and correlation to facies types) and (iii) investigating the influence of the hydrodynamic systems at hydrogeothermal play “4-Central Alpine & Tatric Units”.

At the present the legal framework for a trans-national hydrogeothermal resource management is still missing. Nevertheless, a general management scheme, which is outlined at Table 5, has been developed for the Vienna Basin pilot area based on the achieved models and resource assessment scheme. The proposed data-management scheme is focussing on the identified hydrogeothermal plays. This scheme includes monitoring, modelling and reporting and differs between 3 different levels of utilization (exploitation). Until now the current state of utilization is still at a very moderate level in the Vienna Basin pilot area.

Table 5: General data management scheme for a future trans-national hydrogeothermal resource management.

Level of Utilization	Data Acquisition (Surveys &	Data Management

	Monitoring)	
1 - No Utilization	Closed aquifer: Interpretation of available exploration data (baseline assessment) Open aquifers: Baseline monitoring	Bilateral regional scale numerical models at regional scale; reporting of resources and reserves based on bilateral databases and rasters
2- Moderate Utilization	Interpretation of exploration data and operational monitoring	Bilateral database of baseline and production data; validated numerical models at local to regional scale applied for permission procedures
3 - Intense Utilization, interferences and changed in quantity and quality evident	Operative monitoring Passive monitoring at observation wells Periodical evaluation of existing permissions	Bilateral database of data from passive monitoring; local scale numerical models validated by history matching

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