Austrian-German Cooperation in Modelling and Managing a Transboundary Deep Groundwater Body.

O. Vollhofer* and M. Samek*

* Federal Ministry of Agriculture, Forestry, Environment and Water Management, Stubenring 1, 1030 Vienna, Austria.

Key words: Groundwater Modelling, Groundwater Management, Geothermal Groundwater use

ABSTRACT

The thermal groundwater of the Malmkarst (Upper Jurassic) in the "Lower Bavarian and Upper Austrian Molasse Basin" is of transboundary importance and the only important deep groundwater body in Lower Bavaria and Upper Austria in terms of the WFD.

To avoid an overexploitation and to guarantee a sustainable use of the thermal water detailed research work has been done. It had become necessary because of the increasing economical importance of thermal –water use in the affected area on both sides of the German-Austrian border. Especially the thermal-water use for spa and for hydrogeothermal purposes are of immediate importance.

From 1995 to 1998 a model for the thermal-water aquifer was developed in a German –Austrian cooperation. First a hydrogeological model was developed to describe the hydrogeological, geothermal and water management facts. Based on these facts the conceptual model has been adapted and processed by a mathematical groundwater model.

The mathematical model of the groundwater flow for an extremely heterogeneous karstic aquifer caused by fractures and karst-tubes was done by a two-dimensional steady flow mathematical groundwater model. For the mathematical modelling a 2D-Version software was used.

In order to deal with these questions a 3D- hydraulic-thermal combined groundwater model was developed in German – Austrian cooperation from 2005 to 2007. The main aim of this research work was to gain knowledge and a better understanding of the thermal- hydraulic system and the given relations between the major processes, and furthermore to elaborate common management strategies.

In order to be able to manage the thermal water resources in a sustainable way and according to be best available state of technology the ad hoc expert group was asked to elaborate joint protection and utilisation strategies and to lay down the results in guidelines.

PURPOSE OF THE STUDIES

To avoid an over-exploitation and to guarantee a sustainable use of the thermal water detailed research work has been carried out. It has become necessary because of the increasing economic importance of thermal water use in the affected area on both sides of the German-Austrian border. Especially the thermal-water use for spa and for hydrogeothermal purposes are of immediate importance.

GROUNDWATER BODY

The groundwater body extends from Regensburg in the north to Linz in the south. Its eastern border follows the river Danube on a long distance. With a total area of 5.900 km² the length is 150 km and the width is 55 km. The top of the Malm reaches a depht of about 2000m beow sea level. The thickness of the Upper (karstic) Malm is about 300 m.

HYDROGEOLOGICAL MODEL (CONCEPTUAL MODEL)

First a hydrogeological model was developed to describe, the existing knowledge about geological, structural, hydrogeological, hydrochemical, isotopical, geothermal and water management facts.

MATHEMATICAL GROUNDWATER MODEL

The 2D-mathematical model of the groundwater flow for an extremely heterogeneous karstic aquifer - caused by fractures and karst-tubes - mathematical groundwater model. It combines a continuous approach with a discontinuous model and is able to simulate the influence of fractured zones and of karstic tubes on the permeability and thus on the groundwater flow system.

The various calculations show that temporarily changing production rates and the influence of geohydraulic tests and re-injection tests on neighbouring thermal water utilisations can only be calculated by a nonsteady flow groundwater model. For this reason a nonsteady flow model was used in order to simulate the thermal water withdrawals taking into consideration the temporal decrease of pressure of the highly confined deep thermal water.

This mathematical (hydraulic) model is the relevant instrument for authorities on both sides of the border for evaluating the required water extractions, the potential yield and the implications on other existing wells on a reliable basis.

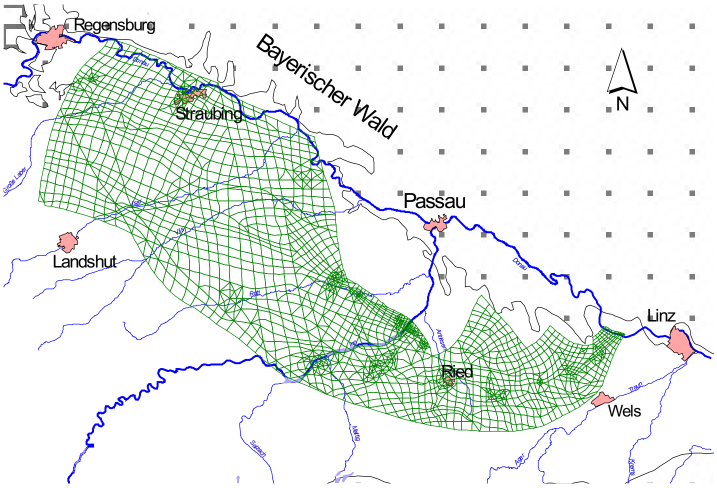

Figure 1. Survey of the water-balance area.

FURTHER PROBLEMS -INTERNATIONAL WORKSHOP MUNICH 2002

The increasing number of sites which re-inject geothermically used water creates a large number of questions which cannot be answered by using only a hydraulic model. Within the framework of an international workshop held in Munich in 2002 those questions which would have to be clarified from the point of view of water management were formulated in order to ensure a sustainable geothermal use of thermal water.

The following questions have to be answered:

Is there a relation between the reduction of the temperature in the deep thermal aquifer and the existing pressure condition?
Is there a relation between temperature and the relevant hydraulic parameters as permeability and storage coefficient?
How can the quality of those parameters be influenced, if the temperature in the deep aquifer is decreasing?
Is there a relation between the extraction of thermal water and the quantity of water (yield) which can be collected from the deep groundwater body?
Other questions concern the way in witch the temperature of the re-injected water, the location of and the distance between the boreholes for extraction and re-injection and the operational mode can influence the thermal conditions such as the temporal and spatial distribution of temperature in the deep thermal groundwater body.

HYDRAULIC-THERMAL COMBINED GROUNDWATER MODEL

In order to deal with these questions a 3D- hydraulic-thermal combined groundwater model on the basis of the results of the model from 1998 was developed in German – Austrian cooperation from 2005 to 2007. The detailed studies were carried out by a German-Austrian-Swiss consortium of engineers, the ARGE TAT. This model is based on the regional geological and hydro-geological situation in the “Lower Bavarian and Upper Austrian Molasse Basin”.

The main aim of this research work was to gain knowledge and a better understanding of the thermal-hydraulic system and the given relations between the major processes, and furthermore to elaborate common management strategies.

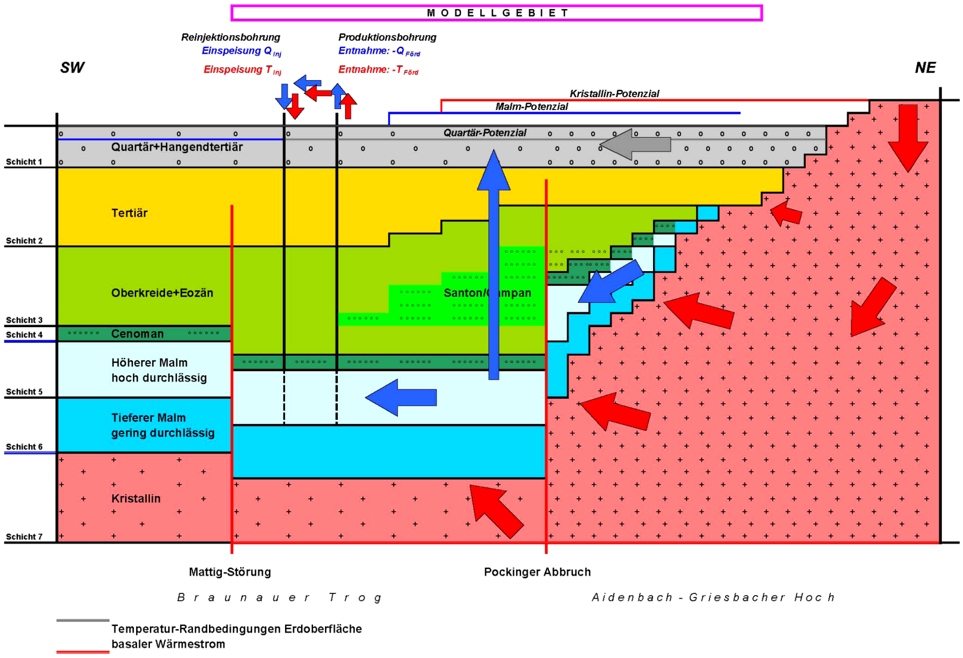

Figure 2. Schematic representation of the hydrostratigraphic units

Figure 2 shows a schematic representation of the hydrostratigraphic units lying above the crystalline taken into consideration in the 3D hydraulic thermal combined groundwater model and the relevant energy flows.

APPLICATION OF THE 3D-HYDRAULIC-THERMAL COMBINED GROUNDWATER MODEL

On the basis of this model detailed studies were carried out for a representative part of the overall system in order to gain a better understanding of the system.

A total of 39 load cases were calculated. Within the framework of these works the effects on the pressure and temperature behaviour on the one hand in the case of a certain configuration of production and re-injection wells and of changing operational modes (varying extraction quantities and re-injection temperatures), and on the other hand of a certain operational mode and changed configurations of production and re-injection wells.
Moreover it is examined how sensitively the pressure and temperature behaviour of the Malm aquifer reacts on changed system parameters.

In general the calculations were made on the basis of a nonsteady flow model for an operational period of 50 years (presently assumed technical lifetime of a geothermal doublet). One forecasting case simulated an operational period of 2000 years, two forecasting cases operational periods of 300 years.

Within the framework of sensitivity analysis system relevant parameters, such as thermal conductivity, rock porosity, permeability contrast faults / matrix and permeability in the higher Malm were varied. The range of variations of the parameters examined has been oriented according to the available measuring results and literature values. Synergetic effects of system and process parameters were initially not being investigated.

Three position configurations (case A, B and C) were examined according to the following scheme:

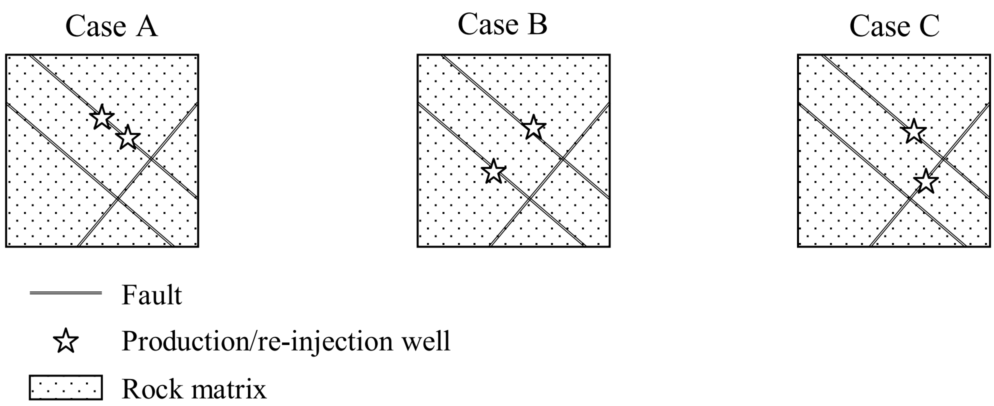

Figure 3: Position configurations for doublets

The following position configurations were taken into consideration with borehole distances of 1 and 3 km in the local models.

Case A: Production and re-injection wells on an identical fault zone.
Case B: Production and re-injection wells on parallel fault zones
Case C: Production and re-injection wells on crossover fault zones

RESULTS:
The model results were evaluated with respect to the following system and process factors.

- Volume flow rate (production and re-injection quantities per time unit)
- Temperature of re-injected water
- Operational mode (annual constant or seasonal withdrawal)
- Location of the fault in relation to the production and re-injection wells
- Distance between the production and re-injection wells
- Difference between the permeability of stone matrix and fault zones
- Heat conductivity of the rock matrix
- Porosity
- Hydraulic conductivity of the rock matrix
- Groundwater re-injection upstream of the production well.

The influence of the individual system and process parameters on the pressure and temperature behaviour in the production and re-injection wells as well as on the dimension of the cone of depression in the section examined are represented in diagrams.

The extent of the effect was evaluated as follows:

LOW The change of a certain parameter shows no or only minor influence on temperature and/or pressure behaviour
MEDIUM The change of a certain parameter shows an already noticeable influence on temperature and/or pressure behaviour.
HIGH The change of a certain parameter shows a substantial influence on the temperature and/or pressure behaviour

The following diagrams show the hydraulic and the thermal impact on the production and on the re-injection well under the input parameters and boundary conditions on which the modelling is based.

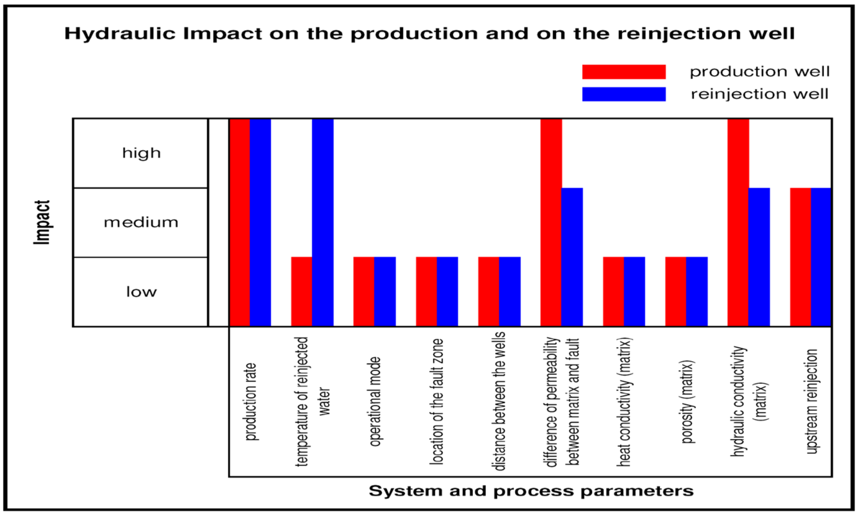

Figure 4.
Hydraulic impact on the production and on the re-injection well

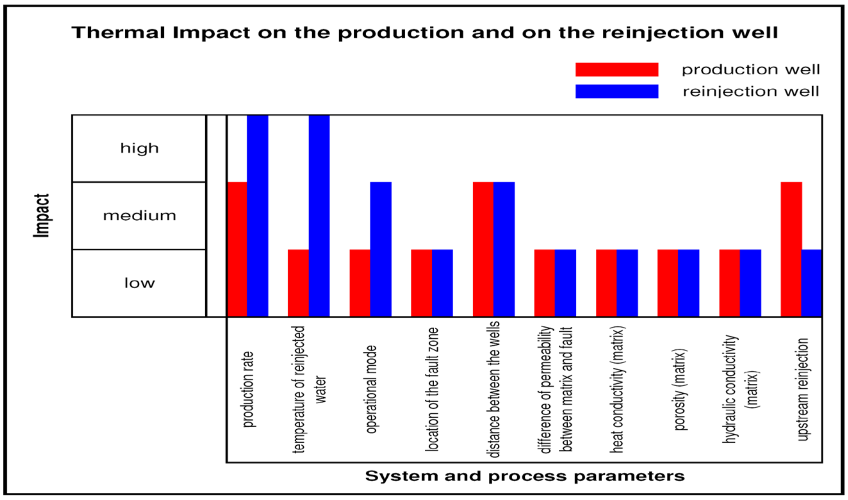

Figure 5.
Thermal impact on the production and on the re-injection well

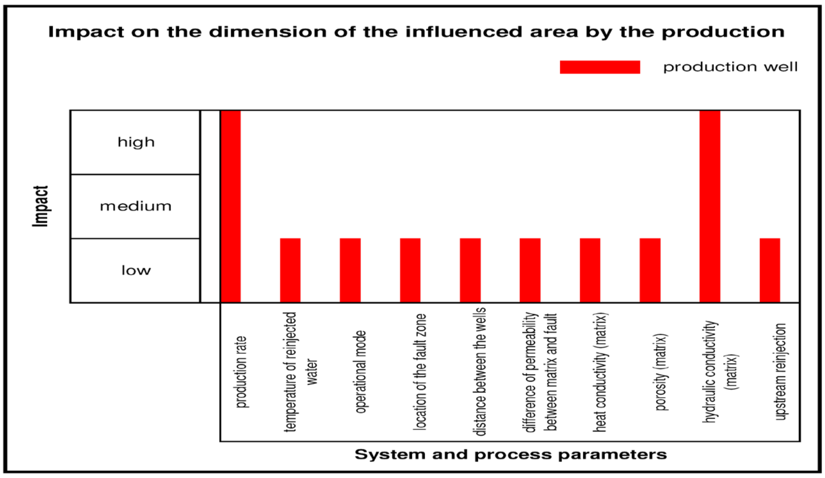

Figure 6.
Impact on the dimension of the cone of depression

Proceeding on the assumption on which the model calculations are based the following conclusions can be drawn for the representative part of the groundwater system:

- The production rate exerts high influence on the pressure behaviour in the production and in the re-injection well.
- The re-injection temperature exerts high influence on the pressure and temperature behaviour in the re-injection well.

- The difference between the permeability of rock matrix and fault as well as the hydraulic conductivity have high influence on the pressure potential in the production and re-injection well.
- The volume flow and the hydraulic conductivity have a high influence on the extension of the area affected by the withdrawal.
- A re-injection of groundwater upstream of the production well has medium influence on the pressure behaviour in the re-injection well.
- Other system and process parameters have basically low influence on the pressure and temperature behaviour in the production and re-injection wells.

GUIDELINES

In order to be able to manage the thermal water resources in a sustainable way and according to be best available state of technology the ad hoc expert group was asked to elaborate joint protection and utilisation strategies and to lay down the results in guidelines.

So far, guidelines are available on the following issues:

- Management principles
- Dimensioning of plants for the thermal water use
- Application, maintenance and further development of the mathematical groundwater model
- Required application documents
- Catalogue of requirements
- Exchange of relevant information and data

SUMMARY:

From the point of view of water management:

A better systemic understanding of the thermal-hydraulic interrelations in the model area could be gained.
The influence of the operational mode on the pressure and temperature behaviour can be better assessed in the model area.
It will only be possible to estimate the dimensions of individual parameters determining the hydraulic and thermal behaviour also in future.
In spite of a better understanding of the system forecasts of the effects of geothermal utilisations on the thermal balance still entail great uncertainties.

The parameter which has a much more restrictive effect on the utilisation of geothermal energy is the utilizable thermal water quantity.
The geothermal doublets will operate over decades without significant changes of temperature and pressure.
A statement on whether the results of the study can be transferred to other bodies of water is currently not possible, further and intensive investigations will be necessary in the future.
Basically one can proceed on the assumption of the extraction of the available energy, even though, taking into consideration the available energy sources, this will be possible over a very long period.
The results have shown that after about 1000 years, thus a relatively very long period, there will be an impact on the temperature in the production well as a consequence of the re-injection of cooled water.
Even though this influence is very low compared to the original temperature it is rather doubtful whether the utilisation of geothermal energy can be called sustainable strictly speaking.

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