CHARACTERIZATION OF GROUNDWATER AND LAKE INTERACTION IN SALINE ENVIRONMENT, AT KELEMENSZÉK LAKE, DANUBE-TISZA INTERFLUVE, HUNGARY

Szilvia Simon

Summary of the thesis

Supervisor: Judit Mádl-Szőnyi Ph.D. associate professor
Department of Physical and Applied Geology, Eötvös Loránd University

Ph.D. program for Geology and Geophysics at the Ph.D. school of Earth Sciences
Chair of the Ph.D. school: Prof. Gyula Gábris
Chair of the Ph.D. program: Prof. Miklós Monostori

Eötvös Loránd University

Budapest, 2010

Introduction

Wetland areas and the understanding of their functioning in connection with groundwater are of special importance all over the world. They have an important role in maintaining the biodiversity of the Earth, hereby require protection. Their wise management needs to be based on the knowledge of their relationship to groundwater. The understanding of their groundwater dependence constitutes the basis of the implementation of the EU Framework Directive, too. Therefore investigation of groundwater and surface water interaction is in the focus of present day research activities (Winter et al., 1998; Klijn and Witte, 1999; Swancar et al., 2000; Winter et al., 2003; Schneider et al., 2004; van der Kampf and Hayashi, 2008 etc). In Hungary, Kelemenszék Lake and the N-S oriented saline wetland zone of the Danube Valley represents a good example and a pilot area where the connection among the different groundwater flow systems and discharge type surface phenomena, i.e. the wetland area and the coupled salinization can be evaluated and understood. The experiences may be projected onto similar areas of the Great Hungarian Plain and other sedimentary basins of the world. The regional scale study of Mádl-Szőnyi and Tóth (2009) showed that Kelemenszék Lake and its surroundings are situated in a hydraulic window where two main flow regimes: an overpressured saline water originating in the Pre-Neogene basement, and to the east a gravity-driven fresh water flow system originating in the Ridge Region of the Danube-Tisza Interfluve reaches the surface. This hydraulic pattern correlates well with the surface saline phenomena (saline wetlands, sodic soils, halophyte vegetation). The present comprehensive study is aimed at understanding the effect of groundwater flow systems on the wetland area and the surface and groundwater salinization, focusing on Kelemenszék Lake.

The research proceeded on two basic lines. The first was the understanding of the interaction between groundwater and lake and the examination of its spatial and temporal variation. This point means a new scientific approach in the area. The second was allocating the source of salt responsible for the salinization in the N–S elongated saline tract in the Danube Valley. In order to answer this question, intensive research activity has been going on since the 19thcentury (Kovács, 1960; Várallyay, 1967; Tóth, 1999; Tóth and Szendrei, 2006). Three basically different concepts have been developed for the explanation of the origin of salts: (1) in situ source in the near surface sediments ('Sigmond, 1923; Tóth, 1999); (2) leaching of salts from the more distant surface sediments and transported by shallow groundwater (Scherf, 1935; Molnár and Murvai 1976; Kuti, 1977); (3) basement source, upward transportation of salts by groundwater and mixing with shallower groundwater (Mádlné et al., 2005; Mádl-Szőnyi and Tóth, 2009). According to the third hypothesis the source of the salt content of the lakes and soils is considered to derive from the ascending, NaCl type (TDS: 2-40000 mg/l), overpressured groundwater. This study intended to find the appropriate solution to settle this debate as well. Considering the two main research lines and the former results the main objectives of the present work are as follows:

1. Fitting the Danube Valley and Kelemenszék wetland area into the complex groundwater flow pattern of the Danube-Tisza Interfluve, Great Hungarian Plain.

2. Evaluating the quantitative and qualitative influence of groundwater flow systems on Kelemenszék Lake.

3. Understanding the spatial and temporal changes in the groundwater and lake interaction in the near surface.

4. Allocating the origin of salt in the saline tract assigned by the saline wetland area in the Danube Valley.

5. Determining the hydrogeological circumstances which are responsible for the extensive salinization in the Danube Valley, compared to the other parts of the whole Study Area and the Danube-Tisza Interfluve.

Methods

The above delineated objectives could be achieved applying an integrated approach, using a wide range of methods. The study is predominantly based on in situ measured data. The detailed investigation of the groundwater-lake interaction required the built up of an observation system around Kelemenszék Lake. Continuous observation lasted from 2005 – 2008, involving water level measurements, measurements of meteorological parameters in the locally established meteorological station, and water and sediment sample collection. Based on the measured water levels detailed hydraulic investigations were carried out in the uppermost ~20 m for understanding the interaction between the lake and the different flow systems in the near surface. The amount of groundwater contributing to the lake, and evaporation influencing the water coverage of the lake and the salinization were quantified by evaporation- and water budget calculations.

The origin of salinization and the chemical features of the close surroundings of Kelemenszék Lake were examined applying different methods from the basement up to the surface. First, the possible pathways of the saline water were attempted to be allocated from the Pre-Neogene aquifer up to the Neogene layers. Afterwards, the chemical composition of the groundwater was followed from the Pre-Neogene aquifer up to the surface by multivariate data analysis on archive chemical data. Following this, the spatial extent of shallow groundwater salinization was allocated by surface geophysical methods in the upper ~100 m depth. In the second phase of the study the shallow groundwater and surface salinization were investigated focusing on the close vicinity of the lake, based on near surface water-chemical, isotopic, sediment and mineralogical data.

Theses

1. Local scale hydraulic investigations around Kelemenszék Lake detected a NW-SE oriented flow-through in the uppermost 20 m, perching on the ubiquitous, ascending groundwater from greater depths. Hereby the regional discharge in the Study Area is superimposed by these local flow conditions. Based on hydraulic data, in this upper ~20 m sublocal (down to ~1-2 m depth) and local (down to ~20 m depth) flow systems were delineated. The recharge area of the flow-through below the lake is the higher elevated part of the Danube Valley towards the NW out of the Study Area. This statement is supported by the water table map of Kuti and Kőrössy (1989). The Kiskunság Canal at the western side of the lake can also raise the level of the water table in its close surroundings, generating sublocal flows toward the lake.
2. Detailed hydraulic investigation showed that Dunavölgy Canal and its western foreground have a significant role, representing the discharge point of the local flow-through below the lake. In addition, considering the former hydraulic results of Mádl-Szőnyi and Tóth (2009), the canal and its foreground is the surface segment of the boundary between the ascending deep saline flow system below the lake, and the fresh, gravity-driven flow systems flowing from the Ridge Region towards the Danube Valley. Because the topographic depression of the Study Area is located in the N-S directed zone of the lake, a discharge point was expected to be situated there. The present situation reveals that the artificial effect of canal construction disturbed the original natural conditions and shifted the base level to the Dunavölgy Canal.
3. Based on water table maps and hydraulic cross sections, the NW-SE directed slope of the water table resulted in a general flow-through condition about Kelemenszék Lake. The lake receives water permanently from NW-W and loses water to SE-E. In the NW-W side of the lake a constant inflow exists from the level of the water table and the canals as sublocal flow system, and a transient inflow from greater depths (5-10 m), from the local

flow system. In addition, seasonally formed water table mounds all around the lake can provide groundwater discharge to the lake during wet seasons. On the downgradient (Eastern) side of the lake constant outflow exits to the local flow system. Below 10-15 m depth a quasi horizontal flow passes through below the lake. This hydraulic pattern shows that the ascending overpressured flow and the gravity-driven flow originating in the Ridge Region do not discharge directly in the lake and in its close surroundings. Their water did not influence the lake quantitatively. The lake is located in its own closed flow system which is hydraulically perched on the ascending saline water and is bordered by the regional gravity-driven flow from the east.

4. It could be established that the lake and the groundwater are in a dynamic interaction. The flow directions between the lake and the groundwater down to 10 m depth show seasonal changes, driven by the local water table fluctuation under the control of meteorological conditions. In springtime, at high water table levels inflow is dominant, almost on every side of the lake. The lake loses water only on its downgradient (Eastern) side into greater depths (< 5 m). Mainly in the downgradient side of the lake seasonal water table mounds generate local recharge to it, resulting in reverse flow conditions compared to greater depths. In early summer (May and June) the same situation is preserved, but the outflow component increases. The inflow from the local flow system diminishes. Dunavölgy Canal represents the main discharge point. In late-summer, autumn and winter, because of continuous decrease of the water table the lake gains water just from northwest, from sublocal flow, and loses water on its total lakebed surface. Simultaneously with the decline of the water table, the connection between the lake and the local flow system ceases and the main discharge point of all flow systems moves to the local water table depression westward of Dunavölgy Canal. In extremely dry seasons simultaneously with the decreasing water table, the lake dries up. By these investigations it was established that the lake is a water table type lake, which can fill up with water when the water table rises above the surface.

5. The water budget calculation about the lake demonstrated, that the lake budget is highly influenced by evaporation (0.4 – 5.7 mm/d) and precipitation (0.03 – 3.5 mm/d), while the groundwater (±0.06 – ±3.2 mm/d, error 10-90%) is only a weak component. Nevertheless, the monthly change in amount of net groundwater flow supported quantitatively the hydraulic results representing the seasonal variation in the groundwater-lake interaction. The net inflow and outflow contributing to the lake compensate each other in an annual budget. Based on the results Kelemenszék Lake is

determined as a water table type lake highly depending on the position of the local water table which is determined by the evaporation and precipitation. Hereby groundwater has a secondary role in the water budget of the lake. The results also proved the presence of the two agents responsible for salinization, the groundwater discharge carrying saline water to the lake, and the evaporation. The net groundwater flow in connection with the lake, characterized by the flux calculation between 5 and 10 m deep wells and the lake level shows smaller values than the water budget calculation (-0,4 – -4,9 mm/d). This deviation is supposed to be because of neglecting the groundwater flow from shallower depth (< 5 m). The groundwater inflow to the lake was measured by seepage meter too, resulting in a smaller value with one order of magnitude than the values of the other methods. These results display the spatially and seasonally different connection between the lake and groundwater as well.

6. Based on seismic interpretation under the Study Area possible pathways were determined for the ascending saline water to approach the surface. In the Study Area the shallow basement depth (< 600-1000 m), the overpressure in the Pre-Neogene basement, and the strike-slip faults detected below the lake assure pathways for the overpressured NaCl-type basement water resulting in the "short cut" and/or the "water exchange" connection between the Pre-Neogene basement and the near surface Great Plain Aquifer. This way the NaCl type groundwater in limited volume is injected into the $NaHCO_3$-type water of the Neogene and Quarternary basin fill and they ascend together up to the surface by the coupled effect of gravity and overpressure. Above these areas continuous salinization can occur on the surface.
7. The presence and spatial distribution of the gravity-driven fresh water and the overpressured saline water flow system in the Study Area was determined from 900 m depth up to the surface by chemical and geophysical methods. Multivariate data analysis of archive chemical data from the Pre-Neogene basement till the surface separated the groundwaters along the hydraulically defined boundary between the two flow systems based on their main element composition and pH. In addition, the results of this new method for this area supported the preliminary statements, that groundwater of the Pre-Neogene basement (NaCl type) and water of the Neogene basin fill ($NaHCO_3$ type) differ significantly (Rónai, 1965; Erdélyi, 1989; Mádl-Szőnyi and Tóth, 2009). In the Neogene and Quarternary layers (< 400 m) the distinguished groups of the archive wells as well as their different Cl^- content assigned the pathways of the saline and fresh groundwater, coincident with the previous hydraulic differentiation of Mádl-Szőnyi and Tóth (2009).

The saline water flow system is characterized by significantly larger Na^+, Cl^- and HCO_3^- values, whereas the fresh water is rich in Ca^{2+}. The measurement detected a fresh water flow system on the western side of the lake which can be identified as the hydraulically assigned local flow system in connection with the lake. The same spatial differentiation could be measured by surface geophysical methods too. In the upper 100 m, based on specific resistivity results a clear boundary could be delineated between the fresh water and saline water regimes. This boundary correlates with the hydraulic flow branch boundary between the gravity-driven and overpressured flow regimes. The change in chemical facies in 10 m depth from $NaHCO_3$(-Cl) to (Ca,Mg)-$(HCO_3)_2$ type along the surface cut of the hydraulic boundary (i.e. Dunavölgy Canal) reflects similar differentiation in the water chemistry. This chemical difference detected on the two sides of the hydraulic boundary supports the different origins of the groundwater. In addition, the saline groundwater with elevated Cl^- content is proved to be present below the lake from the basement till the surface.

8. The boundary detected between the saline and fresh water regimes is not a sharp border, but a 1-3 km wide transition zone. This transition is traced by the transitional change in Cl^- data and the groups of the multivariate data analyses of the deep archive wells along the hydraulic boundary (i), by the transition zone of 30 Ωm resistivity values in the near surface (ii) and by the near surface distribution of chemical data, i.e. the gradual increase of Ca^{2+} and the change in chemical facies from $NaHCO_3$ to Ca-$(HCO_3)_2$, along the hydraulically determined boundary (iii). This gradual change in the chemical pattern in different depths proposes that mixing and dispersion could be the controlling factors between the two flow systems.
9. By stable isotope and ^{14}C measurements it was established that the ascending saline water below Lake Kelemenszék (in 180 m depth) and the Ridge Region (in 355 m depth) is of Pleistocene age and it is represented by close to present meteoric water type isotopic composition. These data support that the basement component (NaCl type water) in the ascending saline water is present only in traces, but chemically largely influence the main element composition, providing extra Cl^- content.
10. The discharge of the ascending basement and basin origin saline water in the close vicinity of the lake was evaluated by interpreting the chemical data of the shallow dug and the deeper observation wells in comparison with two reference wells, representing the ascending saline ($NaHCO_3$-Cl type), and the gravity-driven fresh water (Ca-$(HCO_3)_2$ type). The similar composition of main elements, trace elements, and stable isotopes in

the saline reference and the observation wells at the eastern side of the lake (O4 and O5) proved the discharge of the ascending saline groundwater below the lake. The discharge center is assigned by the highest TDS and Cl^- values of these observation wells in 10 and 20 m depth. The discharge of this highly saline water can provide salt source to the salinization. The salinity of discharging saline water is enhanced by the evaporation, mainly in the N-S oriented zone of the lake. At the eastern side of the lake the increasing Ca^{2+} and Mg^{2+} content show the effect of the “fresh water” of the gravity-driven flow system as well. On the western part of the lake the smaller TDS and Cl^- values (in well O1-2) signify discharge of the local groundwater flow system, identified in the course of the hydraulic study around the lake. In the lake based on stable isotope data, the saline and fresh water also discharge.

11. The permanent chemical pattern around the lake supports the constant effect of upwelling saline groundwater in the area and water supply from the meteoric regime to the East. In this situation the lake is in connection with the local system acting in the upper 20 m. Consequently the deep originated flow system did not influence quantitatively the wetland area and the lake, but qualitatively it is the determining factor in surface and groundwater salinization. Its saline water is distributed by the overprinting local flow system near the surface.
12. Mineralogical investigations supported that the composition of the shallow groundwater and lake water in the saline tract can not be deduced from fresh water and local sediment interaction. The Cl^- content of the groundwater and lake water can not be derived from the sediment-water interactions in the shallow environment, either, because there is no Cl^- source in the sediments. Exchangeable cation values of the fresh water and saline water bearing sediments in the Ridge Region and around Lake Kelemenszék did not show any difference, implying that the main chemical pattern around Kelemenszék Lake is not influenced by ion exchange along local flow paths.

As a summary the lake is situated in a regional discharge area superimposed by a local flow system from a Danube Valley height to the Dunavölgy Canal. The source of salt in the area is the basin and basement origin ascending saline groundwater. This ascending saline groundwater flow did not influence the lake water budget quantitatively, but develops a constant chemical pattern, which cannot be contributed to local hydraulic effects.

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