# GEOLOGICAL, HYDROGEOLOGICAL AND HYDRAULICAL INVESTIGATION OF THE HAJDÚDOROG BATH

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***Abstract***

*In our work, a preliminary hydrogeological investigation was carried out to identify the thermal bath of Hajdúdorog's hydrogeological setting and analyze the area which it is in. Literature review was performed to understand the geological, hydrogeological conditions as well as analyzing the production wells of the bath themselves. Based on the analysis a simple hydrodynamic modeling was performed to better understand the magnitude of the volume of water that can be extracted without disturbing the nearby Hajdúnánás Bath. Based on Our results, the Hajdúdorog Bath can produce more water from the aquifer to initiate infrastructural expansion for the future.*

***Keywords:*** *thermal water, medicinal water, modeling, Hajdúdorog*

## 1. Introduction

The Hajdúdorog Bath located in the Eastern part of the Hungarian Great Plain, more closely on the Hajdúság Region of the Carpathian-basin. Regionally speaking it is included in the 2-17 Hortobágy-Berettyó planning subunit of the River Basin Management Plan of Hungary, which has an area of 4864.8 km$^2$. The main river of the area is the Hortobágy, Berettyó, and the Eastern and Western Canals. The area includes 5 shallow groundwater body, 5 deep groundwater body and 3 thermal groundwater body.

The area has a 99% drinking water supply, with no water quality issues other than some problems with arsenic, boron, ammonia. The other main water use is irrigational water production, the reason behind it, that the area is used mostly for agricultural. The most important thermal water production facilities are the Hajdúszoboszló and Debrecen Baths (OVF, 2019).

## 1.1. Geological and hydrogeological conditions

The Hajdúnánás-I hydrocarbon exploration well provides knowledge about the deep geological conditions of Hajdúság. The exploration well was drilled to 2,000 meters. Quaternary formations were found in the borehole to a depth of 128 m, forming clayey, sandy, loess formations belonging to the Lower Middle and Upper Pleistocenes. Below the Quaternary strata, Upper Pannonian sediments are deposited at a thickness of 967 m, with layers of clay, sand, sandstone, clay marl and woody lignite between them (Papp & Kertész, 1979).

The thickness of the Sarmatian layers is 164 m, which is characterized by the layers of lime marl and tuffite. It is followed by torton layers consisting of layers of clay marl, lime marl, 151 m thick. Below this, 455 m thick volcanics were crossed by the drilling, the volcanites are represented by rhyolite, rhyolite tuff, rhyolite agglomerate and hyperscenes. A part of Hajdúság was land for a long time from the end of the Pannonian, as evidenced by the settlement of red clay 2-3 meters thick in the Pannonian layer. These are Upper Pliocene Pannonian and Lower Pleistocene fossil soils (Mátyás, 2004).

On the highest rising Pannonian surface of Hajdúság, there were droughts and protrusions until the middle of the Pleistocene. In the meantime, the sediment cone of Nyírség rose higher and higher due to the filling activity of the rivers, and the Pleistocene strata reached the heights of the Pannonian surface of Hajdúság. The alluvium of the rivers first pushed into the deeper Pannonian strata and then reached the highlighted surfaces as well (Rónai, 1985).

At the beginning of the Neo-Pleistocene, the rivers were still able to fill up most of Hajdúhát. Later they were forced to leave the areas south of Hajdúböszörmény. After that, the rivers could only deposit their sediments in those parts of Hajdúság that have a surface height of less than 100-105 meters. Wind has been the most important factor on the surface of Hajdúhát without river water since the middle of the New Pleistocene. In the areas north of the latitude of Hajdúvid, strong north winds blew running sand out of the muddy river sand everywhere. To the south of that line, loess cover formation was under way.

Loess formation spread to the northern part of Hajdúhát towards the end of the Pleistocene and put an end to the sand movement. In the deeper parts of Hajdúság, mainly fine-grained sediments were deposited in the floodplains from the middle of the New Pleistocene. Sediments rich in sludge and clay assumed a loess structure in the periglacial climate of the Upper Pleistocene. Since the beginning of the Holocene, most of Hajdúság has not undergone a significant transformation. The biggest change in the Holocene process was the further deepening of the erosion valleys cut into the surface of Hajdúhát.

The lower, varied surface area to the north extends to the width of Hajdúvid. The height of the surface in this part varies between 100-110 meters, the height of 110 meters is reached or exceeded in only a few cases. In this part of Hajdúhát, a strong sand movement took place at the beginning of the new Pleistocene. As a result of the sand movement, different types of wind furrows, ridges, and residual ridges were formed. The area is characterized by deflationary flats. The diameter of the flats can reach up to 2 km in some cases. Those of deflationary origin are evidenced by the accumulation of quicksand south of them. Most mounds are higher than 5 meters. These types of quicksand are very fragile, so they moved little.

The settlement of completely clean running sand in Hajdúhát could not develop, because the loess and sandy loess at the end of the Pleistocene covered the running sand mounds. There was no sand movement anywhere in Hajdúhát during the Holocene. The mounds, well protected from the loess cover, could no longer be attacked by the wind during this period.

Towards Nyírség there is more and more sand fraction in the loess. In the deeper parts, a slightly muddy version of loess developed. The thickness of the loess varies, in some places only 3-4 meters, while in Hajdúböszörmény it reaches 10-15 meters.

In the second half of the Neo-Pleistocene, fine-grained silty, clayey sediments were deposited on the riverine layers in most of Hajdúság. The fine-grained sediments assumed a loess structure during the periglacial period of the Upper Pleistocene.

The deepest known reservoir formations in the area (800-1100 m) are the loose sandstones of the Upper Pannonian middle-sized, which have a high gas content and high salinity, usually sodium chloride-type thermal waters. Initially, they were characterized by a positive pressure state, which has now generally become negative (Erdélyi, 1960).

The Upper Pannonian Upper, as well as the Pliocene (formerly Levantine), contain only fine sand settlements with finer granular development that are barely suitable for filtration. The main drinking water formations in the area are the stratum waters stored in the Lower Pleistocene River sands (typically between 70 and 150 m), which are low-solids, calcium-magnesium bicarbonate waters with a negative pressure state. The Upper Pleistocene sand layers of less good water supply, typically located between 15 and 35 m, have a similar hydrochemical composition (Rónai, 1963).

The Pleistocene sedimentary assemblage is clayey, silty with a predominantly sandy development. It is located up to 130 m. This is followed by the Levante assemblage, which is more clayey for its development and thus unsuitable for water abstraction. From 550 m to 1100 m the Upper Pannonian ensemble begins. For the purpose of thermal water exploration, the uppermost resp. the sand layer group developed at the lowest level is the most suitable.

The depth of the groundwater is between 2-6 m in most of the landscape, but below 6 m south of Hajdúböszörmény. The amount is insignificant. Its chemical nature is mainly calcium-magnesium bicarbonate. Its hardness is between 15-25 nko, but it goes over 45 nko near the settlements. The amount of stratified water is not significant at the regional level, the number of artesian wells is large. Their depth is usually more than 100 m and their water flow is around 200 l/min (Rónai, 1975).

## 1.2. The wells of the Bath

The thermal water well of the Bath was drilled in 1976, with 1,084 m depth. The Pleistocene sedimentary assemblage, which has a clayey, silty, predominantly coarse sandy development of, is located up to approx. 130-140 m. This is followed by the Levante layer, which is more clayey in its development and thus unsuitable for water abstraction. From 550 m to 1100 m the upper Pannonian ensemble follows, and from 1100 m the lower Pannonian layer. For the purpose of thermal water exploration, the sandy stratum group developed in the upper and lowest level of the Upper Pannonian sedimentary series is the most suitable.

The wells geological layers are, the first 1 m is Holocene, from 1 to 135.6 m Pleistocene to 223 m Levante and the rest is upper-Pannonian. When it was constructed the static water level was at -24.0 m, with a discharge rate of 600l/min, and a temperature at 64.4 °C.

Geophysical measurements were delivered, and the calculated geothermal gradient is 57.8 °C/km. The pumping tests showed, that with 1000 l/min discharge, the operating water level is at 12.6 m, and with 1350 l/min, it is at 21.9 m. The outflow water temperature is 62 °C.

There is a cold water well, also drilled in 1976 operating at the Bath. It has a 140 m depth, with a static water level at -6.7 m. The maximum discharge level is 900 l/min, but it operates at a constant 500 l/min value.

The wells were tested in June 2021. In the 1084 m well, a fallen U-shaped piece was detected in 432.3 m, which was resting on a packed joint. The foreign object does not currently obstruct the flow of water, but its removal is definitely recommended. Depending on the nature of the obstacle, one of the procedures used in the well construction and repair practice shall be used. (cable cylinder rescue tool, pipe wrench, etc.) The well is currently suitable for water production.

The water temperature is 63.43 °C and the outflow water temperature is 61.6 °C. The specific water flow of the well is 98 l/min/m. Based on the water flow curve of the well, it can be stated that the combined resting pressure of the strata decreased by 0.13 m compared to the studies of previous years, but there is no change in the specific yield of the well.

Depth capacity testing and pressure rise measurements were also performed. The water flow from the well is 615 l / min at an operating water level of -26.33 m.

## 2. Sustainability testing and hydraulic calculations

In the case of the Hajdúdorog Bath, we had to take into account the current thermal water use of the spa, as well as the thermal water uses in the area that may interact with each other. The aim of the hydraulic model building is whether the increase of the thermal water use of the bath in Hajdúdorog can have an impact on the surrounding thermal water uses. Near Hajdúdorog, in Hajdúnánás, there is another spa that produces and uses thermal water from great depths to fill the bathing pools. The subject of our study was the effect of these two water abstractions on each other. Three thermal wells in Hajdúnánás and one in Hajdúdorog provide the thermal water supply to the spa, all screened to the same aquifer. The most important data of these wells are summarized in Table 1.

***Table 1.*** *The main parameters of the wells of Hajdúnánás and Hajdúdorog*

| | Hajdúnánás | | | Hajdúdorog |
|---|---|---|---|---|
| | Well No. 1 | Well No. 2 | Well No. 3 | K-73 |
| Cadaster No. | K-114 | K-180 | K-202 | K-73 |
| EOV X | 279121 | 278841 | 276187 | 278968 |
| EOV Y | 827461 | 827630 | 827126 | 833536 |
| Z (m above sea level) | 97 | 96 | | 107 |
| Depth (m) | 1019 | 1102 | 1029 | 1084 |
| Static water level (m) | -10.4 | -20.5 | -30.6 | -24 |
| Static water level (m above sea level) | 86.6 | 75.5 | | 83 |
| Volume of bounded water ($m^3$/yr) | **260709** | | | **13354** |

The data required for model building are obtained from the hydrological log of the wells as well as from the drilling logs. Version 10.6.1 of the Groundwater Modeling System was used for hydraulic modeling. Since the MODFLOW program can only map the real geological structure within certain limits, we need a simplified geological model, which can be obtained by "merging" the layers. The layers of the geological model were determined from the hydrogeological log of well K-73. After completing this task, the otherwise complex geology was replaced with 5 different layers. These layers, and their main properties are shown in table 2.

***Table 2.*** *The main parameters of the model*

| Layer number | Material | Layer top (m) | Layer bottom (m) | Layer thickness (m) | Horizontal hydraulic conductivity (m/d) |
|---|---|---|---|---|---|
| 1 | Sand, silty sand | 0 | 85.6 | 85.6 | $8.6x10^{-3}$ |
| 2 | Silty sand | 85.6 | 351.4 | 265.8 | $8.6x10^{-4}$ |
| 3 | Silty clay | 351.4 | 905 | 553.6 | $8.6x10^{-5}$ |
| **4** | **Sand** | **905** | **1037** | **132** | **$8.6x10^{-3}$** |
| 5 | Clay | 1037 | 1084 | 47 | $8.6x10^{-7}$ |

In the borehole datas we realized that several thin sand layer closed to each other is screened in the wells. We handled them as 1 sand layer. In Table 2, the sand layer represents the aquifer layer that the filters of the wells intersect at several levels. We had to determine the initial water levels based on the hydrogeological logs. The initial water level of the upper layers was determined based on the data of the shallow wells in the area. The uppermost layer is defined as an unconfined system, and the layers below it as a confined system. When determining the hydraulic head of the aquifer, the pressure level of the production wells was taken into account. Based on the initial pressure level of the wells, an east-west flow with a small hydraulic gradient could be determined. When determining the yield of the wells, we used the assumption that one well in Hajdúnánás and Hajdúdorog produces the annual volume of water in 365 days, so we divided the annual volume of water by the number of days in the year. Thus, the flowrate values was 36.59 $m^3$/day in the case of Hajdúdorog and 714.27 $m^3$/day in the case of Hajdúnánás II.

Below, we summarize the main simplifications we used during the modeling:

- simplification of the geological stratification based on drilling data,
- extracting the annual water volume with a constant yield,
- assumption of a permanent flow environment,
- neglecting cold water production,
- approximate determination of leakage hydraulic parameters.

## 2.1. Results

As a first step in the modeling, we tried to determine the current hydraulic situation. Our aim was to determine the depression field and the hydraulic effect of the wells on each other. For the current yield, the figure below shows the depressive space in the aquifer.

The depression generated in Hajdúnánás well extends roughly to the area of Hajdúnánás, where a decrease in pressure levels can be seen. In the course of the modeling, our aim was to determine the effect of the intensification of the production in the Hajdúdorog Bath and the influence of the Hajdúnánás water abstraction in the production of higher water yields. To do this, we calculated two scenarios for yields. In the first scenario, the yield of the K-73 well was doubled (73.18 $m^3$/day), and in the second scenario, the yield of the same well was tripled to the current yield (109.77 $m^3$/day) and examined the changes. Calculating the yield values of the first scenario, it can be seen that doubling the yield of well K-73 causes only a small change in depression, the greater effect of the change in pressure level is limited to the environment of well K-73. In the case of Hajdúnánás well no. II, a change between 0 and 0.5 m was calculated, which is negligible for such a system.

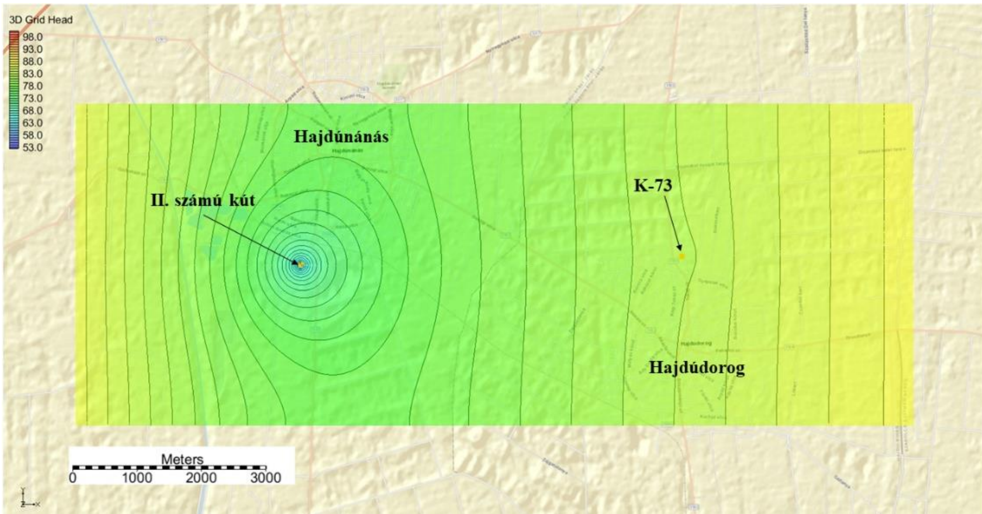


***Figure 1.*** *The current situation in the area of Hajdúdorog*

In the second scenario, we increased the yield of well K-73 to three times the current yield and examined its hydraulic effect. The pressure levels as well as the pressure level differences from the current situation were determined. Based on the modeling, it can be said that in this case there is no significant effect on the Hajdúnánás well II. The pressure level distribution formed by well K-73 with a yield of 109.77 $m^3$/day and well II with a yield of 714.27 $m^3$/day is shown in the figure below (Fig. 3.).

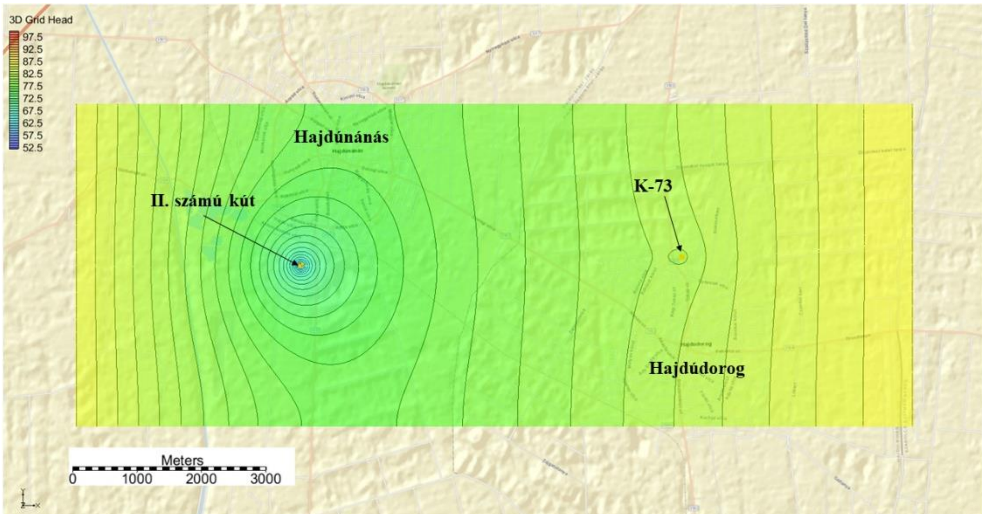


***Figure 2.*** *The first scenario in the area of Hajdúdorog*

It can be seen that although the resulting pressure level difference is wider in the case of triple yield, the Hajdúnánás II. It does not fundamentally affect the operation of wells, as the water level change is between 0 m and 0.5 m even in this case. Observing the yield values, it can be seen that even if the yield of the K-73 well is tripled, the water abstraction of Hajdúdorog is only a fraction of the water abstraction of Hajdúnánás.

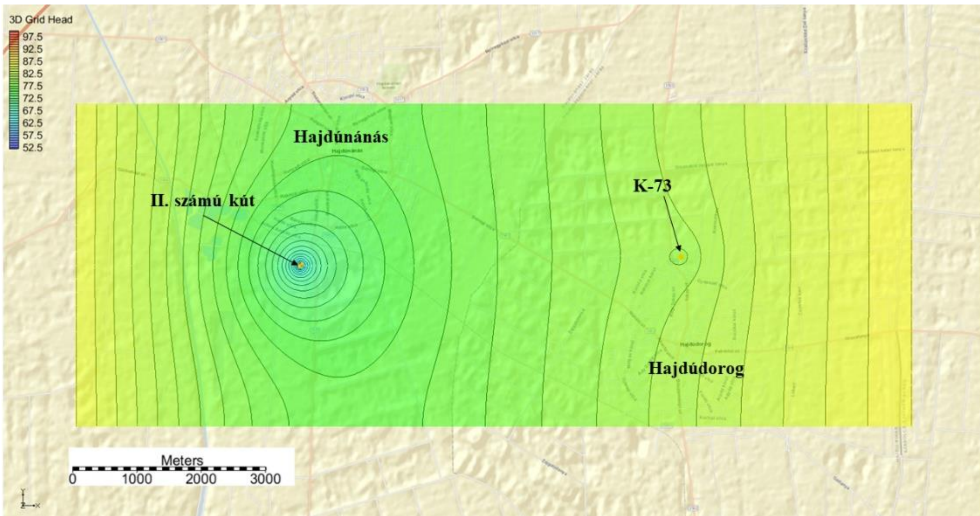


***Figure 3.*** *The second scenario in the area of Hajdúdorog*

## 3. Summary

Water supply opportunities are good for both thermal and cold water. The base of thermal water production in both Hajdúdorog and Hajdúnánás is provided by Upper Pannonian sand layers with good hydrogeological conditions. From the point of view of water management, it can be stated that the porous thermal water body on which the production is based is in good condition both in terms of quantity and chemistry. The supply of cold water can also be easily ensured in the area of Hajdúdorog Bath from Pleistocene sedimentary layers, as is currently the case with the operating cold water well.

Overall, it can be said that in the case of the K-73 thermal water well, the instrumental tests detected a fallen U-shaped piece in the 1084 m well and 432.3 m in the gland. The foreign object does not currently obstruct the flow of water, but its removal is definitely recommended with the help of a company specializing in well repair. In addition, it is recommended that a reserve thermal water well be installed at a similar depth in the future, especially regarding future expansion plans that would result in increased thermal water production.

With the help of a preliminary simplified hydrodynamic model, we proved that the 13354 $m^3$ / year thermal water production capacity included in the current water rights permit can be doubled or tripled in a sustainable way. The increasing thermal water production in this range does not have any negative impact on the operation of the relatively close thermal water wells in Hajdúnánás. The results obtained clearly show that there is a very good chance that the water rights permit could be amended in the future in connection with a spa development.

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