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The groundwater province in the Lower Bavarian and Upper Austrian Molasse Basin: a groundwater budget in the Malmkarst using a mathematical model

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ABSTRACT

From **1995** to **1998** a model **for** the thermal-water aquifer (Malmkarst) in the Lower Bavarian and Upper Austrian Molasse Basin was developed in a German-Austrian cooperation. A mathematical 2-D ground-water model was installed in order to calculate the amount of thermal water in this area. It based on a hydrogeological model. The model covers the area from Regensburg (Germany) in the north to Linz (Austria) in the south and contains about *6* 000 km². This model allows the simulation of different water extraction- and reinjection- configurations. It became necessary because of the increasing economical importance of thermal-water **use** in the area of Bad Füssing, Bad Birnbach and Bad Griesbach located in German and Altheim and Geinberg located **in** Austria. Especially the thermal-water **use** as medicinal water and **for** hydrogeothermal purposes are of immediate importance. By the model the German and **the** Austrian authorities have got a relevant instrument to evaluate the required water extractions, the potential yield and the implications on other existing wells, on a reliable basis. A survey of the model area and the essential **results** of the hydrogeological and the mathematical model is worked out.

KEYWORDS

Thermal water, Malmkarst, ground-water balance, ground-water model, hydrogeological model. mathematical model

1. Introduction

The thermal water of the malmkarst (Upper Jurassic) in the Lower Bavarian and Upper Austrian Molasse Basin is used **for** spa purposes and in order to gain hydrogeothermal energy. The thermal-water use in Bad Füssing, Bad Birnbach and Bad Griesbacb in the German area and Altheim and Geinberg in the neighbouring Austrian region, bas become an increasing economical importance; this can be seen by the high number of overnight stays and its steep increase during the last years.

From 1984 to 1989 a group of about 20 scientist realised the research project "Hydrogeothermal Energy Balance and Ground Water Resources of the Malmkarst in the South German Molasse Basin" for the German Ministry of Research and Technology. The essential result was, that the natural discharge of thermal water in this area all in all was only about 1,5 m^3/s. This was the reason that further researches in the subsidiary area of the Molasse Basin were started. In the meantime better data were available and thus a more detailed research work was possible.

2. Regensburger Vertrag (Contract of Regensburg)

In April 1992 the "Ständige Gewässerkommission nach dem Regensburger Vertrag" instructed the ad hoc Expertengruppe "Tiefenwasser" to ask the Geotechnische Biiro Prof. Dr. Schuler/Dr.-Ing. Gödecke, Augsburg for a tender about a ground-water model for the thermal water in the Lower Bavarian - Upper Austrian Molasse Basin. This model should be a relevant instrument for the German and the Austrian authorities to evaluate the required water extractions and the potential yield under consideration of other existing wells on a reliable basis. Especially with respect to required groundwater extraction in this area, some prognoses should be possible for thermal ground-water management as well as detailed statements about existing thermal - water use. The ad hoc Expertengruppe "Tiefenwasser" had to supervise the elaboration of the model until it was finished. The group bad two members from Austria and three members from Germany. From case to case some external advisers were consulted.

Segensburger Vertrag

nternational Treaty from **01.12.1987**

between

- **BRD** + EG and the
- Republic of Austria

about the watermanagement cooperation in the catchment area of **the** Danube

Draanisation:

- **Ständige** Gewasserkommission (**9** members from the **BRD** + **EG**, ***6*** members from Austria) There are **2** Sachverstandigen AG installed:
- **Sachverständigen-Arbeitsgruppe** „Gewässerschutz"
- **Sachverständigen-Arbeitsgruppe** „Wassermengenwirtschaft, Wasserbau" **On** its suggestion the
- ad-hoc-Experlengruppe „Tiefenwasser" **was** installed and instructed to supervise the elaboration of the around-water model.

Figure 1: "Regensburger Vertrag"

3. Ground-water balance

The ground-water balance of the study area is presented in figure 2 and extends from Regensburg and Landshut in the north to Linz in the south. The eastern border is accompanied for long distances by the river Danube. With a total area of 5900 km^2 the length is 150 km and the width is 55 km.

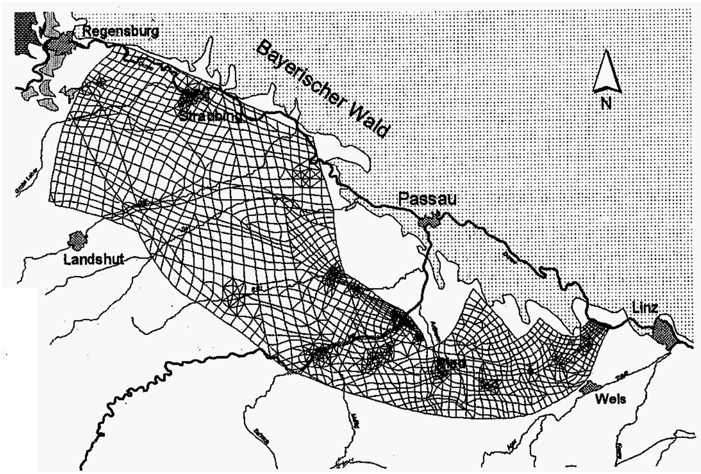

Figure 2: Survey of the water-balance area

4. Geology

The investigation area is bordered by

- the crystalline massif of the Bavarian Forest in the north-east
- the Landshut-Neuötting structure in the south-west
- the north boundary of the alps and a zone of highly mineralised, stagnating deep ground-water in the south and
- a ground-water dividing line in the west

Figure 3 shows a simplified geological map.

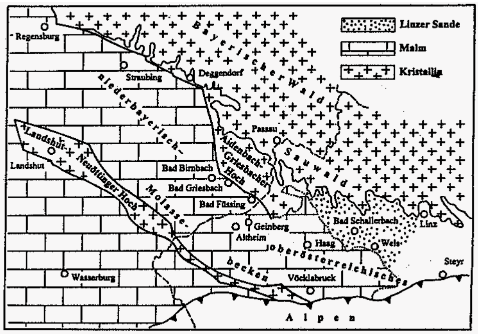

Figure 3: Geological survey of the model area

The thermal water flows within the carbonatic Malm as an aquifer. The Malm (Upper Jurassic) crops out near Regensburg and dips towards the south as shown in figure **4.** Near the river Inn the top of the Malm reaches a depth of about 2000 m below sea level. From the Inn to the east the aquifer is ascending to the river Danube west of Linz, cut by important tectonic structures. Near the city of Wels the Malm is thinning out and is there substituted by the clastic Linzer Sands (tertiary). The aquifer overburden mainly consists of clayey layers (Cretaceous and Tertiary).

The following longitudinal section shows the aquifer level running from the north-west to the south-east.

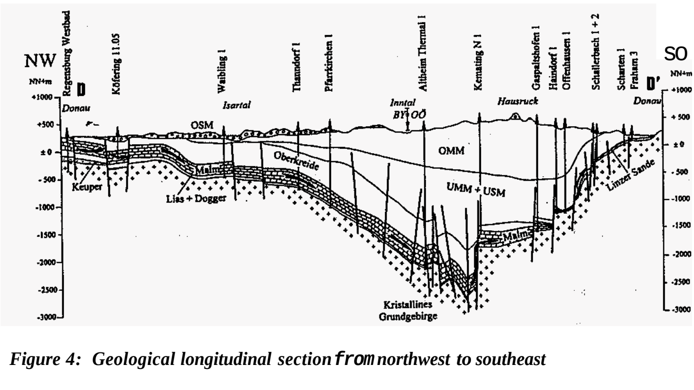

Figure 4: Geological longitudinal section from northwest to southeast

5. The hydrogeological model (conceptual model)

The purpose of the hydrogeological model was to describe, to abstract and to scbematise the existing knowledge about geologic, structural, hydogeologic, hydrochemic, isotopic, geothermic and watermanagement facts. After that it could be adapted and processed by a mathematical ground-water model. Based on existing data

- the sedimentological character within the Malm was developed
- structural and isopach maps of the Malm were constructed
- the thickness of the water tilled aquifer, the pressure head of the thermal aquifer **taking** in account a defined virtual model water, the different permeabilities of fault zones and tectonic blocks, the distribution of temperature and the hydrochemic and isotopic ground-water situation in the investigated area were worked out and described.

Essential results of the hydrogeological model are the following:

- The flow direction in the thermal aquifer is orientated from north-west to south-east
- The balance area is bordered by a ground-water ridge in the north
- The southern border of the balance area is west of Linz. The discharge of the thermal aquifer occurs through the Tertiary Linzer Sands to the Danube River
- Highly mineralised and saliniferous deep ground water, not participating in the general flow, border the balance area in the south
- The thermal water is recharged vertically west of Straubing through the Cretaceous and Tertiary overburden (leakage), between Regensburg and Passau by lateral infiltration from the crystalline massif of the Bavarian Forest and by lateral infiltration from the Upper Austrian Sauwald within Tertiary sands
- The thickness of the water tilled thermal aquifer reaches from 40 to 250 meters.

The complete flow of thermal water within the Lower Bavarian-Upper Austrian Molasse-Basin was balanced to 620 l/s. About 130 **l/s** (21 %) are used at present. About 490 l/s discharge to the Danube River. With regard to the existing intensive use of thermal water in Lower Bavaria and Upper Austria it is to take into account that a considerable amount **(330** to 340 **l/s)** of the thermal water is recharging the aquifer eastward and therefore downstream of the main users. This high part of balance is only at the disposal of users east of Haag in Upper Austria. The users west of Haag (at present 55 **%**) have no advantage of this recharge. The present safe yield of about 70 l/s is low compared with the upstream recharge of about 280 l/s to 290 **l/s.** Thus the development in the central region with 25 % is very high.

The hydrogeological model is based on the most actual scientific knowledge. It allows an overall and consistent description of the investigation area and the thermal ground water. The hydrogeological model is a reliable basis for the mathematical ground-water model.

6. Mathematical ground-water model

The mathematical modelling of the ground-water flow for an extremely heterogeneous karstic aquifer caused by fractures and karst-tubes was done by a 2-dimensional steady flow mathematical groundwater model with a numerical solution. For the mathematical modelling a 2D-Version of that software was used which was developed by Prof. Dr. L. Kiraly, Université Neuchâtel, Switzerland for the research work "Hydrogeothermal Energy-Balance and Ground-water Budget for the Malm-Karst in the South German Molasse Basin". The mathematical program 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 ground-water flow system. The most important advantage of this program can be seen in the fact, that it is able to respect regionally differing transmissivities, ground-water recharge areas and discharge areas as well as areas of boundary inflow. In addition all the tectonic structures being mapped can be introduced in the model calculation.

The calibrated model covers 3 100 elements and 5 800 knots. The location and the shape of the elements are mainly determined by the tectonic structures, by areas of differing sediments, by the outfalls, as well as by the boundaries of different recharge rate areas and permeability zones (see figure 2). The boundary conditions were defined either as boundary inflows or fix potentials or as nonflow boundaries. The values and distributions of the boundary in - and outflows as well as the areas of differing ground-water recharge and outseeping ground-water were introduced in the hydrogeological model. A rough survey can be seen in figure 5).

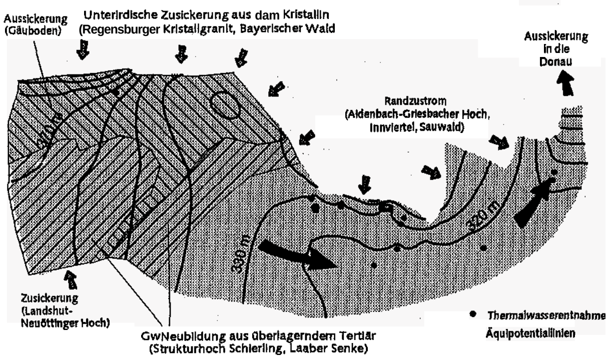

Figure 5: Ground-water budget for the thermal water in the model area

The analysis of the existing data shows, that the thermal water can be separated in zones of different temperature and mineralisation. As the logged piezometric heads are influenced by the temperature and the mineralisation, it was necessary to adjust the measured values to a standardised temperature of 10°C and a mineralisation of 500 mg/l.

The numerical model was developed in the following steps:

- Construction of the model-geometry including the development of the element net on the basis of the hydrogeological model
- Working **out** a strategic concept for the modelling of the ground-water flow and fixing the field and boundary conditions.
- Calibration by several **runs** with variations of parameters, boundary inflows, recharge and seepage rates, but taking the ground-water budget of the whole model area into consideration.
- Sensitivity analysis **of** the whole ground-water system with respect to a variation of the most important parameters.
- Prognosis calculations under steady and nonsteady flow conditions for various cases with different capture and reinjection configurations referring to existing and designed thermal water utilisations.

The various calculations showed that temporally changing production rates and the effects **of** short geohydraulic tests and reinjection tests on neighbouring thermal-water utilisations can only be calculated by a nonsteady flow ground-water model. For this reason a nonsteady flow model was used in order to simulate the thermal water withdrawals taking into consideration the temporal relaxation of the highly confined deep thermal water. The results **of** the calculations with the steady flow model showed, that a relatively good correspondence between the calculated and the measured values was reached. It also could be well simulated the dependence of the drawdown and the uplift curves from the locally differing storage coefficient.

In total **4** different cases were investigated and calculated under steady and nonsteady flow conditions. The main results are the following:

- Up to now an overproduction **of** the thermal-water aquifer cannot be observed
- Effects of future productions can be forecasted with a sufficient reliability
- A total reinjection **of** hydrogeothermally used deep water is mandatory
- The deep water with high salinity in the southern boundary area of the model can be mobilised, the pressure conditions should be held stable as well as possible.

7. Summary and conclusions

The ground-water model, that was developed in a German-Austrian cooperation, is a reliable instrument for the German and the Austrian authorities to evaluate the required water extractions. It allows:

- to balance the ground-water occurrence in the lower Bavarian-Upper Austrian Molasse-Basin
- a sufficient quantification of the ground-water recharge and
- a quantification of possible effects on existing neighbouring wells.

New data will be available by changing water extraction- and reinjection-configurations and by additional thermal-water extractions and reinjections. Based on these data a new calibration of the mathematical model can be carried out from time to time. Thus the exactness and reliability of prognoses can be improved and therefore stated more precisely.

The registration of data shall be coordinated as well as the exchange of data shall be guaranteed. This will be managed within the German-Austrian cooperation.

The good results of the ground-water model have finally shown, that the common efforts on both sides - the German and the Austrian one - were worthwhile. But there must not only be a common interest of the authorities to evaluate the ground-water occurrence in this area correctly. Especially the thermal-water users in the spas and health **resorts** as well as the users **of** hydrogeothermal energy should have a special interest to know more about their thermal-water resource. They must learn to utilise thermal water economically and carefully. This **is** necessary to ensure a sustainable **use** for the following generations and for the existence of the health resorts.

Apart from the quantitative and qualitative results of the ground-water model the most important realisation is, that the German and Austrian authorities as well as the thermalwater **users** on both sides of the river Inn are all in the same boat. For a sustainable use of this resource it is necessary to have a close and trusting cooperation of all persons involved in this subject.

Acknowledgements

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