Limits for the use of thermal waters on the example of the conceptual model of the Benesov-Usti aquifer system
of the Bohemian Cretaceous basin

PhD thesis

Résumé

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The very work was carried out in the Bohemian Cretaceous Basin, which forms the largest basin structure of Upper Cretaceous age in the territory of the Czech Republic and takes up a major part of northern and eastern Bohemia. A crucial impulse for the research was new exploratory work in approximately the last 10 years, whose intention was to intensify thermal water sources exploration. Several new boreholes and wells were drilled and these have brought to light information about the hydrogeological structure exploited.

The groundwater system of the Benesov and Usti nad Labem area, taking up around 2000 square kilometers, is more or less a closed hydrogeological unit with a relatively easily definable boundary. Its groundwater occurs mainly in Cretaceous aquifers. In some parts it is necessary, though, to take into account the ground water in underlying and surrounding geological structures as part of the hydrological balance.

The largest thermal water accumulation known so far in the Czech Republic with temperatures often exceeding 30 degrees centigrade and in some spots approaching 40 degrees centigrade can be found in the voluminous and spacious Cretaceous aquifers, particularly in the basal (A, AB) and middle (C, BC) aquifers of the groundwater system of the Benesov and Usti nad Labem area. Exploitation of these thermal waters has thus far been concentrated in the Usti nad Labem and Decin regions.

Apart from the presence of the thermal waters, the groundwater system of the Benesov and Usti nad Labem area also represents, particularly in its eastern part, a water resource system of exceptional importance with great potential of fresh groundwater exploitation. The existing output estimates of the groundwater natural resources in this system have been around 10 cubic meters per second, about half of which represents water yield (Hercik et al. 1999). The extent of actual groundwater treatment is relatively small and does not even amount to half of the estimated water yield.

The fresh groundwater and thermal waters of the groundwater system of the Benesov and Usti nad Labem area can be found in various places and depths. They occur in the same aquifers, in whose space there is a regional connection of fresh and thermal waters. This regional connection consists in groundwater which flows to the distances of up to many dozen kilometers from the infiltration place to the drainage zones. During the course of the flow, some groundwater descends many hundred meters in depth in the central part of the groundwater system. In these depths its temperature rises due to the core temperature of the earth. The chemical composition of the groundwater is being altered at the same time. Thermal water is thus gradually formed and it then flows to the natural drainage zones or to extraction spots. Possible future increase in fresh groundwater extraction in the vicinity of

the infiltration areas may reduce thermal water production.
Thermal water of Usti nad Labem and Decin areas had not been known in the past with the exception of some minute, locally discovered warm water instances in the Decin area (Spa of St. Joseph). Nonetheless, these are quite insignificant from the point of view of overall hydrological and thermal balance of the groundwater system. Therefore, before deep boreholes have helped discover the thermal water resources, the whole area of thermal waters known now represented a hydrogeological structure with very slowly flowing, almost stagnating groundwater. Exploiting the resources has made the groundwater flow significantly faster. Even though the area of interest belongs to zones of increased heat flux in the deeper parts of the earth's crust, the question arises whether sufficient heating of these waters will occur with the current accelerated groundwater flow and whether in the future the temperature of the thermal water resources will not fall. It is important to bear in mind that the thermal waters have been exploited for a relatively short period of time. In the Usti nad Labem area, the thermal water resources have been used for approximately one century while intensive exploitation of those in the Decin area has been taking place for an even considerably shorter time as recent as a few decades. These periods are too short considering the pace of the hydrogeological processes, so no substantial negative consequences of the the exploitation can be expected. With continuing or even increasing exploitation of the resources, however, falling temperature and possible quality changes cannot be excluded in the future.
The research work was concerned with collection of all the available data on the geological conditions and occurrence of groundwaters in the environment of the north-western part of the Bohemian Cretaceous basin and their processing in the form of a conceptual model. This is an area bounded by important tectonic features – the Krusne hory Mts. fault, the Bohemian Middle Mts. fault and the Luzice fault, which are characterized by separate groundwater flow regimes. The lower part of this Cretaceous basin structure contains thermal waters with a temperature of 30-40 ^{o}C, which were discovered at the end of the 19th century and have been used since then, first for industrial purposes as utility water and later for recreational purposes (swimming pools and spas) or as a source of thermal energy for heating. The use of the water is currently concentrated in Usti nad Labem and Decin.
The main impulse for preparation of this work consisted in two circumstances:
- a gradual increase in the amount of thermal water taken from the structure without any knowledge of the long-term sustainable yield of this structure
- over the past three years, some new research information has been obtained on the geological unit, particularly in connection with the ISPA project, in the framework of which new monitoring wells were created for the Czech Hydrometeorological Institute. This new information should be processed on a regional level so that former concepts of the occurrence of thermal waters can be compared with new data.

This work was prepared in the framework of a broader research project financed by the Czech Science Foundation (the author of the work is also the main responsible person for this research project), the main output of which will be a numerical model of thermal water flow and, on this basis, preparation of detailed hydrological balance calculations and

determination of the long-term sustainable yield of thermal water. From this standpoint, it is necessary to view the conceptual model as the first step necessary for preparation of a numerical model, as it entailed the collection of the necessary data, their evaluation, classification and regional processing so that they could be used for formulation of a numerical model.
The conceptual model was based on all the available information that could be collected. One of the chief sources consisted in the Hydrogeological Synthesis of the Bohemian Cretaceous Basin and specifically the part related to balance unit 3, which was prepared in the 1980's (Nakladal et al.1987) and published in the 1990's (Hercik et al. 1999). It was found that, even after 20 years and in the light of new data, most of the conclusions of this research continue to be valid, reflecting the highly professional knowledge of the authors of the Synthesis.
Limiting factors for the use of thermal waters consist both in the balance of the amount of water in the structure and also the balance of the amount of heat flowing into the structure. In relation to the professional subject of the study, this work concentrated on the former – hydrogeological – aspect of the problem. The second aspect is considered in the framework of the above-mentioned broader research project.
The collected data were processed and evaluated in three basic areas:
4. definition of the hydrogeological environment and definition of hydrogeological bodies (aquifers and aquitards)
5. evaluation of the groundwater flow regime in this environment
6. accumulation of data on groundwater quality (chemical composition, temperature) and their regionalization.

Most of the inputs for the work were prepared in the graphic form of figures, maps, hydrogeological cross-sections and tables, so that the conclusions of the work would be as graphical as possible and most useful for the ongoing research.
Main conclusions of the work:
- ❑ professional liquidation of older boreholes in the drainage areas substantially reduced unregistered losses of hot water, which was favorably reflected in the piezometric conditions in the structure
- ❑ the flow method was employed to calculate the framework balance for the basal and main cretaceous aquifers (where thermal waters are located) of the defined area and yielded the maximum sustainable yields of natural thermal waters in the drainage areas – 43 l/s in the Usti area and 292 l/s in the Decin area. Because of the lack of precision in the calculation, these are approximate values that, however, do not differ from estimates to date and practical experience in the utilization of thermal waters and are in accordance with all the available professional documents.
- ❑ The main drainage sites for the whole structure were defined – in addition to the Ústí and Decin areas, the Kamenice area in the north and the Litomerice area in the south are important drainage areas. In the south-eastern part of the territory, a substantial part of fresh (not thermal) groundwater is drained in the Brenna and Peklo areas (Ploucnice and Robecsky streams).
- ❑ Data on the occurrence of tectonics and their hydrogeological function were collected and newly evaluated. The main conclusion corresponds to the predominant complicated

structure of important faults, which form the entire fault zone consisting of variously large blocks shifting relative to one another. The groundwater regime in these zones can be quite complicated and relatively independent of that in the surrounding territories.

- ❑ The new Vilsnice 2H295 borehole indicates that the aquitard between the basal and main aquifers need not be fully developed in the Decin area. Thus, drainage in this area and exploitation of thermal waters can affect both these aquifers, with important consequences for the balance of thermal waters in this area.
- ❑ A three-dimensional view of groundwater flow yields 6 hydrogeological cross-sections constructed across the studied area, which were drawn into the geological document of J. Valecka (2008), which was prepared especially for this purpose.
- ❑ Some of the parameters of the chemical composition of the groundwaters indicate a completely different composition of the groundwater in the south-western part of the structure (Usti –Teplice area). These are waters of the Na-HCO_3 type with higher overall contents of dissolved substances and elevated fluoride contents, in contrast to the remainder of the structure, with a predominance of water of the Ca-HCO_3 type with lower mineralization.
- ❑ Processing of the temperature indicated that the warmest water is concentrated in the Decin and Usti areas, where their use is also concentrated. Simultaneously, the greatest temperature gradients were also found here, confirming suggestions of higher heat flow connected to the Ohre river tectonic structure.
- ❑ On the basis of data from the new boreholes, data on the thickness of the aquifers, depths of important geological boundaries and the piezometric contours of both aquifers were updated.
- ❑ The basic hydraulic parameters (k,T) were supplemented by new data and regionalized. Assumptions about the higher permeability and transmissivity of the environment in the drainage areas were confirmed, while slightly lower values were obtained for the recharge territory. The great scatter of values (by several orders of magnitude) indicates the substantial heterogeneity of the environment with double porosity. It is apparent that, from the standpoint of flow of thermal water, not the average, but rather the maximum values characterizing the main flow paths are important.
- ❑ Analysis of the piezometric contours of the basal and main aquifers indicated areas with the greatest potential for vertical groundwater flow.
- ❑ Sections were delimited on surface water courses with drainage of groundwaters with deeper flow and thus the areas with predominantly drainage function were defined.
- ❑ The available hydrological data from the Czech Hydrometeorological Institute were collected in the form of 20-year time series (levels from 13 monitoring wells), the flow rates in 8 measured profiles on surface water courses and climatic data from two meteorological stations. This data is necessary for formulation and tuning of the numerical model.
- ❑ Methodical evaluation of the use of geophysical well-logging methods was performed for evaluating data from new boreholes, for both lithological purposes and for determining hydrogeological data and the technical condition of boreholes. This generalizing part of the entire work has been accepted for foreign impact publication in Environmental Geology.

The terms of reference and objectives of the work were fulfilled; a concept of the flow of thermal waters in the particular geological structure has been prepared in the form of a conceptual model on the basis of collected older and new data. This model will be further

used for preparation and tuning of a numerical model of groundwater flow and hydrological and thermal balances. In addition, the work contains a number of general conclusions and outputs that can be useful for work of a similar character under similar geological conditions