The importance of electromagnetic methods to build numerical groundwater flow model for an area with complex geology in the case of Tihany Peninsula, Hungary

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Wetlands and the understanding of their connection with groundwater is a highlighted topic nowadays. These areas have an important role in maintaining the biodiversity of earth, therefore they require protection. Groundwater influenced lakes and wetlands are hydrologically and ecologically linked to adjacent groundwater bodies, but the rate of their interactions is highly variable. A lake can gain groundwater or lose water to the groundwater systems and these processes can vary in space, depending on the position of lake in flow systems, moreover in temporally. The lakes can connect to the groundwater in three different ways: recharge, discharge type, and flow-through lakes (Winter *et al.*, 1998). This relationship depends on the water table configuration, relation of the lake water level to the water table and to the subsurface potential field, the geological framework, climate, and the vegetation around the lake (Winter 1976, 1978).

These issues are more complex in areas with complex geological settings. The understanding of groundwater flow systems here therefore have high importance in water supply issues, land use planning or in management of natural conservation areas. The study concentrates on the Tihany Peninsula (natural conservation zone) surrounded by the Lake Balaton, Hungary. The lakes of the peninsula are located in paleo-maar structures being formed during the Neogene phreatomagmatic volcanism of the region (Németh *et al.*, 2001). The lakes were supposed to be recharged exclusively from precipitation. However, based on the above mentioned considerations, and on the numerical and theoretical studies of Winter (1976), connection of the lakes with the groundwater can be presumed. In this area, beside the primary effect of the topography, the geology significantly controls the flow systems: the paleo-maar environment, the variation of siliciclastic and carbonate rock formations, and the tectonic features. The main goals of the study were (1) to understand the groundwater flow pattern in that complex geological framework, (2) to determine the hydraulic position of the lakes in the flow systems of the Peninsula and to find explanation for the different hydrological behaviour of the lakes and (3) to evaluate the connection of the groundwater system with Lake Balaton.

The hydraulic data for the whole peninsula are scarce; therefore 3D numerical modelling (Comsol Multiphysics 4.2a) was used to achieve the purposes. In order to build up a model, hydrostratigraphic characterization of the geological formations was achieved. Indirect geophysical methods were used to determine the geometry of the units and the hydraulic conductivity: radio-magnetotelluric (RMT), audio-magnetotelluric (AMT), VLF resistivity, VLF electromagnetics and gradient methods. Hydraulic conductivities were derived by conversion of the measured resistivity values. Based on the detailed geological characterization, the flow systems were simulated during different scenarios.

As a result of the study (1) a hydraulically continuous subsurface flow field was recognised for the area, which is driven mainly by topographic gradients. The model (2) indicated the different hydraulic position of the lakes, in good agreement with the field measurements (hydrogeochemical analyses, ecohydrological, archive and recent field observations): the Rátai Csáva, situated in the highest topographic position, is a recharge lake. The Inner Lake can receive water from the surrounding local heights and it can lose water toward the Outer Lake. The Outer Lake is in the lowest topographic position consequently it is a discharge lake receiving groundwater from every direction. Furthermore, the study revealed: (3) hierarchically nested flow systems for the whole succession, (4) the barrier role of Pannonian Formations in flow field and the hydraulic behaviour of structures, (5) the diffuse discharge at the edge of the peninsula, (6) groundwater discharge in the Lake Balaton in ~50 m wide zone around the peninsula (Fig. 1).

These conclusions can be decisive concerning water balance and ecological aspects of these wetlands as well as in the management of the nature protection area. The results can also initiate further research to understand the interaction between flow systems and lakes in similar geological environments.

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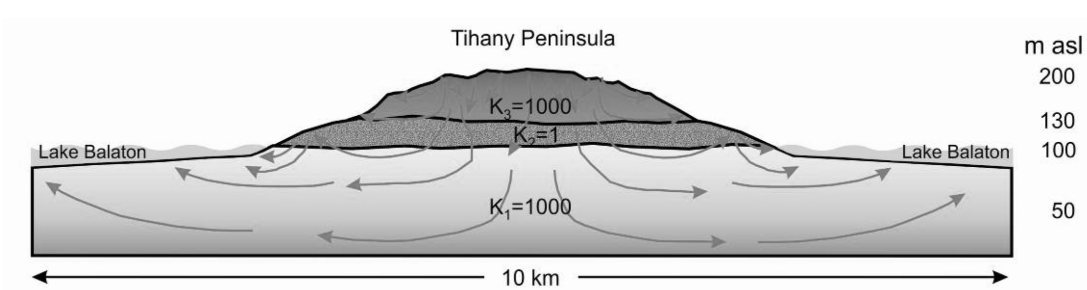

Fig. 1.: Schematic figure of the flow system of Tihany Peninsula. This pattern can be generalized for geologically complex peninsula