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THE HYDROGEOLOGICAL ASPECTS OF LAKE FEHÉR, KARDOSKÚT, SOUTHERN HUNGARY

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ABSTRACT

The Lake Fehér near Kardoskút village (Békés County, S Hungary) is a highly protected area of the Körös-Maros National Park (Fig. 1). The regular desiccation of the lake violates the habitat of the migrating birds. In order to understand the mechanisms of the water supply of the lake, six groundwater-monitoring wells and two water gauges were made in the area. Data were evaluated by geostatistical methods. Water levels in the two automatically measured monitoring wells changed differently with precipitation. One, which was located in the southern margin of the lake, responded to precipitation immediately and also with a twelve-day delay. While the other one, situated between the lake and the canal, had not any significant reactions. Groundwater flow direction is towards the canal (Fig. 3) every time, independently of the season. The canal, depending on water level in it, disturbs groundwater flow. Based on pressure-elevation profiles [p(z)], upward flow from deeper layers was established. Chemical data supported upward flow too.

Key words: groundwater flow, discharge area, water chemistry, pressure-elevation profile [p(z)]

INTRODUCTION

The Lake Fehér near the village of Kardoskút, is the largest lake in the Körös-Maros Interfluves, located about 12 km southwestward from the town of Orosháza (Fig. 1). The East-West extension of its basin is 3,6 km, divided by an artificial dam. The widest north-south extension of its western part is 500 m, however, that of its eastern part is less than 100 m in many places. The area belongs to the small landscape called the Csongrád Plain. There are no significant differences in the relief. Its value is ranging between 85 to 88 m a.s.l.. The lake is the largest highly protected area of the Körös-Maros National Park. Year by year, it serves as a resting place for some hundred thousands of birds of passage, therefore, it is protected by the Ramsari Convention. The lake, as it is common for salt lakes, dries out in every summer. Arid climatic conditions, characteristic for the last one and a half decade have caused serious problems in the water balance of the lake. Therefore, understanding the mechanisms of water recharge is of crucial importance.

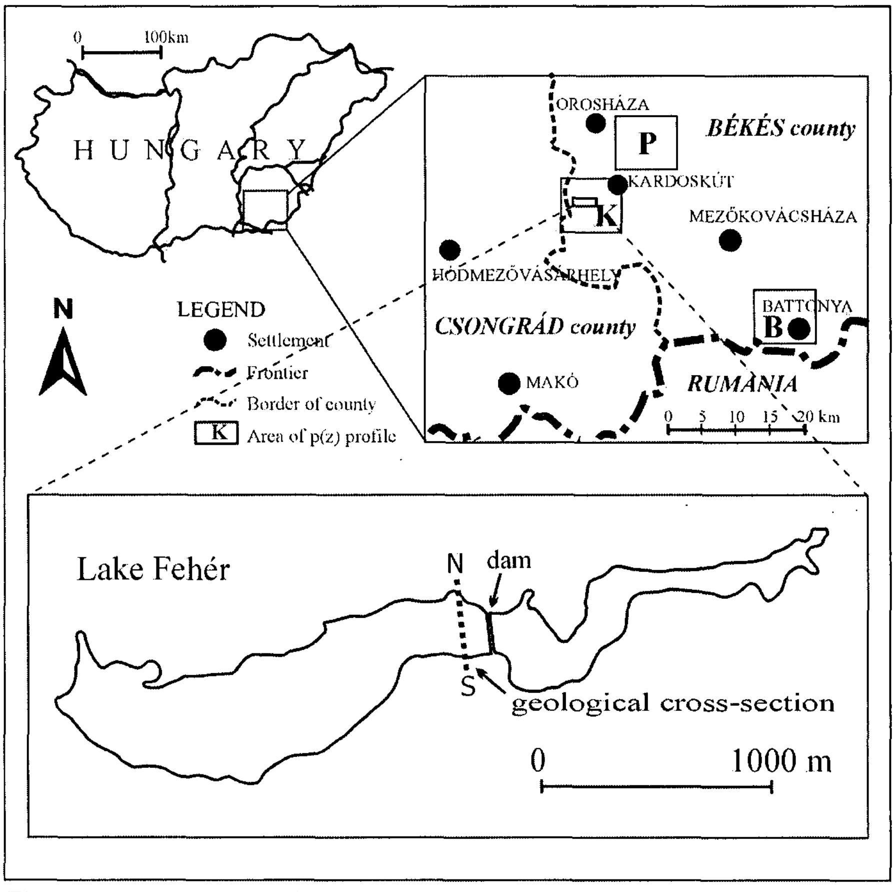

Fig. 1. Location of the Study area.

This study intends to justify the significant role of groundwater in the water recharge of the lake. The major aim of this study is to establish the character of the hydrogeological regime in the environment of the lake.

GEOLOGICAL AND ENVIRONMENTAL SETTINGS

There are several theories about the origin of the lake. The lake basin is regarded as a cut-off channel of the ancient River Maros. The basin was developed in a Pleistocene depression during the beginning of the Upper Würmian (Molnár and Mucsi, 1966; Sümegi, 1999). The region is located between two sub-basins – the area of the Rivers Körös and the mouth of the River Maros. The environment is built up from alluvial sediments and loess, which were deposited at the end of the Pleistocene on sandy layers of some meters thick.

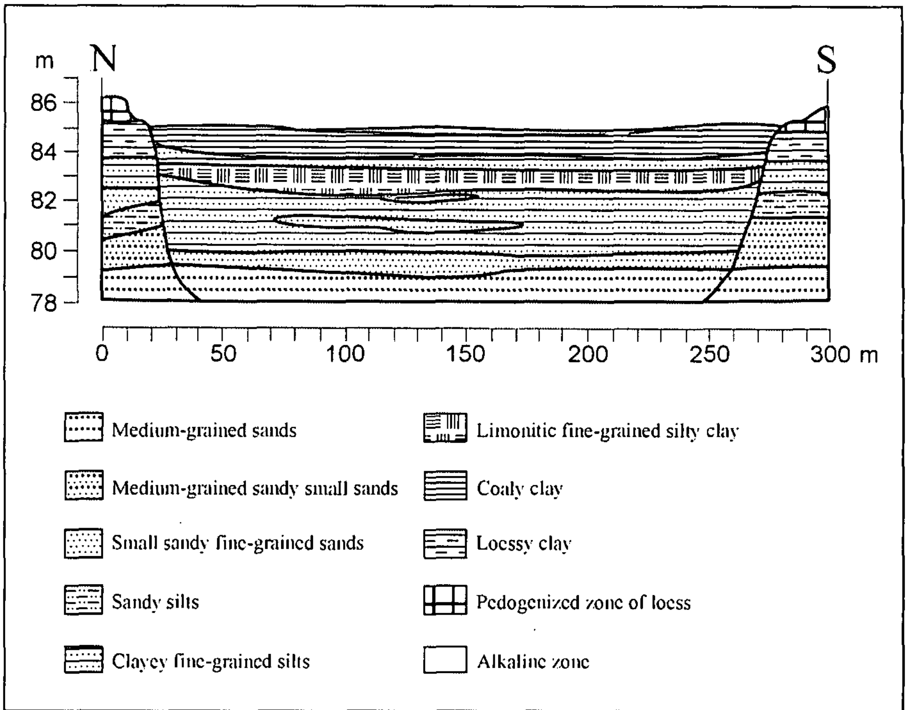

Fig. 2. N-S Geological cross-section of Lake Fehér (after Sümegi et al. 1999).

On the basis of litho- and biofacies analyses, these sediments must have been deposited in a slowly moving or stagnant aquatic environment characterized by rich palustrine vegetation (Sümegi et al., 1999). Due to groundwater fluctuations, salty layers could have formed in the near-surface layers of the loess-like sediments of high clay and carbonate content within a relatively short time. The Quaternary history of the area was basically determined by the formation and transformation of a river system in the southern part of the Great Hungarian Plain. Alluvial fan was dominantly influenced by small local subsidence and uplift (Sümegi et al., 1999). The Orosháza Plain extending as far as the Apuseni Mountains is situated between depressions. The area of this alluvial fan was formed by the River Maros. The lake can be found at the margin of this alluvial plain (Molnár and Mucsi, 1966).

According to Sümegi et al. (1999) the overburden is made up of medium-grained sands indicating fluvial environment. Going upwards silt becomes dominant with sporadic appearance of fine-grained sand lenses and bands within the layers. These lenses denote a progressive formation of an abandoned meander, where connections to the river may have been restored from time to time. Clayey sediments representing lacustrine conditions follow these layers. The coarse-grained silts appearing in the beds must have come from the loess on the banks. Finally, a salty layer of several cm precipitated on the top of the lacustrine sediments (Fig. 2).

The presences of water upwelling in the area of the Lake Fehér are well known. Changes in the vegetation clearly mark these sites (Kiss, 1962). On the basis of his observations, Kiss (1962) concluded that high groundwater levels and inland waters are not always connected to precipitation. When the soaked surficial loessy sediments subside, the salty surface becomes impermeable because of the salt remaining on the surface, which also inhibits water infiltration. During the past decades inland waters (every 14-16th year) caused serious problems on the plain, however, in the deeper flood plain of the River Maros inland waters do not even appear, in general.

The first botanical study of the area was making by Kiss (1963). Molnár and Bíró (1997) performed ecological investigations in 1995 and 1997. The long period of arid climate significantly modified the vegetation: xerophilous weeds appeared to the detriment of the palustrine plants. The humid interval from 1995 to 1997 temporarily reversed this process (Molnár and Bíró, 1997).

CLIMATIC CONDITIONS

The climate of the area is continental and the aridity index is lower than one. Regarding the annual pattern of precipitation, climatic influences characteristic for the Carpathian Basin are effective. In May and June the maximum of precipitation is the result of a superposition of the dominant arid continental climate and an oceanic influence. Because of a mediterranean effect, a secondary maximum of precipitation occurs in October and November, too. The least humid months are February and September. Precipitation of high intensity is frequent in the summer. The duration of snow-cover is 30 days. Long dry periods, mainly in summer, may last as long as 45-50 days. The lowest and highest rates of the annual amount of precipitation are 300 and 900 mm, respectively. On the basis of the 100 years data series of the precipitation monitoring station in Orosháza, the average annual precipitation is 550 mm. Using temperature, precipitation and evaporation data, the calculated average potential evaporation of several years is 882 mm per annum in the area. The value of the estimated water deficit is 140 mm per annum.

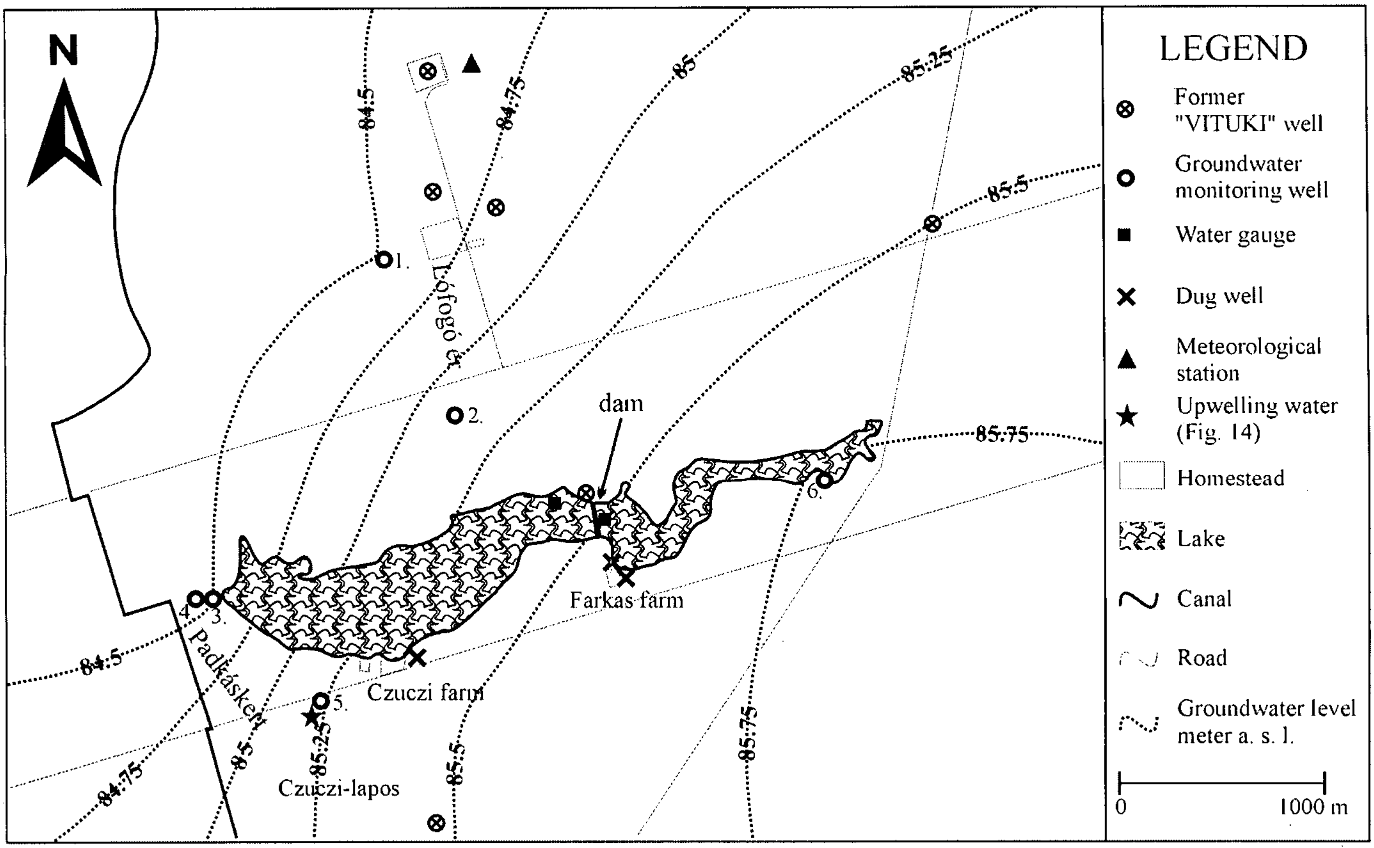

Fig. 3. Groundwater level of the study area (07.09.2001.) with the location of wells and water gauge.

METHODS

Data

No systematically collected hydrogeological data were available from the area of the Lake Fehér until 1998. Systematic observations of the lake and its environment have been carried out since 1999. In the summer of 2001 five 10 m and one 5 m deep groundwater monitoring wells were deepened, and two water gauges were placed in the wells located at the eastern and western basin of the lake (Fig. 3). Ott Thalimedes type automatic water level registration equipments have been working in two wells (No. 4 called as "western" and No. 5 called as "Czuczi") since March 2001, taking measurements every 12 hours. Data from these wells could have been downloaded and processed with the help of a computer. In December 2002 an automatic meteorological station (Fig. 3) was put into operation in the area under investigation. Besides the water level and precipitation data coming from these equipments, former precipitation and well data were also utilized in our work.

On the basis of the well data from Hungarian Inventory of Wells, pressure-elevation [p(z)] profiles of the Kardoskút, Pusztaföldvár and Battonya area were constructed, and fluid potential was given in graphical way (Tóth and Almási, 2001).

Theory

Driving forces of flows in sedimentary basins can be derived from gravitation, sediment compaction, osmosis, tectonic compression, and thermal convection (Tóth, 1995). From a hydrogeological point of view groundwater flows driven by gravitation are the most important. Their geometry can be described by mathematical and physical equations in an exact way. A uniformly sloping groundwater table results one flow system in a homogeneous basin. In fact, the different topographic conditions modify the groundwater relief, thus flow systems of different order (local, intermediate, regional) are formed (Tóth, 1963) (Fig. 4).

Hydraulic head (h) is the elevation of the standing level measured in a well from the datum level (z=0) in meters. Its value can be expressed as the sum of the pressure head (φ) and the height of the measuring point above the datum level (z) [m]:

$$h = \varphi + z.$$

The regional system revealed by this method serves as a basis for the evaluation of the distribution of the fluid potential and its gradient, the driving force of the water.

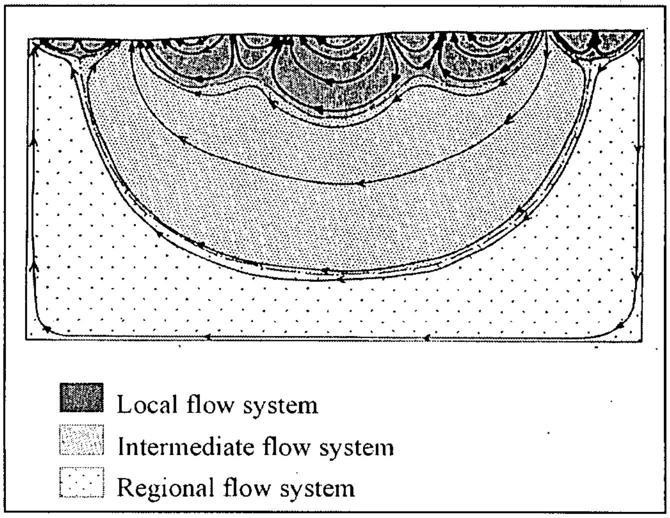

Fig. 4. Composite basin with homogeneous rock framework, showing flow-system types (Tóth, 1963).

Flow direction corresponds to the direction of the decreasing hydraulic head because it is directly proportional to the fluid's potential energy (Φ) [m^2/s^2]:

$$h = \Phi / g$$

where g is the gravitational acceleration [m/s^2]. Then the energy content per unit mass (Hubbert's energy equation) can be calculated with the following equation:

$$\Phi = gz + \frac{p}{\rho}$$

and

$$h = z + \frac{p}{\rho g} = z + \frac{\rho}{\gamma}$$

where z is the elevation of the measuring point above the datum level (sea level, in general), p is pore pressure [Mpa], ρ is water density [kg/m^3]; thus, every component of h is measurable. If the estimated dynamic pressure gradient is larger than the static gradient (9,8067 MPa), then the vertical component of the groundwater flow points upwards. Conversely, this component points downwards.

In order to reveal the effects of precipitation on the groundwater, geostatistical analyses were performed. The software Stratigraphics was used for cross-correlation analysis of daily precipitation and groundwater level data.

To perform hydrochemical analyses two series of samples were collected from both the newly deepened groundwater monitoring wells and the former "VITUKI" wells (Fig. 3). Hydrochemical analyses of the samples have been carried out in the laboratory of the Natural Protection Survey of the Lower Tisza Region. The analyses of stable isotopes have been made at the Department of Earth and Atmospheric Sciences of the University of Alberta, Edmonton Canada.

RESULTS AND DISCUSSION

Field observations

One of the most interesting phenomena is the overflowing water in the dug wells in springtime, despite the fact that the level of groundwater did not reach the surface in the surroundings of the well (Fig. 14). Most of these wells can be found in the farms situated on the southern banks of the lake.

1. Dug well in the Farkas farm. There were two wells on the yard of the farm, and the overflowing one was closer to the lake. Now, only the latter one is available next to the ruins of the farmhouse. Its depth is 2.8 m, the upper part is bricked, and the lower is boarded. Boarding was mainly used at wells abounding in water. This bed is penetrated by an iron tube of 2 inches in diameter (its length is unknown), probably for eliminating the aquitard (clayey layers). This well was dug around 1910, providing artificial water inflow to the lake every spring since then. On the 7th of July 2001 the well was dewatered in order to measure its re-fill: it proved to be 450 l/hour.

2. Dug well in the Czuczi farm. The well was dug in 1904. Later it was partially infilled with debris as it flooded the yard. Its recent depth is 2.8 m the original value is unknown. The upper part is bricked, and the lower is boarded.

The appearance of wet areas in the basin after desiccation is quite a fascinating phenomenon. Remnant waters could not have played a role here as wet areas generally develop only after the basin is fully dried out. According to our findings, the upper 15 cm zones of these areas are totally saturated. However, profiles are dry under this zone down to the groundwater table (it may exceed a depth of 120 cm). The wet areas are circular with about 1,5 meter diameter having green vegetation cover even in the arid periods. Most of them are on the southern bank of the lake. They are in sharp contrast with the background. Piercing the "flexible layers" found in the areas covered by inner waters behind the Czuczi farm, we managed to observe intensive upwelling in three sites. The versatility of the vegetation also indicates a possible subsurface water source, as the vegetation receiving moisture only from the precipitation is quite uniform (Zsemle, 2000).

The horizontal direction of shallow groundwater flow has been defined by the water level data (Fig. 3). Defined flow direction occurred towards the canal every time, independently of the season (apprehensive time: September 2001, March 2002, August 2002). In our assumption, the canal disturbed the motion of the shallow groundwater flow, because of its bed was situated deeper than the lake bottom.

Hydrogeological conditions

Flow systems of the Great Hungarian Plains were hydraulically studying by many hydrogeologists (Erdélyi, 1975; Halász, 1975; Marton, 1982; Tóth and Almási, 2001). Tóth and Almási (2001) concluded that there are two principal driving forces in the basin: gravitation and compression. The two flow regimes are vertically separated from each other, the lower compression province influences the geometry of the upper gravitational system as it were perched by the lower one. Gravitational flow systems are divided into regimes (recharge area, flow area, discharge area) on the basis of their place in the flow system and other diagnostical hydraulic parameters as the vertical component of the flow direction.

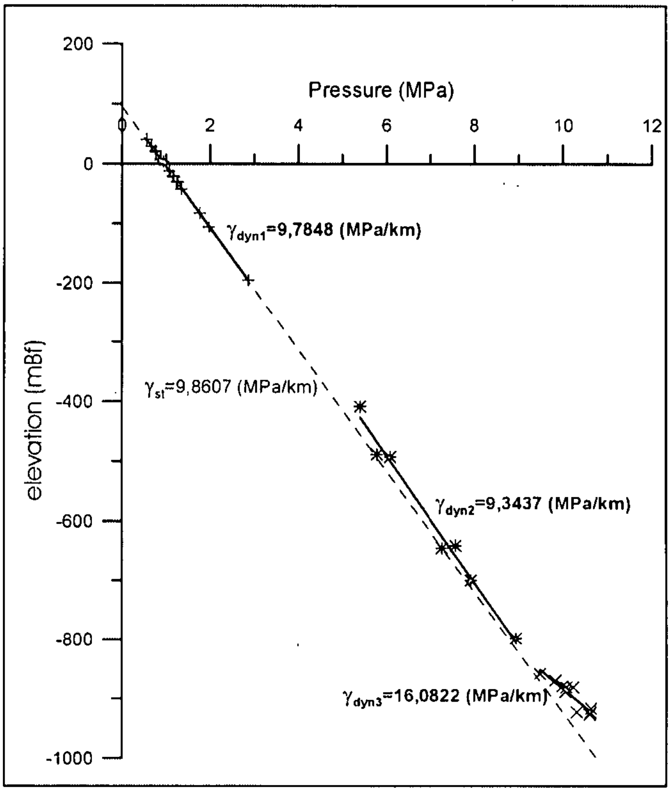

Fig. 5. Pressure-elevation profile [p(z)] Battonya region (for location, see Fig. 1).

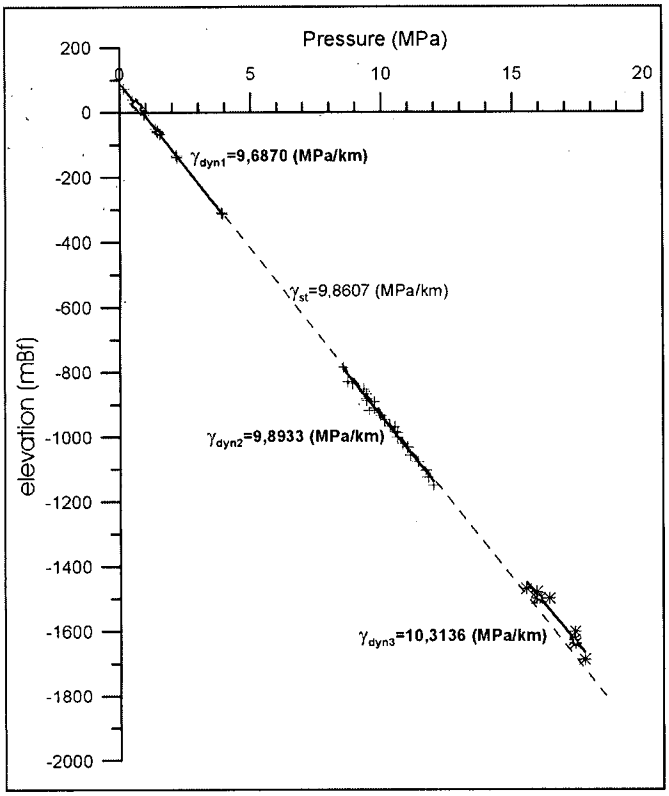

Fig. 6. Pressure-elevation profile [p(z)] Pusztaföldvár region (for location, see Fig. 1).

Since in the case of the Lake Fehér the gravitational system could be supplied from NNE or SE, around Kardoskút because of relief, so [p(z)] profiles have been constructed for Battonya and the Pusztaföldvár-Orosháza regions beside Kardoskút as well. (Elevation is 110 and 95 m over the Baltic Sea level, respectively.)

The most time-consuming part of the building-up of a pressure-elevation profile is data collection. Data from more than one thousand wells are available, but they are incomplete, so 28 wells near Kardoskút, 40 wells near Battonya, 63 wells near Pusztaföldvár were used for further implementation. (Wells having incomplete data or filtered at two or more places were ignored in our analysis.) The most significant parameters determining the usability of the data were the initial piezometric levels, the depths of the wells, and the elevations of the area above sea level.

According to the pressure-elevation profile of the Battonya region (Fig. 5) the gradient was lower than the hydrostatic gradient from the surface to a depth of 850 m. Therefore, this can be regarded as a recharge area down to this depth. Below 850 m the gradient is much higher than the hydrostatic one, thus the vertical movement of the water is upward in the low zone.

The pressure-elevation profile of Pusztaföldvár-Orosháza (Fig. 6) indicates a recharge for the upper 300 m, intermediate (only horizontal flow component) from the depth of 800-1200 m and a discharge from the next measured depth (1500 m), however, the gradient is much lower than in the case of the previous figure.

In the case of Kardoskút, data were available for the upper 300 m (Fig. 7). The curve is over the hydrostatic pressure-line with a gradient higher than the hydrostatic gradient, i.e., the deeper wells have higher initial hydraulic heads. This fact obviously refers to a discharge area.

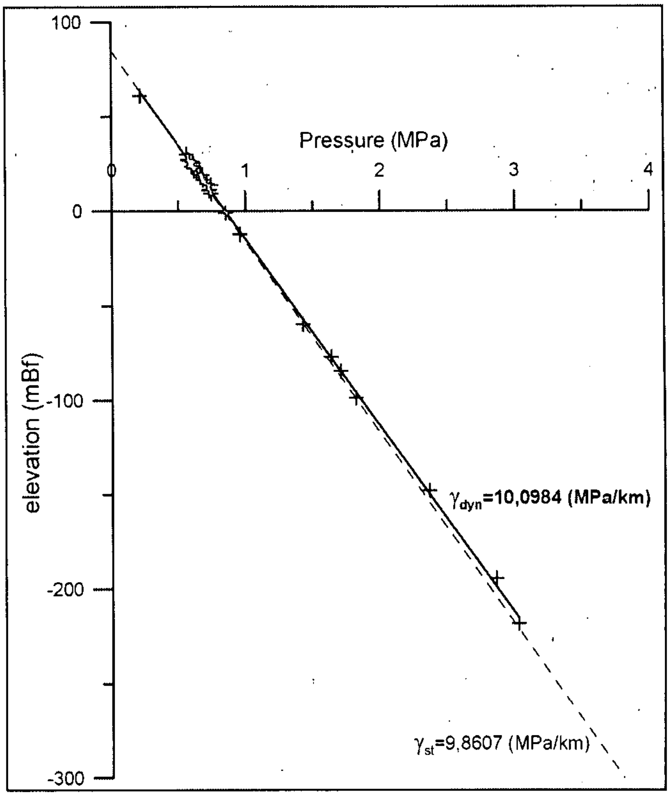

Fig. 7. Pressure-elevation profile [p(z)] Kardoskút region (for location, see Fig. 1).

Almási (2001) divided the Great Hungarian Plain into recharge, discharge, and intermediate areas according to the character of the regime of the upper 400 m. (This analogize with other authors classification, for example Erdélyi, 1975.) He classified the Kardoskút area as a discharge province adjacent to the intermediate flow zone situated in the western margin of the Battonya-Pusztaföldvár plain (Fig. 8).

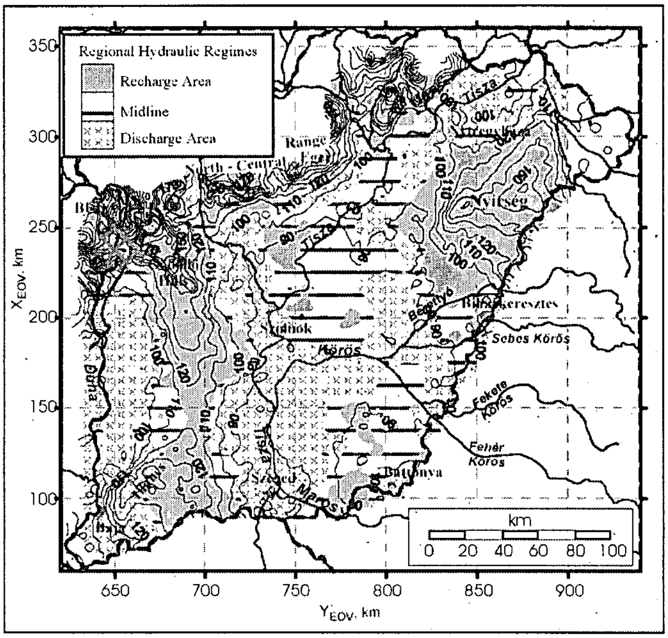

Fig. 8. Calculated distribution of regional groundwater regimes in eastern Hungary inferred from fluid-potential maps between the land surface (z_o) and z=-300m elevation, and from p(z) profiles. Topographic elevation contours are in meters (Almási, 2001).

Statistical analysis

Comparing the daily data series of groundwater level in the well No. 4 (western) and No. 5 (Czuczi), which are located at a distance of 800 m apart, surprising conclusions can be drawn (Fig. 9). Although the elevation of the wells is almost absolutely the same, the ground water level in the well next to the upwelling (Czuczi) is more than 1 m higher than that of the other. Variation of the levels in the two wells is totally opposite in the first 50 days.

Reactions of the two wells to the precipitation were analyzed by cross-correlation (Fig. 10 and Fig. 11). Daily measurement data from the precipitation monitoring station in Orosháza were used. The essence of this method is that aquitard delayed effects, or even the degree of retardation can be numerically expressed.

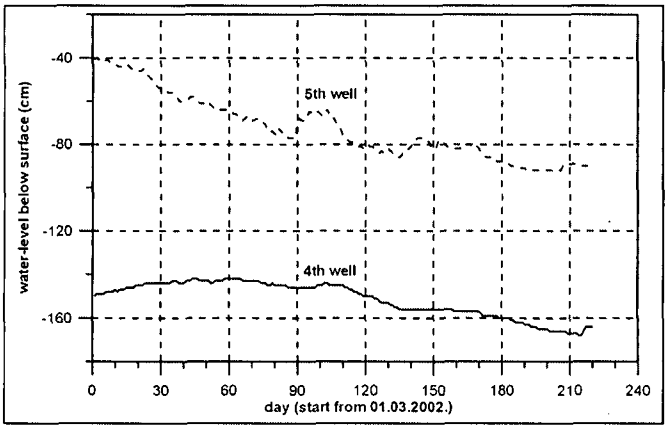

Fig. 9. Water level in two monitoring wells versus elapsed time.

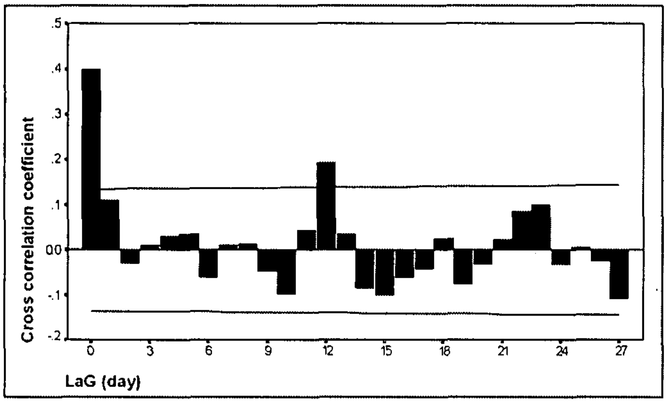

Fig. 10. Cross-correlation coefficient between water level and precipitation, well N° 5.

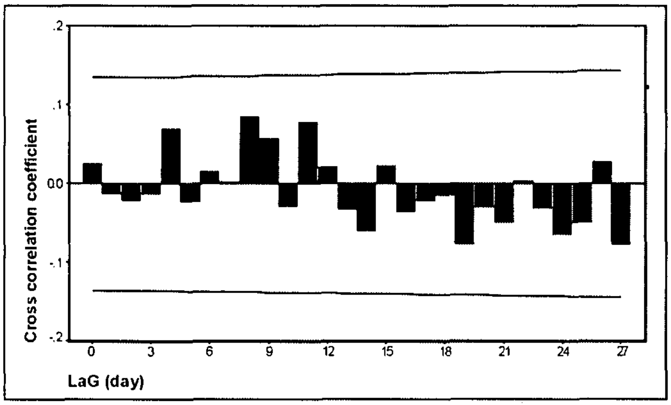

Fig. 11. Cross-correlation coefficient between water level and precipitation, well N° 4.

As Fig. 10. shows, well No. 5 situated in the southern margin of the lake responded to changes in precipitation immediately and with a 12-day delay, i.e. precipitation raises the water level in this well immediately and with a 12-day delay. It is supposed that the beds near the well allow for the quick infiltration of precipitation into the soil, and the pressure front of the upstream water increases the piezometric level 12 days afterwards. In case of the well No. 4 there is no significant connection between the precipitation and the daily regime of the groundwater (Fig. 11). The upper 8 m is built up by clayey beds in the environment of the well (the western end of the lake), therefore, immediate infiltration of the precipitation is not possible. No groundwater pressure wave can be observed which suggests that the water supply of this well is totally different from that of the well No. 5. Moreover, well No. 4 has a special chemical character.

Hydrochemistry

Twelve samples were collected from the Kardoskút area from 9 m up to 150 m below surface. The chemical composition of groundwater is quite uniform to a depth of about 15 m. Concentrations and spatial distributions of the chemical components suggest the presence of upstream in the area. According to the uniform water quality the rate of local chemical reactions is lower than the speed of the water movement. Waters coming from a depth of less than 15 m are not uniform chemically. There are local differences, which are increasing towards the surface. The largest differences in the chemical compositions of the water samples can be found in the shallowest zone (9 m depth). The lack of homogeneity indicates that local factors control the chemical composition of water in the near surface layers (Fig. 12 and Fig. 13).

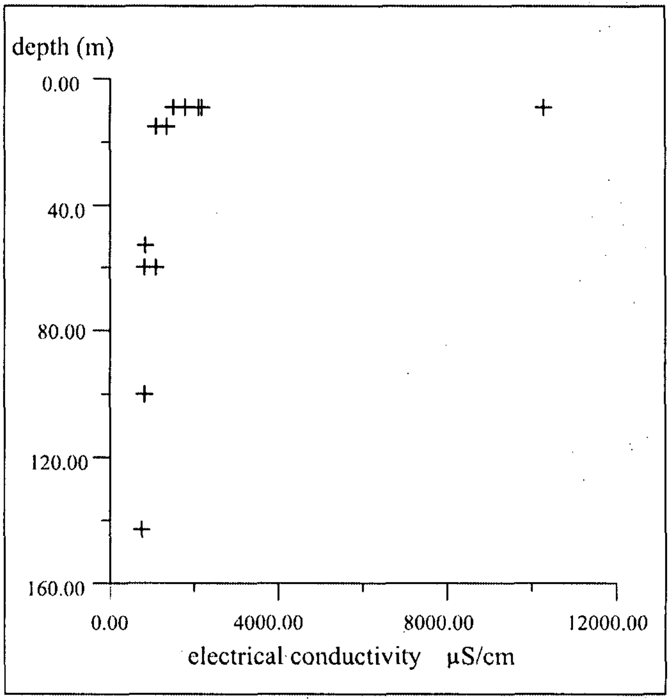

Fig. 12. Electrical conductivity versus depth in monitoring wells.

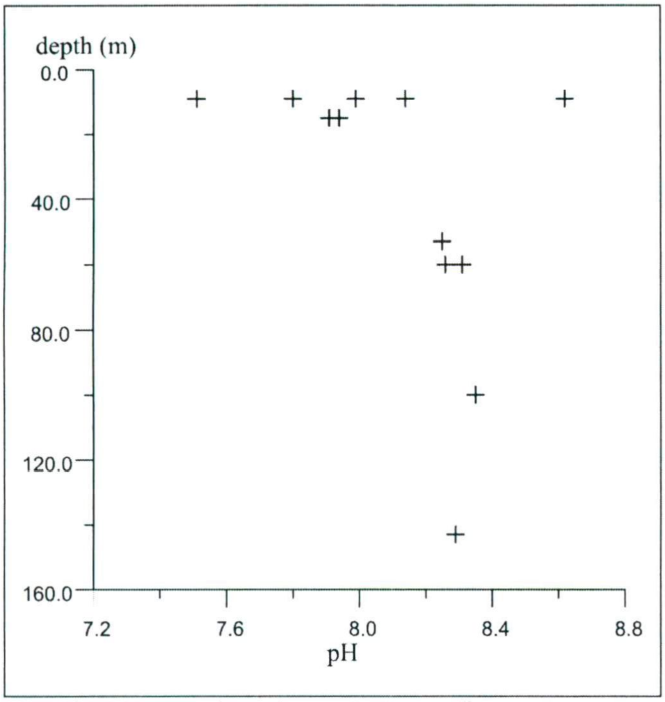

Fig. 13. pH versus depth in monitoring wells.

CONCLUSIONS

The environment of the Lake Fehér near Kardoskút village is hydrogeologically a unique area. According to the former observations and our studies it can be regarded as a discharge area of a regional flow system (Fig. 14). Special variations of the automatically registered piezometric level of two wells as well as upwelling also seem to justify this hypothesis. Upwelling is also underlined by the results of the chemical analysis of the ground water.

In our opinion the canal must have an effect on the water balance of the lake as well. The measured groundwater levels indicate a water-flow to the direction of the canal (Fig. 3), so the lake is depleted by the canal. Furthermore, the water level in the well near the canal does not show any dependence on the precipitation.

Fig. 14. Upwelling water near bank of Lake Fehér (10. 03. 1999.).

The best alternative to enhance the water balance would be to store the spring precipitation in the area so it can infiltrate into the soil, and reflow it a few months later to the surface.

A detailed study and a small-scale description of the stream require further registration data series of 3-4 years. With data series and the results of the stable isotope analyses, presently in progress, at hand, we will be able to calculate and plan the recharge mechanisms.

ACKNOWLEDGEMENTS

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