ASSESSMENT OF GEOTHERMAL WATER RESOURCES IN HORNONITRIANSKA KOTLINA BASIN

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Abstract: Statistical methods and mathematical modelling were used for assessment of geothermal water resources in the basin. Statistical analysis showed seasonal character of groundwater level fluctuation in wells tapping geothermal waters at Bojnice and the influence of shallower cold groundwater in some sources. Numerical model demonstrated that the exploitation rate from Bojnice should not exceed 27 l/s to keep groundwater level stabilised. The total amount of geothermal energy of the Hornonitrianska kotlina basin was estimated on 19.6 MW_t.

Key Words: geothermal water, geothermal resources, statistical analysis, mathematical modelling, exploitation rate

INTRODUCTION

Hornonitrianska kotlina basin is located in the Central part of Slovak Republic (Figure 1). It extends between the Žiar Mts. in the Northeast, Vtáčnik Mts. in the Southeast and Strážovské vrchy Mts. in the West and Northwest. All the mountain ranges are separated from the basin by faults.

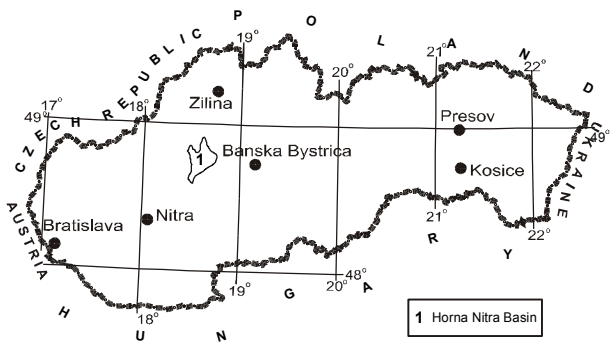

Figure 1. Location of the Hornonitrianska kotlina basin

Rocks of Ipoltica group, predominantly Choč nappe carbonates in the central part, and Krížna nappe with envelope Mesozoic in the northern tract of the Prievidza depression, create the pre-Tertiary substratum of the basin. The basal Paleogene (breccias, conglomerates) and flyschoid facies overlie the Mesozoic substratum. The earliest Neogene – Eggenburgian is composed of conglomerates and sandy clays, overlain by calcareous, sandy clays interbedded with sandstones. The next sedimentation started in Badenian and was accompanied by volcanism (Šimon, 1999). Thin coal beds overlie andesite tuffs near Jánova Lehota. Younger filling of the basin consists of sedimentary and volcanic rocks (andesite conglomerates, sandstones, siltstones, coal beds, clays, tuffites). The youngest component of the Neogene filling of the basin is the Lelovce formation (fluvial gravels, sands, sandy clays and fresh water limestones).

Geothermal waters in the Hornonitrianska kotlina basin are bound to Triassic carbonates of the Choč and Krížna nappes. Geothermal waters from Choč nappe carbonates are of Ca(Mg)-HCO_3 type with T.D.S. below 1 g/l, and those from the Krížna nappe fall into the Ca(Mg)-SO_4 type with T.D.S. of 1.3 g/l (Franko et al., 1995). Surface geothermal manifestations were known in Chalmová and Bojnice spas. The temperature of natural geothermal springs ranges from 39 °C to 45 °C.

STATISTICAL ANALYSIS OF THE RELATIONSHIP AMONG FRESH AND GEOTHERMAL WATERS

Regime of fresh and geothermal waters was evaluated using mean monthly groundwater levels in two geothermal wells NB-5 and BR-4 in Bojnice high block, mean monthly discharges of the Thermal Lake (representing natural outflows of geothermal waters) in Bojnice high block, total mean monthly discharge of all utilised geothermal sources in Bojnice spa, monthly yields of fresh groundwater springs in the adjacent area, and monthly precipitation measured in the meteorological station in Prievidza. All the data were obtained for the period 1990 – 1994.

At the same time a long–term hydrodynamic test was performed on the geothermal well Š1-NB II consisting of measurements of the static value of the hydrostatic pressure at the wellhead during the period 2.6.1993 – 7.7.1993, measurements of the temperature profile of the well and static value of the hydrostatic pressure at a depth of 1350 m in the period of 8.7. – 9.7.1993, measurements of the dynamic value of the hydrostatic pressure at a depth of 1350 m and at the wellhead, measurements of the free outflow, water temperature, air pressure and amounts of gasses in the period of 10.7. – 15.7.1993, measurements of the free outflow, water temperature and dynamic pressure value at the wellhead in the period of 16.7.1993 – 15.7.1994 and pressure increase after the well S1-NB II was

closed in the period of 15.7. – 12.8.1994. During the hydrodynamic test on the well S1-NB II a free outflow of 26 l/s and temperature of 66 °C at the wellhead were measured.

Statistical evaluation of the input data was based on homogeneity assessment, analysis of the time series components and analysis of the interrelationships among geothermal and fresh water in connection to precipitation amounts. Homogeneity of time series was evaluated using normal probability plots and double mass curve method. Time series of Dubnica spring was used as a relative time series for double mass curve construction after its homogeneity was proved by proportional cumulative curve. Analysis of double mass curves for wells NB-5 and BR-4 was complemented by residual analysis (Fendekova and Fendek, 1993). Points, in which changes of the curve direction occurred, corresponded with the periods of minimum and maximum values of groundwater level due to seasonal fluctuation. No other influence was shown. The analysis of seasonal component (Figure 2) showed that:

- in the well NB-5 minimal groundwater levels occurred in the period from November to March with the absolute minimum level regularly in February, maximum levels occurred in the period from May to July, with the absolute maximum level regularly in June,
- the situation estimated for the well BR-4 was quite similar, but the period of maximum groundwater levels was shifted to the period from April to July and the period of minimum groundwater levels to the period from December to March. The lower maximum groundwater levels in November indicates more intensive influence of shallow cold fresh water which reacted on precipitation maximum in November. The influence of shallow cold fresh water on geothermal water in the well BR-4 also indicated the shift of the maximum groundwater level period to the earlier spring months in accordance with the seasonal fluctuation of Dubnica spring fresh water.

The existence of decreasing trends in groundwater levels and yields of Dubnica spring was estimated. Cross correlation coefficients were used for analysis of interrelationships between pairs of time series. Statistically significant correlation coefficients were estimated for relationship of Dubnica spring yields and both wells NB-5 and BR-4 respectively. The highest value was 0.36 for the lag of +13 months, but all correlation coefficients with lags of 11 – 15 months were statistically significant. The significance of the correlation coefficients was tested by Fisher's test of correlation coefficient significance, taking into account the length of a time series (Sachs, 1984). The same lag of 13 months was estimated for the relationship of precipitation and groundwater levels in wells NB-5 and BR-4, but the correlation coefficients were statistically insignificant (Jezný et al., 1995).

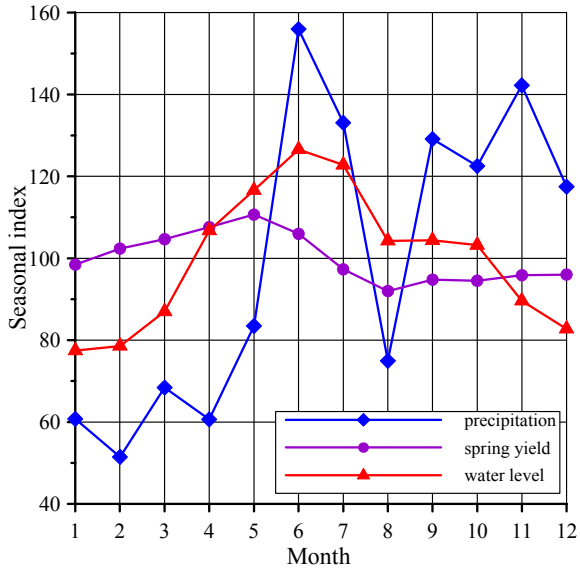

Figure 3. Seasonal components of time series of precipitation (Prievidza), spring yield (Dubnica) and geothermal water level (Well NB-5)

MATHEMATICAL MODELLING

An analytical model was created for free outflow of the well Š1-NB II. Results of hydrodynamic measurements on Š1-NB II performed in the period of 2.6.1993 – 12.8.1994 were used as the input data. The storativity coefficient was estimated using data from hydrodynamic measurements in 1980 when well Š1-NB was used as a piezometer. The estimated transmissivity coefficient was 4.52×10^{-3} m^2/s and the hydraulic conductivity had the value of 2.60×10^{-5} m/s. The storage coefficient had the value of 2.6×10^{-4} (Jezný et al., 1995). All estimated hydraulic parameters are in Table 1. The known value of storativity coefficient allowed the calculation of the skin effect. The model was used to calculate the maximal exploitation rate of Š1-NB II of 20 l/s.

A distributed parameter numerical model for Hornonitrianska kotlina basin was created with the AQUA program package developed by Vatnaskil Consulting Engineers (1992) to solve the groundwater flow and mass transport by differential equations using the Galerkin finite element method with triangular elements. The model is two-dimensional.

Table 1. Results of hydraulic parameters calculation for Š1-NB II geothermal well

Date	Coefficient of intrinsic transmissivity (m^3)	Coefficient of transmissivity (m^2/s)	Coefficient of hydraulic conductivity (m/s)	Coefficient of storativity
16.06.1980	1.15×10^{-10}	2.61×10^{-3}	1.50×10^{-5}	
16.06.1980	1.26×10^{-10}	2.86×10^{-3}	1.65×10^{-5}	1.0×10^{-4}
02.07.1980	6.86×10^{-11}	1.56×10^{-3}	8.95×10^{-6}	
02.07.1980	1.57×10^{-10}	3.56×10^{-3}	2.05×10^{-5}	2.6×10^{-4}
15.07.1994 I	1.23×10^{-10}	2.78×10^{-3}	1.59×10^{-5}	
15.07.1994 II	2.01×10^{-10}	4.52×10^{-3}	2.60×10^{-5}	

The total surface area covered by the mesh was about 231.864 km^2. It covered the area of Bojnice high block up to outcrops of crystalline rocks of Strážovske vrchy Mts. in the Northwest, Mesozoic rocks outcrops in Strážovske vrchy Mts. in the West and in Žiar Mts. in the East. As the south boundary, contact of impermeable young Palaeozoic rocks with carbonate aquifers was chosen. The pumping area was located in the western part of the modelling area. Boundary conditions for the distributed groundwater flow model were established based on geological setting, tectonics, geophysical measurements and water level measurements. The no-flow boundary was established along the whole reservoir area and only small areas in the surrounding mountains were used as boundary with constant potential. As for the initial state, prior to production it was assumed that the reservoir water head was constant.

Production rates were taken as monthly averages for each supply well from 1990 - 1994. The initial values for transmissivity and storage coefficient are taken from the results of well tests. The transmissivity, storage coefficient, anisotropy and porosity were determined by matching observed and calculated reservoir response. The **transmissivity** in the area covered by the model varied from **4.2×10^{-3} to 6.3×10^{-6} m^2/s**. The **storativity coefficient** in the area covered by model ranged from **5.1×10^{-4} to 5.1×10^{-6}**.

Model solutions suggest that there is a particular exploitation rate, which will result in stable geothermal water levels in the Bojnice high block. From the modelled cases it follows that the total exploitation rate in Bojnice high block should not exceed 27 l/s. For the deep part of Hornonitrianska kotlina geothermal reservoir 42 l/s was estimated to be the optimum exploitation rate. The total amount of thermal-energy potential of geothermal waters in Hornonitrianska kotlina basin was estimated to the value of 19.6 MW_t.

CONCLUSION

The main problem to be solved was to prove or disprove the interconnection between the Bojnice high block and the deep part of the Horna Nitra geothermal reservoir. Potential utilisation of geothermal water from the well S1-NB II and its influence on the usable amount of geothermal waters in Bojnice spa had to be investigated.

Statistical analysis of data showed the seasonal character of groundwater level fluctuation in wells tapping the geothermal waters of Bojnice high block. The existence of decreasing trends in groundwater levels and yields of Dubnica spring was estimated. The influence of shallower cold groundwater was documented by groundwater level fluctuation in the borehole BR-4. No influence of long-term (1-year) hydrodynamic test performed on the borehole Š1-NB II was documented in the case of Bojnice high block geothermal waters.

Using an analytical model the maximal exploitation rate of the well Š1-NB II on 20 l/s by free outflow was estimated. A two-dimensional numerical model confirmed that the regime of level fluctuation in Bojnice high block is dependent mainly on geothermal water exploitation, and it does not depend on precipitation directly. This conclusion is in agreement with the results of a statistical analysis, which shows no relationship between precipitation and geothermal water levels.

The numerical model demonstrated that the exploitation rate from the Bojnice high block should not exceed 27 l/s if the level of geothermal water is to be stabilised at present levels. It was confirmed that the Bojnice high block structure and deep geothermal reservoir of Hornonitrianska kotlina depression are two independent structures separated by the Malomagursky fault. The utilisation of geothermal water from the well Š1-NB II will not influence the exploitation rate in the Bojnice spa. The total amount of thermal-energy potential of geothermal waters in Hornonitrianska kotlina basin was estimated to the value of 19.6 MW_t.

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