ESTIMATION OF GROUNDWATER RECHARGE CHANGE AT A HUNGARIAN TEST SITE USING ENVIRONMENTAL ISOTOPE MEASUREMENTS

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ABSTRACT
A quantification of natural groundwater recharge was performed using environmental tracer techniques, mainly based on use of bomb peak tritium and the ^3H/^3He technique at suitable locations using multilevel wells in Hungary. A flow and transport model based on the MODFLOW and MT3DMS packages was built, which was calibrated by the measured tritium contents under the surface at different depths. The test area in Méntelek is located on the Great Hungarian Plain between the Danube and Tisza rivers. This area is a typical recharge area with nearly vertical groundwater flow. This is the reason why this place was first selected as a test area to demonstrate the applicability and reliability of the proposed investigation. Tritium contents profile was measured here in 1998 in the course of drilling of a 24 m deep borehole at 11 different levels under the surface. As a next step, a transient model was created covering the 60-year-long time period between 1951 and 2010. The tritium content of the Hungarian precipitation was estimated for this period using measured data of Hungarian precipitation since 1972, wine samples of 1960 to 1977 and GNIP data of Vienna and Ottawa. Based on these data and information, the transient tritium transport model was calibrated with the field data from 1998. Nearly perfect match with very low RMSE was achieved between the measured and simulated tritium data. The calibration result confirmed the reliability of the applied transport model at the recharge area. As a result, the average groundwater recharge and the vertical dispersion behavior of the investigated subsurface layers were determined. The derived average groundwater recharge between 1951 and 1998 was 53 mm/year at the test site, and the vertical dispersivity is 0.03 m. The new tritium, ^3He and ^14C profile at four different depths in a well nest developed in this borehole was also measured in 2010. Based on these results, a new calibration was carried out to determine how the average recharge changed between 1998 and 2010. This is a significant result, because this new value can reflect whether there is a change in groundwater recharge due to climate change at the investigated region.

1 INTRODUCTION
The Duna-Tisza-köze is one of the largest recharge areas in Europe. There is an ongoing international project, which is coordinated by the IAEA to investigate the natural groundwater recharge at some test places in Europe. In Hungary, a special research group carries out this special research program at a sampling site named Méntelek. The aim of this research is to build a flow and transport model for the sample site, which is based and calibrated on tritium isotope measurements. After the field investigations, we could estimate the annual groundwater recharge, and we could understand the underground hydraulic situation of this area. A quantification of natural groundwater recharge was performed using environmental tracer techniques, mainly based on use of bomb peak tritium and the ^3H/^3He technique at suitable locations using multilevel wells in Hungary (Juhász, 2002). A special transport model based on the MODFLOW and MT3DMS packages was built, which was calibrated by the measured tritium contents under the surface at different depths.

2 MATERIAL AND METHODS TO ESTIMATE GROUNDWATER NATURAL RECHARGE
The ^3H is the radioactive isotope of the hydrogen. From the 1950s high-altitude nuclear tests introduced large amounts of tritium into the atmosphere. Because the short half-time of the tritium we can get some information from the last 50 years happening. Tritium isotopic measurements were applied at the lysimeter site in Méntelek, which is 12 km far from Kecskemét. The test area is located on the Great Hungarian Plain between the Danube and Tisza rivers. The aim of the field measurements was get more information from the well-nest, which was built in 1998. This well-nest contains 4, smaller diameter wells (Figure 1). Each well filters different layers in different depth.

This area is a typical recharge area with nearly vertical groundwater flow (Erdélyi, 1976, Deák, 2002). This is the reason why this place was selected as a test area in Hungary. Tritium contents profile was measured here in 1998 at 11 different levels under the surface (Deák, 2006). A numerical transient transport model was created
covering the 60-year-long time period between 1951 and 2010.

This area is a typical recharge area with nearly vertical groundwater flow (Erdelyi, 1976, Deák, 2002). This is the reason why this place was selected as a test area in Hungary. Tritium contents profile (Figure 4) was measured here in 1998 at 11 different levels (Table 1) under the surface Deák, 2006). A numerical transient transport model was created covering the 60-year-long time period between 1951 and 2010. The tritium content of the Hungarian precipitation (Figure 3) was estimated for this period using measured data of Hungarian precipitation since 1972 (Deák, 2006), wine samples of 1960 to 1977 (Kozák, 1980) and GNIP data of Vienna and Ottawa.

The research site in Méntelek developed in the early 1950s. Some hydrological parameter became measurable, like: groundwater level, groundwater temperature, soil temperature, precipitation, evaporation, interception, solar radiation and wind velocity. Some lysimeter stations were also developed for monitor the groundwater recharge in 1955.

For the investigation of the general geological characterization of the site, a trench was deepened. The sampling showed that the main rock in this region is the sand, and the gravel-sand. At the lower parts, the clayey sand and clay are the dominant components. The change of the moisture content was established on the soil profile. The horizontal hydraulic conductivity was estimated about $5 \times 10^{-5}$ m/s, the vertical component is lower with 2 orders of magnitude with the depths.

Based on these data and information, the transient tritium transport model was calibrated with the field data from 1998. Nearly perfect match was achieved between the measured and simulated tritium data (Figure 2). The calibration result confirmed the reliability of the transport model (Szucs et al. 2006). As a result, the average groundwater recharge and the dispersion behavior of the investigated subsurface layers were determined. The derived average groundwater recharge is 53 mm/year, and the vertical dispersivity is 0.3 m.

The new tritium profile at four different depths was also measured in Méntelek in 2010. Based on these results, a new calibration will be carried out to determine how the average recharge changed between 1998 and 2010. This would be a significant result, because this new value can reflect whether there is a change in groundwater recharge due to climate change. This new transport model calibration will be carried out in March 2012.
Groundwater flow and transport modeling and simulations based on all available information can help the decision makers to find the most effective and environment-friendly solutions. In our case, the Processing MODFLOW for Windows 7.0 (PMWIN Pro) software (Chiang and Kinzelbach 2001) was used for natural groundwater recharge estimation. The finite-difference MODFLOW 2000 module (Harbaugh et al., 2000) is an industrial standard used to create accurate and reliable 3-dimensional groundwater flow models. The PMWIN Pro can handle contamination transport processes using its well-known MT3DMS program. In most cases, transient-state simulations are required to follow up the consequences of the time-dependent processes.

**Table 1. Measured tritium contents.**

<table>
<thead>
<tr>
<th>Depth [m-m]</th>
<th>Tritium [TU]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 - 6.5</td>
<td>13.8</td>
</tr>
<tr>
<td>7.5 - 8.0</td>
<td>14.8</td>
</tr>
<tr>
<td>9 - 9.5</td>
<td>19.1</td>
</tr>
<tr>
<td>10 - 10.5</td>
<td>22.5</td>
</tr>
<tr>
<td>11 - 11.5</td>
<td>45.3</td>
</tr>
<tr>
<td>11.5 - 12.5</td>
<td>48.5</td>
</tr>
<tr>
<td>12 - 12.5</td>
<td>54.7</td>
</tr>
<tr>
<td>13 - 13.5</td>
<td>49.3</td>
</tr>
<tr>
<td>14.5 – 15</td>
<td>14.0</td>
</tr>
<tr>
<td>15.8 – 16.9</td>
<td>1.2</td>
</tr>
<tr>
<td>21.1 – 23.1</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Figure 3.** The tritium profile from 1998.

**Figure 4.** The measured and calculated tritium profile under the surface based on the calibrated tritium transport model.

**Figure 5.** Calibrated tritium transport model (Méntelek, December 5, 1998).
MODFLOW is a U.S. Geological Survey modular finite-difference flow model. This computer code can solve the groundwater flow equation. The governing partial differential equation solved numerically in MODFLOW is given in the following form:

$$\frac{\partial}{\partial t} \left( K \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K \frac{\partial h}{\partial z} \right) + W = S_j \frac{\partial h}{\partial t} \quad [1]$$

Where $K_{xx}$, $K_{yy}$, and $K_{zz}$ are the values of the hydraulic conductivity along the x, y, and z coordinate axes (L/T), $h$ is the hydraulic head (L), $W$ is the volumetric flux per unit volume representing the sources and sinks of groundwater, for which the negative values denote extractions while the positive values denote injections (T$^{-1}$), $S_j$ is the specific storage of the investigated aquifer (L$^{-1}$), and $t$ is time (T). This program is widely used throughout the world by hydrogeologists to simulate the flow of groundwater through aquifers. The code is free software, written in the FORTRAN language, and can be compiled and run on the DOS, Windows, or UNIX operating systems. Since its original development in the early 1980s (McDonald and Harbaugh 2003), the USGS have released four major versions of this code, and is now considered to be the de facto standard industrial code among the groundwater specialists for aquifer simulation. Currently, there are many actively developed commercial and non-commercial graphical user interfaces for MODFLOW.

The MODFLOW-2000 version was released on July 20, 2000. Many new packages and enhancements were also released, including new solvers, and stream and saturated flow packages. The following packages of MODFLOW-2000 were used to describe the different source and sink terms during the above-mentioned simulation activity of the present studies: General-Head Boundary, Drain, Evapotranspiration, Reservoir, Lake, and Well and Recharge.

There are several graphical interfaces to MODFLOW, which often include the compiled MODFLOW code. These programs provide convenient means of supplying the input data for creating MODFLOW models. Commercial MODFLOW programs are typically used by governments and consultants for practical applications of MODFLOW to real-world groundwater problems. The applied PMWIN-Pro may be considered as a professional commercial version of MODFLOW. A three-dimensional flow model considering forty-four-layers was applied in the current project work. This model was used to characterize the nearly vertical groundwater flow of the investigated area in Méntelek, which is a main recharge region on the Hungarian Great Plain (Toth 2005). The input data required for the flow model were readily available from an earlier geological and hydrogeological prospecting activity. The flow model was first calibrated to the measured groundwater level data prior to the simulation of the natural groundwater recharge phenomena (Szucs and Ritter 2002). The calibrated flow model describes the real groundwater flow system quite accurately. Therefore, the calibrated well-working flow model could be used to simulate successfully the different recharge scenarios. Besides the flow model, a transport model was also built to investigate tritium concentration distribution under the surface due to the groundwater recharge from precipitation. The tritium transport movement investigations were carried out in the field-study by the help of the MT3DMS model (Zheng and Wang, 1999), where MT3D stands for the Modular 3-dimensional transport model, and MS denotes the multi-species structure for accommodating add-on reaction packages. MT3DMS has a comprehensive set of options and capabilities for simulating the advection, dispersion, diffusion, radioactive decay and chemical reactions of contaminants in groundwater flow systems under the general hydrogeologic conditions. The MT3DMS was developed for use with any finite-difference flow model such as MODFLOW, and is based on the assumption that changes in the concentration field will not affect the flow field appreciably.

The partial differential equation describing the fate and transport of chemical components or contaminants of the species $k$ in a three-dimensional space in transient groundwater flow systems can be written as follows:

$$\frac{\partial (\phi C_k)}{\partial t} = \frac{\partial}{\partial x_i} \left( D_{ij} \frac{\partial C_k}{\partial x_j} \right) - \frac{\partial}{\partial x_i} (\phi v_j C_k) + q_i C_k + \sum R_k \quad [2]$$

Where $\phi$ denotes porosity of the aquifer, dimensionless, (fraction), $C_k$ is the dissolved concentration of species $k$, (M/L$^3$), $t$ is time (T), $x_i$ is distance along the respective Cartesian coordinate axis (L), $D_{ij}$ is the hydrodynamic dispersion coefficient tensor (L$^2$/T), $v_i$ is the seepage or linear pore water velocity based on the Darcy equation (L/T), $q_i$ is the volumetric flow rate per unit volume of aquifer representing fluid sources and sinks(1/T), $C_k$ is the concentration of the source or sink flux for species $k$ (M/L$^3$), and $\sum R_k$ is the chemical reaction term (M/L$^3$/T).

3 CONCLUSION

Nowadays the isotope hydrology is the most accurate tool for the determination of relativegroundwater age. A hydrodynamic and transport model can be a useful and practical solution for the reliable estimation of natural groundwater recharge conditions. These special calculations are based on the dating of the groundwater. In this case, the appropriate isotope tool was the tritium technique. With the measured and appropriate data, the transport model became calibrated, so the model run realistic. The obtained results give new information to understand the groundwater flow behavior of the Hungarian Great Plain.

4 ACKNOWLEDGMENT

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REFERENCES


