

ESTIMATION OF THE GROUNDWATER REPLENISHMENT CHANGE AT A HUNGARIAN RECHARGE AREA

Peter SZUCS¹, Laszlo KOMPAR¹, Laszlo PALCSU², & Jozsef DEAK³

¹University of Miskolc, Department of Hydrogeology and Engineering Geology, MTA-ME Research Group of Geoengineering, 3515. Miskolc-Egyetemvaros, Hungary, e-mail: hgszucs@uni-miskolc.hu, hgkompar@uni-miskolc.hu

²Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary, palcsu@atomki.hu
(3) GWIS Plc., Dunakeszi, Hungary, deak47@gmail.com

Abstract: Groundwater tritium and helium isotope measurements were used to estimate the natural groundwater recharge at a Hungarian test site (Méntelek), which is a typical recharge area in the middle of the Great Hungarian Plain. As a first step, a previous groundwater tritium profile at 11 different levels of a 24 m deep borehole measured in the test site in 1998 was re-evaluated. A hydrodynamic and transport model assuming nearly vertical flow was created and calibrated by the measured tritium profile resulting 50 mm/year average groundwater recharge and 0.3 m dispersivity for the time period between 1951 and 1998. A new tritium and ³He profile at four different depths in a well nest developed in the described borehole was also measured in 2010. The average infiltration rate for 1951 to 2010 was calculated by new tritium data as 70 mm/year using the same models. ³H/³He ages are linearly growing via depth resulting in 0.32 m/year vertical flow velocity and 64 mm/year infiltration rate. Based on these results, a new simulation has confirmed that significant alteration in groundwater recharge between 1998 and 2010 could not be detected although it had been assumed by earlier climate change information.

Key words: groundwater replenishment, recharge area, environmental isotope, tritium transport, climate change

1. INTRODUCTION

Hungary is located on the Danube basin (watershed) in the Carpathian basin, which is one of the most closed basins of the world concerning the water budget (Fig. 1). 96% of the surface water volume inside the Carpathian Basin arrives from abroad. This geographical feature has significant effects on surface waters as well as on groundwater resources in Hungary. The fact that our relatively small country is neighboring with seven other countries forms special conditions in groundwater management for Hungary having the most transboundary aquifers in Europe. The watershed management plan of Hungary delineated 185 groundwater bodies, out of which 40 are officially registered as transboundary aquifer, although the actual dependency is even higher. Approximately 50% of the groundwater bodies is divided by national borders, thus external effects influence the quantity and quality of our groundwater resources in a serious manner (Juhász, 2002).

Groundwater resources took over the leading role in drinking water supply all over the world in front of surface water (Szűcs et al., 2009). Its share in Europe has reached 74%, while in Hungary drinking water supply is provided from groundwater at the rate of 95%. Although the total nominal capacity of drinking water supply systems in Hungary is approximately 1 700 million m³ per year, the total annual production volume is only around 700 million m³. Besides our drinking water resources the value of those reservoirs providing mineral waters, cure waters and thermal waters shall be increasing in the future to cope with water supply related problems affecting more than half of the ever increasing population of the globe. Beyond the threats caused by changing natural conditions there are unfortunate anthropogenic impacts on the groundwater resources such as contamination of environmental elements or our human impacts on climate change. This means that information concerning groundwater replenishment of recharge areas is extremely important to achieve sustainable utilization of groundwater resources.

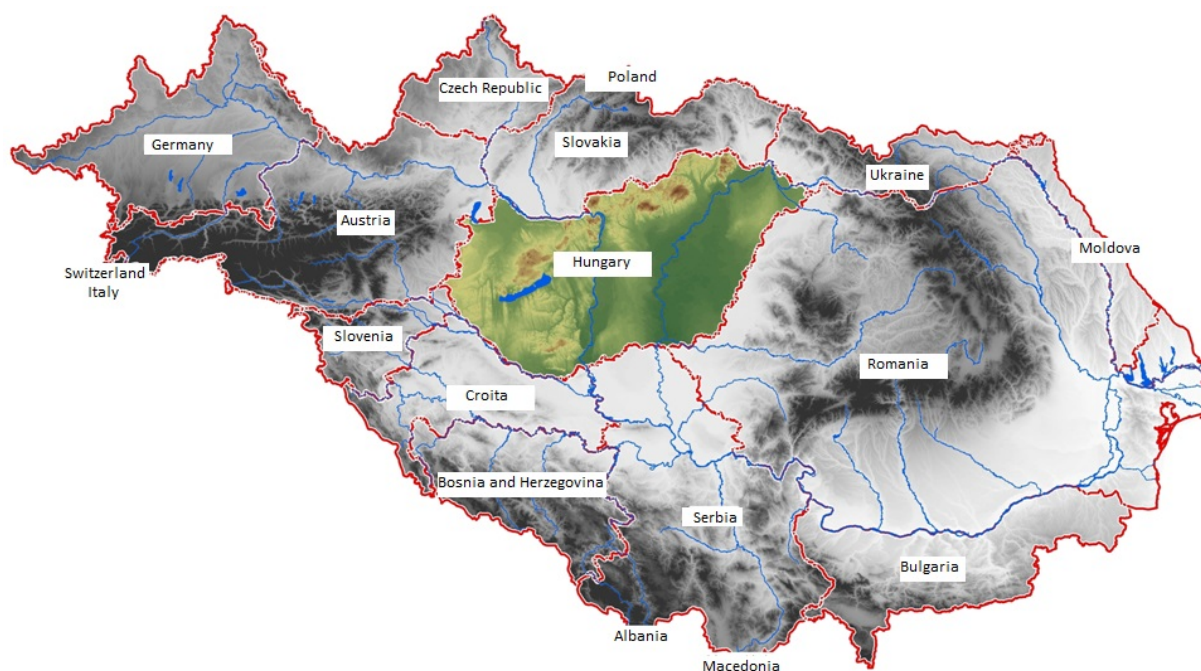


Figure 1. Hungary is located on the Danube watershed inside the Carpathian basin.

There is an ongoing international project, which is coordinated by the International Atomic Energy Agency (IAEA, Vienna) to investigate the natural groundwater recharge at some test places in the world (Czech Republic, France, Hungary, Japan, Morocco, Pakistan, Turkey, United Kingdom, United States of America) for a comparative study. A cooperative national project named as Well aHEAD (TÁMOP-4.2.2.A-11/1/KONV-2012-0049) in the framework of the New Hungarian Development Plan is also investigating the groundwater recharge. The aim of these research programs is to build a reliable flow and transport model for the sample site, which is based and calibrated on tritium and helium isotope measurements. In Hungary the same research group carries out both of these unique research programs. First results of this study at Méntelek sampling site are presented.

2. AREA OF INVESTIGATION

Eastern lowland part of the Carpathian Basin is named as Great Hungarian Plain. The Danube Tisza Region (DTR) of 13.000 km² is geographically situated between the Rivers Danube and Tisza. The middle part of DTR (where the study area, Méntelek is lying) is a sandy ridge area of 9.000 km² with about 20 to 60 m higher elevations than the deeper parts of the Great Hungarian Plain (Fig. 2). The potentiometric surface (hydraulic head) of the groundwater steadily decreases via depth and dominance of sandy aquifers of some hundred

meters allows the vertical seepage of groundwater to higher depths. Hydraulic head of groundwater in the main aquifer (lower Quaternary) is 10 to 40 m higher on the ridge area than on the deeper (discharge) areas of the Great Hungarian Plain suggesting horizontal flow to the deeper parts of the area (regional system on Fig. 2).

Conceptual (Tóth, In references list is Thot 1970; Erdélyi, 1976) and mathematical models (Sanford et al., 2001) and groundwater age data (Deák, 2006) have demonstrated the existence of a gravitationally driven regional groundwater flow system in the upper 200 to 400 m thick Quaternary sediments recharging in the Danube-Tisza Ridge area (Fig. 4). A hydrogeological cross section prepared by piezometric (hydraulic) head data of existing wells proves the nearly vertical groundwater flow at our test area (Méntelek) (Fig. 3), lying on the former research station of VITUKI (Water Resources Research Center).

The nearly vertical groundwater flow is one of the main reasons why this place was selected as a pilot area in Hungary for natural replenishment estimations. This research station was developed in the early 1950's and permanently operated through forty years. Different data series of some hydrological parameters like: groundwater level, groundwater temperature, soil temperature, precipitation, evaporation, interception, solar radiation and wind velocity are available.

Some lysimeter stations in the vicinity were also developed for monitor the groundwater recharge in 1955.

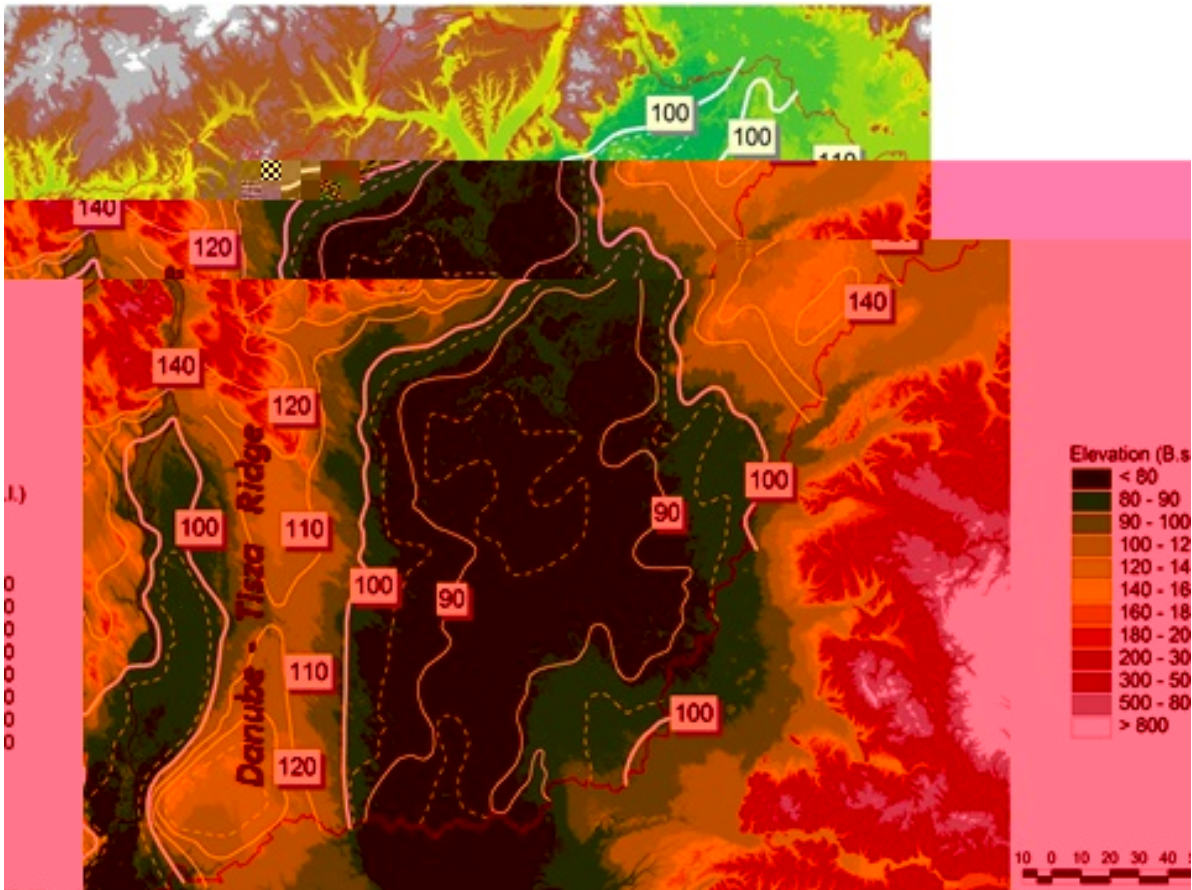


Figure 2. The hydraulic head contours of the shallow groundwater resources at the Great Hungarian Plain.

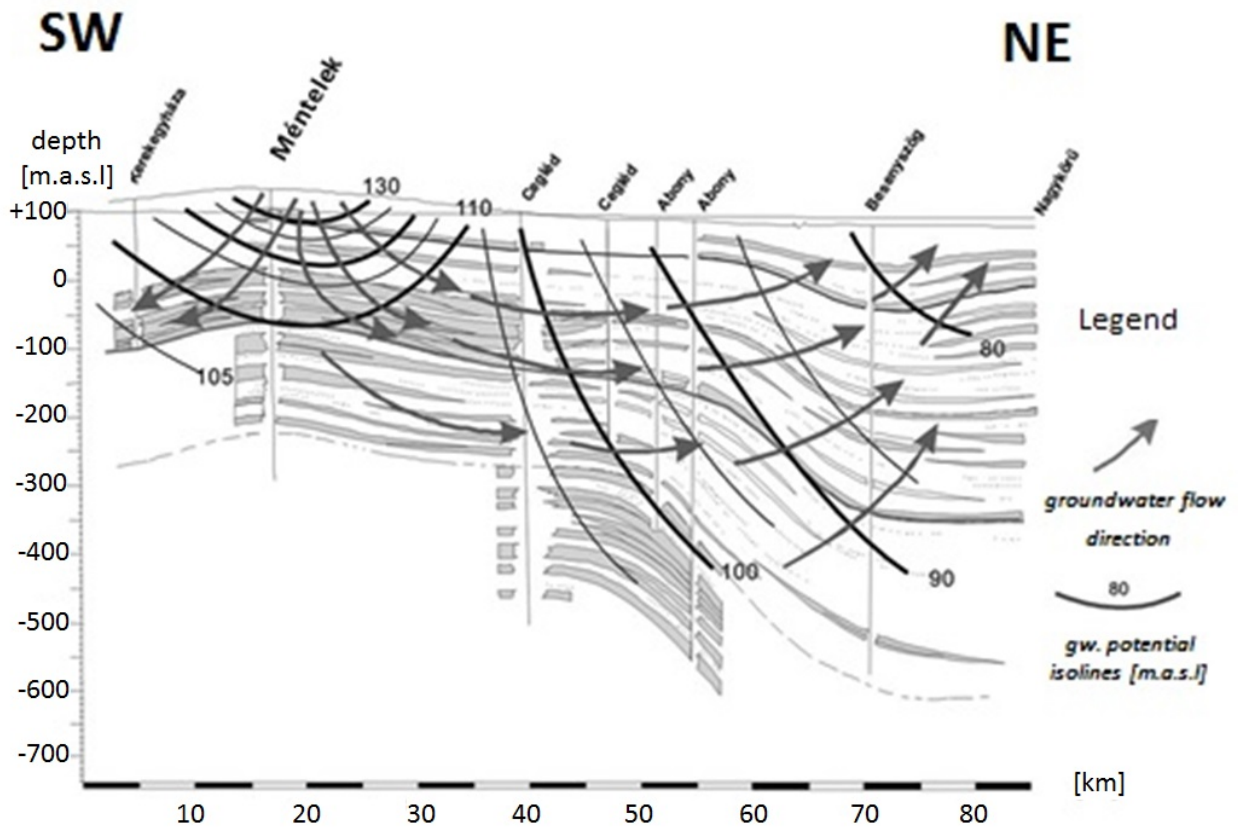


Figure 3. A hydrogeological cross section describing the flow lines and the hydraulic heads.

The hydraulic heads of the Danube-Tisza Ridge also indicate a significant recharge area for the whole Great Hungarian Plain (Fig. 3). Figure 4 also describes the Danube-Tisza Ridge recharge area with the test site location of Méntelek.

The profile was measured at the test site in Méntelek first in 1998 sampling a 24 m deep

borehole at 11 different depths (Deák, 2006). These data have been evaluated using the simple tritium peak and tritium balance methods. After sampling a well-nest consisting of 4 low diameter (60 mm) wells were built in the borehole. Each well filters different layers in different depth.

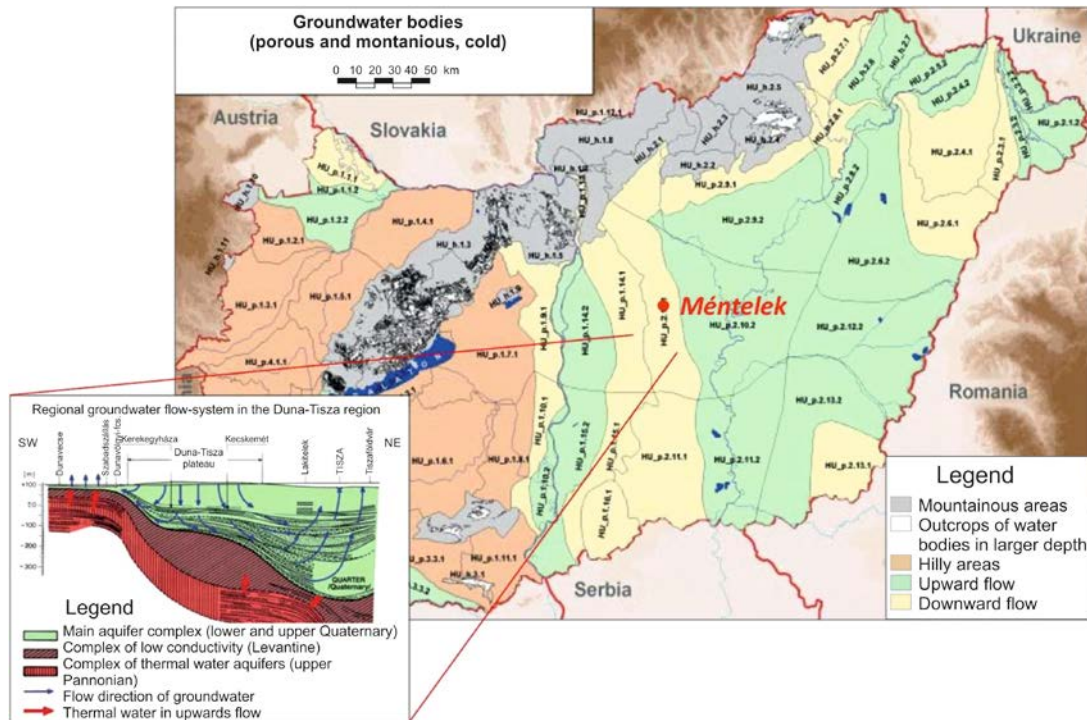


Figure 4. The Danube-Tisza Ridge (yellow), which is one of the main groundwater recharge areas of the Great Hungarian Plain and the area of investigation (Méntelek).

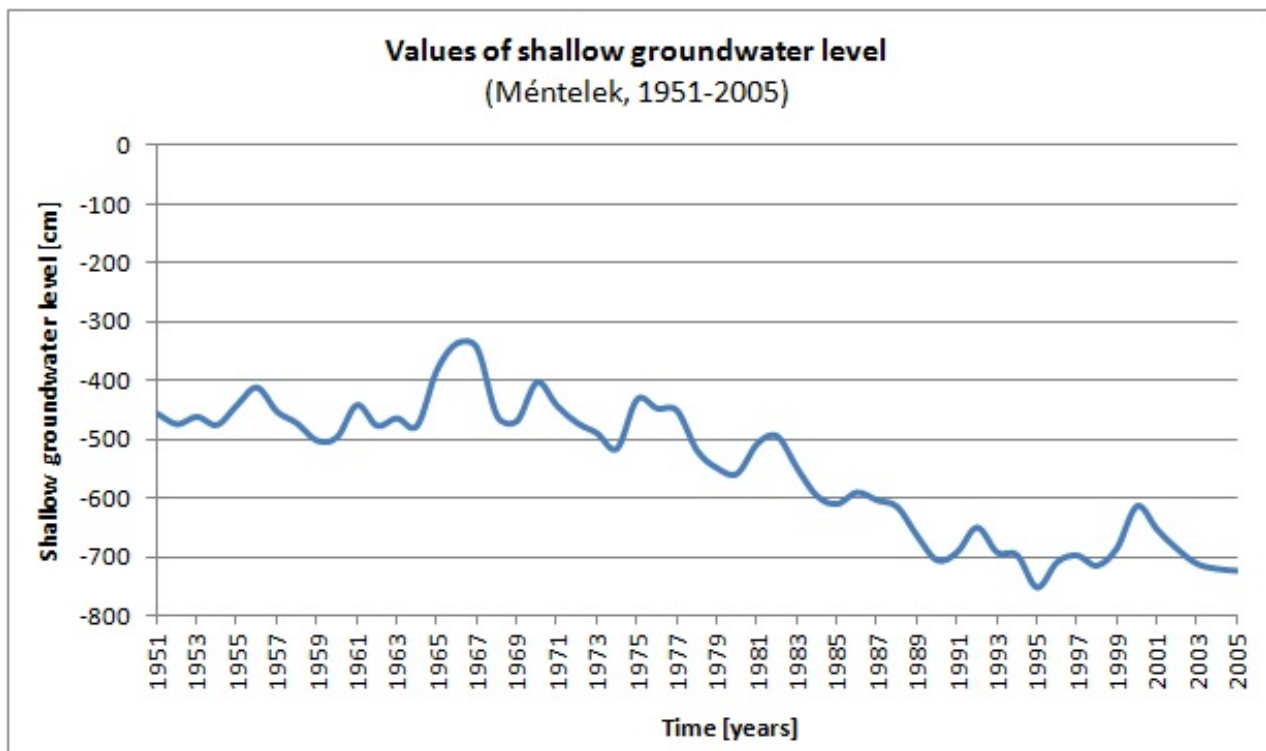


Figure 5. The depth of shallow groundwater level under the surface since 1951.

For the general geological characterization of the site, a 2 m deep trench was created in 2010. The sampling showed that the main soil 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 $5 \cdot 10^{-5}$ m/s by field tests. The different tests also prove that the vertical component of the hydraulic conductivity is lower with 2 orders of magnitude than the horizontal values. The depth data of shallow groundwater from the beginning of 1951 were also available from a shallow groundwater monitoring well close to the well-nest (Fig. 5). These data show a trend that there is a slight continuous decrease in the shallow groundwater level position. This important information was incorporated in the modeling approach. On the other hand, information is also available concerning the annual precipitation data since 1951. Generally speaking, a slight decrease in the annual precipitation can also be observed based the trend analysis (see Fig. 6). This important information was incorporated in the modeling approach.

3. THE APPLIED METHODS TO ESTIMATE GROUNDWATER RECHARGE

Quantification of natural groundwater recharge was performed using environmental tracer techniques, mainly based on use of bomb peak tritium and the $^3\text{H}/^3\text{He}$ dating technique. Besides

analytic calculations, a special transport model based on the MODFLOW and MT3DMS packages was built, which was calibrated by the measured tritium and ^3He contents under the surface at different depths and at different times to derive groundwater recharge information.

3.1 Tritium method to estimate groundwater natural recharge

Tritium (^3H) is the radioactive isotope of the hydrogen, so it is conservative tracer because integrated into the water molecule and follow its movement (Solomon & Sudicky, 1991). From the 1950's the high-altitude nuclear tests introduced large amounts of tritium into the atmosphere. Tritium content of the Hungarian precipitation (see Fig. 7) was estimated for this period using measured data of Hungarian precipitation since 1972 (Deák, 2006), wine samples of 1960 to 1977 (Kozak & Biro, 1984) and GNIIP data of Vienna. One can see the tritium peak of 1963 (just before the “nuclear-stop” agreement) which is an excellent tracer of groundwater recharge. Based on the tritium content measurements, the following opportunities are available:

- Simple tritium peak method,
- Tritium balance calculations,
- Verification and calibration of mathematical models.

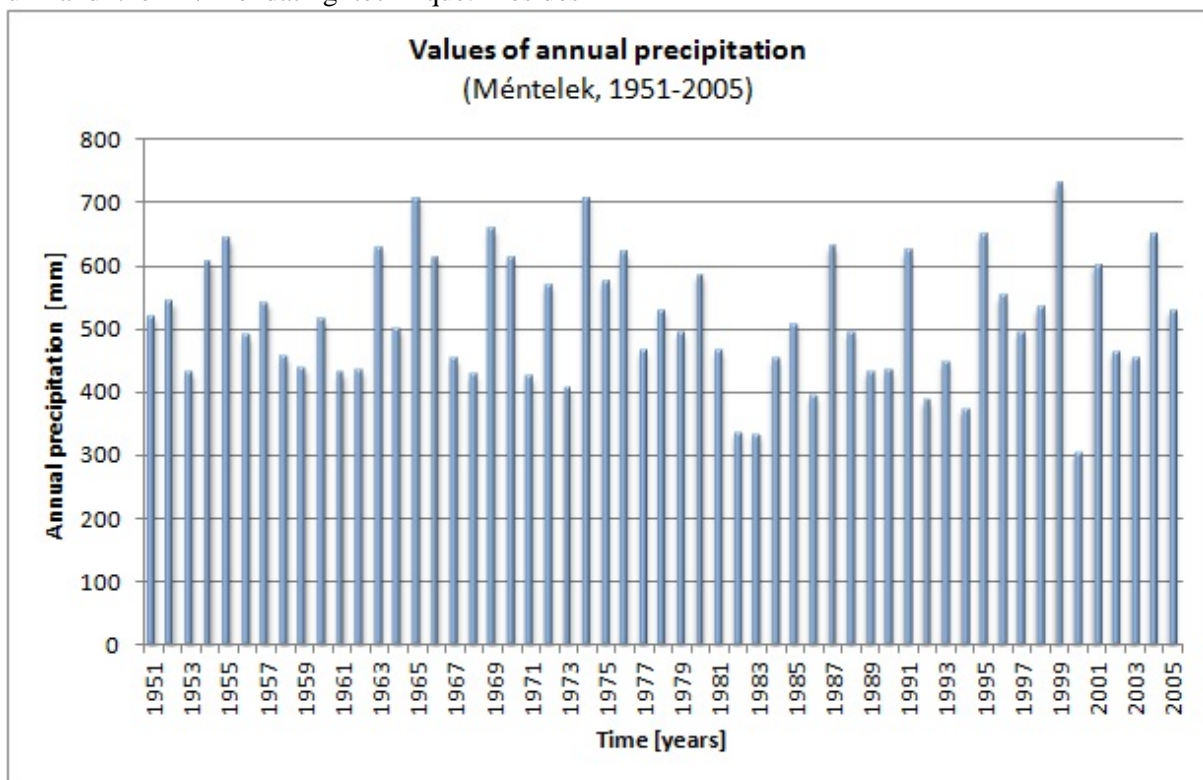


Figure 6. Annual precipitation data since 1951 and linear trend analysis.

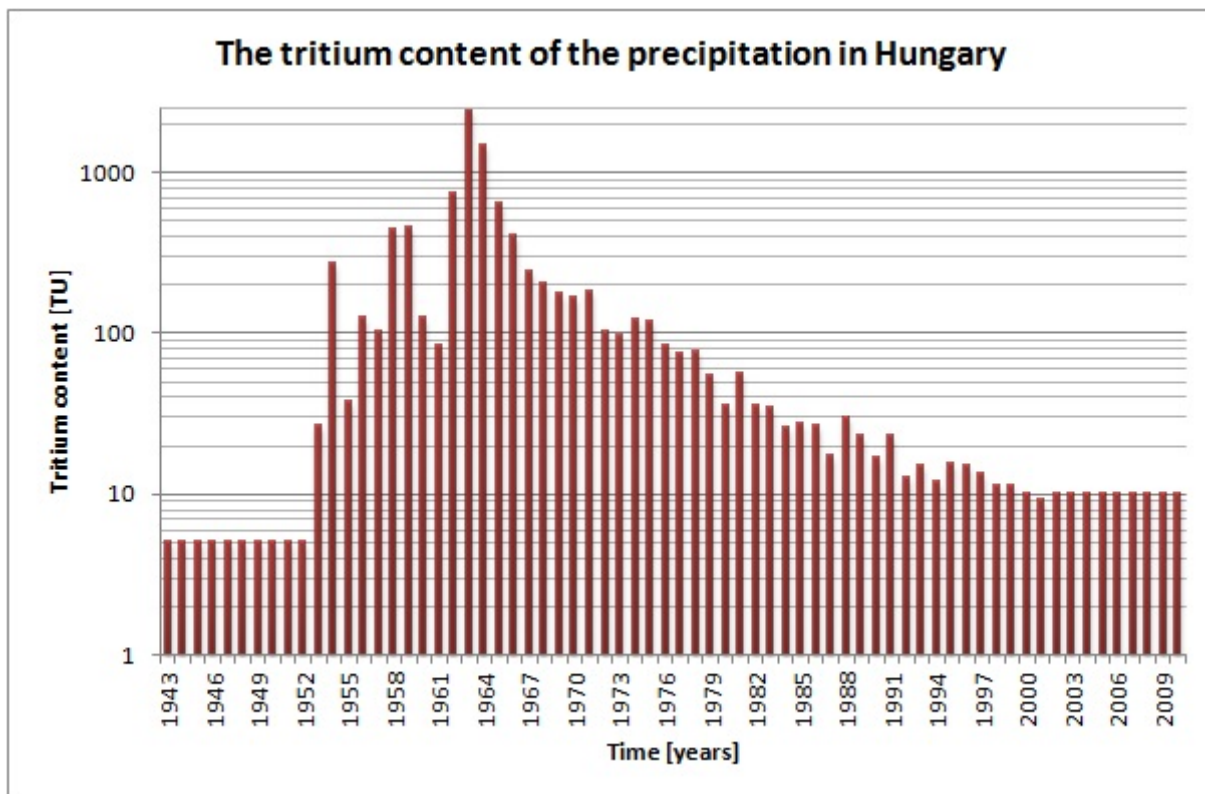


Figure 7. The tritium content of the precipitation in Hungary.

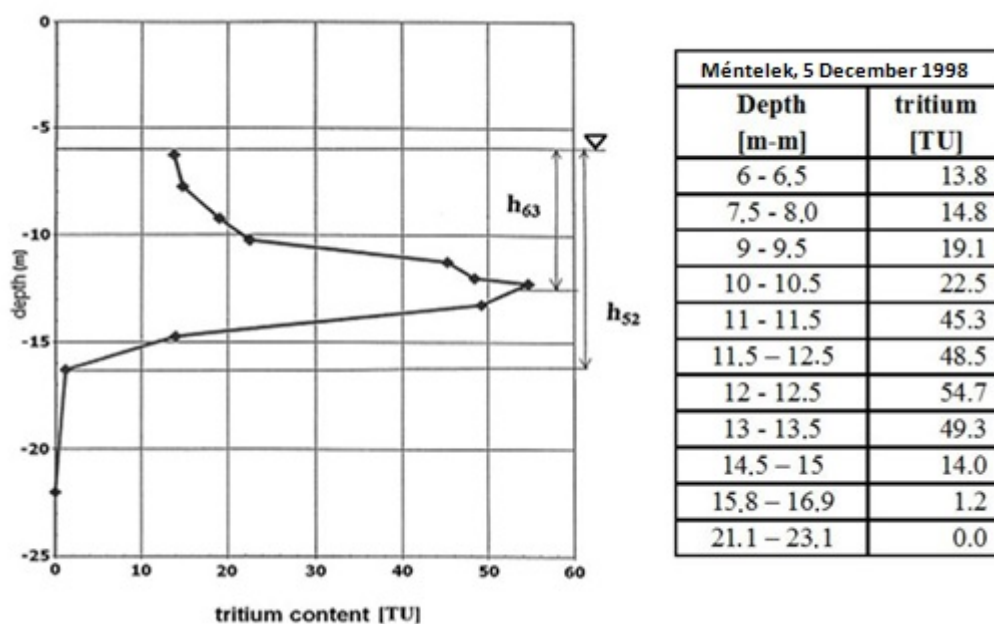


Figure 8. The tritium profile from 1998 and the measured tritium contents.

Tritium as well as noble gas concentrations including $^3\text{He}/^4\text{He}$ isotope ratios were determined in the Hertelendi Laboratory of Environmental Studies, Debrecen, Hungary. The tritium amount of groundwater samples was determined using the ^3He -growth method (Palcsu et al., 2010). Noble gas concentrations were determined mass-spectrometrically (Papp et al., 2012).

When the above-mentioned well-nest with four small diameter wells was created in Méntelek, the groundwater level and the tritium profile (Fig. 8) were measured at the test site in Méntelek first in 1998 sampling a 24 m deep borehole at 11 different depths (Deák, 2006). These data have been evaluated using the simple tritium peak and tritium balance methods. After sampling a well-nest

consisting of 4 low diameter (60 mm) wells were built in the borehole. Each well filters different layers in different depth.

3.2. Tritium transport model simulations to derive more accurate recharge estimations

A flow and transport model was built to simulate the investigated recharge system (McDonald & Harbaugh, 2003). In our case, the Processing MODFLOW 7.0 for Windows (PMWIN Pro) software (Chiang & Kinzelbach, 2001) was used for natural groundwater recharge estimation. The finite-difference MODFLOW module (Bear & Cheng, 2010) is an industrial standard used to create accurate and reliable 3-dimensional groundwater flow models. The PMWIN Pro can also 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. In our case, the flow model was rather simple, as vertical downward flow was assumed because of the pure recharge area behaviour. Groundwater level measurements in many observations wells at the site and close to the site proved this vertical down-flow assumption.

A three-dimensional flow model considering forty-four-layers was implemented with the help of the MODFLOW-2000 module in the current project work. This model with good vertical resolution was used to characterize the nearly vertical groundwater flow of the investigated area in Mentelek, which is the main recharge region on the Great Hungarian Plain (Tóth, 1995). The input data required for the flow model were readily available from an earlier geological and hydrogeological prospecting activity. Based on these available data and information, the transient tritium transport model was calibrated with the field data from 1998 (Szucs & Ritter, 2002).

MODFLOW is a U.S. Geological Survey modular finite-difference flow model. This program is widely used throughout the world by hydrogeologists to simulate the flow of groundwater through aquifers.

The tritium transport movement investigations were carried out in the field-study by the help of the MT3DMS model (Wang & Zheng, 2000), 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.

4. RESULTS

As it was mentioned earlier, the main objective of the study program was to determine the average groundwater recharge and the change of the recharge in time.

4.1 Previous results at the study area

The simple tritium peak method was applied by Deák (Deák, 2006) after the 1998 field measurement to derive a first estimation for the average groundwater recharge. The first rough analytical calculation gave 48 mm/a and 42 mm/a for the natural recharge at the investigated test site using tritium peak and tritium balance method respectively.

4.2 Calibration of transport model by previous and new tritium data

Because of the 12.32 years half-life of the tritium we can get some information from the last 60 years happening. To involve these data into calibration, the numerical transient tritium transport model was created covering the 60-year-long time period between 1951 and 2010. Nearly perfect match was achieved between the measured and simulated tritium data (Fig. 9). 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 50 mm/a for the time period between 1951 and 1998, and the vertical dispersivity is 0.3m.

As it was mentioned earlier, the second tritium profile at four different depths was measured in Mentelek in 2010. Based on these additional results, a new calibration was carried out to determine how the average recharge changed between 1998 and 2010. This can be a significant result, because this new value can reflect whether there is a change in groundwater recharge due to climate change.

There is a main problem that it turned out that the resolution of the measured tritium profile

with the measurements at for four different depths is adequate. The derived new average groundwater recharge is 70 mm/a for the time period between 1951 and 2010, and the vertical dispersivity is 0.3 m. On the other hand, the reliability of this calibration result is questionable (Fig. 10) because there were only four measured data.

4.3 Estimation of recharge by $^3\text{H}/^3\text{He}$ groundwater ages

Groundwater ages estimated by $^3\text{H}/^3\text{He}$ dating method are linearly growing via depth (Fig. 11) representing 320 mm/a vertical flow velocity and 64 mm/a average infiltration (accepting 0.2 as porosity) for the period of 1965 to 2010.

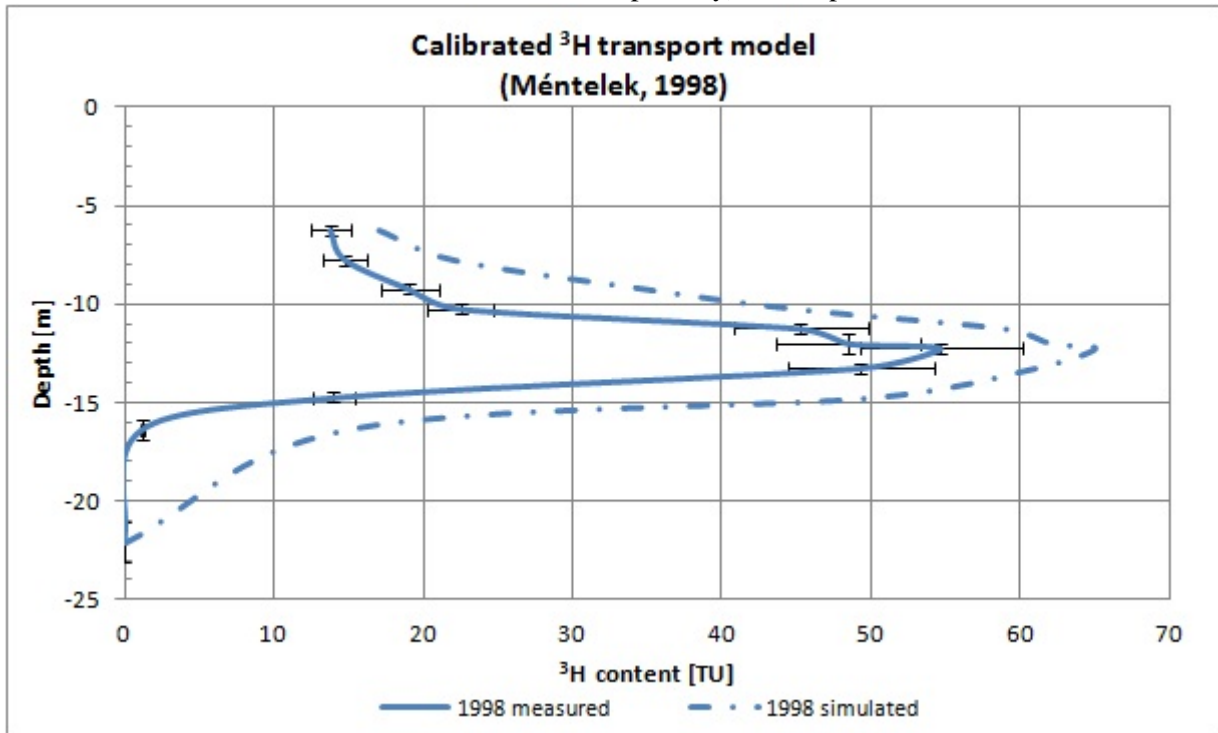


Figure 9. The measured (1998) and calculated tritium profile under the surface based the calibrated tritium transport model.

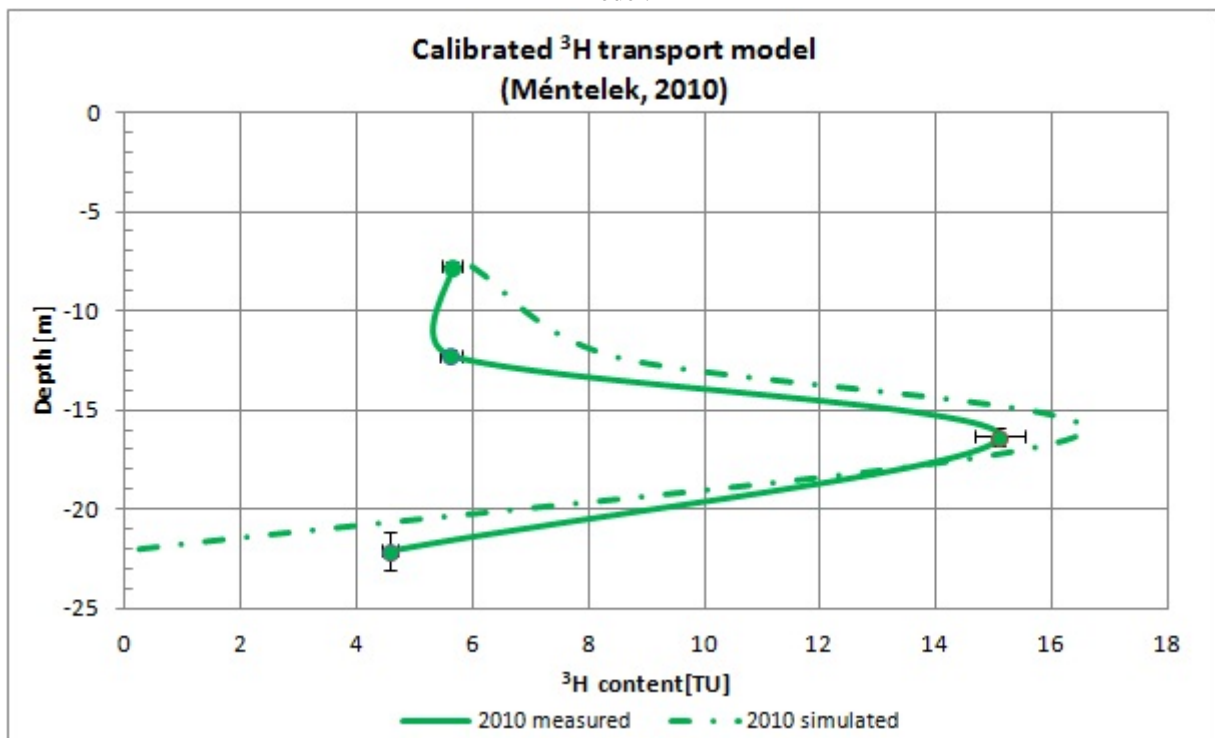


Figure 10. The measured (2010) and calculated tritium profile under the surface based the calibrated tritium transport model.

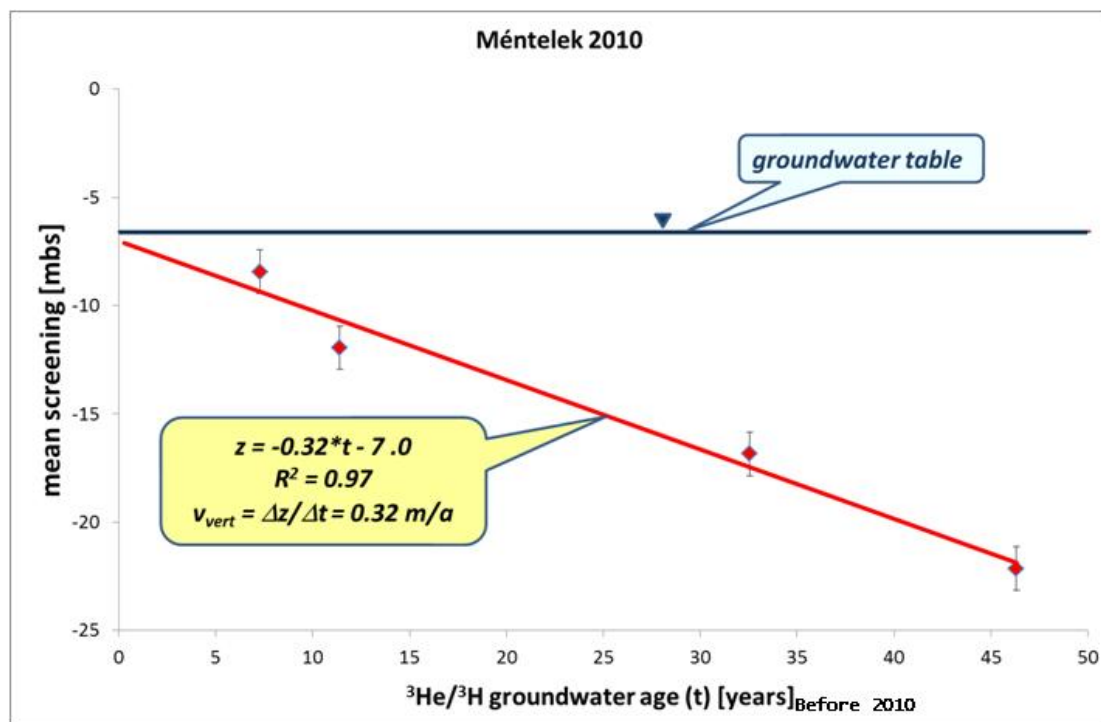


Figure 11. Groundwater ages for different screen depths estimated by $^3\text{H}/^3\text{He}$ dating method.

The “He clock” is starting to operate at the surface of groundwater (at -7 m depth), because in the unsaturated zone the helium is in contact with soil-air so the excess ^3He originating from tritium decay can be degassed.

5. CONCLUSIONS

Nowadays the application of environmental isotopes is one of the most accurate tools for the determination of relative groundwater age. A hydrodynamic and transport model can be a useful and practical solution for the reliable estimation of the natural groundwater recharge conditions. These special calculations are based on the dating of the groundwater. In the demonstrated Hungarian case-study at a recharge area site, the appropriate isotope tool was the tritium technique. With the measured and appropriate data, the transport model was calibrated, so the simulations were accurate and reliable. The obtained results give new information to understand the groundwater flow behavior of the Great Hungarian Plain. On the other hand, it is also turned out that at least 10-11 different depths should be used for tritium concentration measurement to catch the tritium peak in the groundwater.

Acknowledgments

The research was carried out in the framework of the Sustainable Resource Management Center of Excellence at the University of Miskolc, as part of the TÁMOP-4.2.2/A-11/1-KONV-2012-0049 „WELL

aHEAD” project in the framework of the New Széchenyi Plan, funded by the European Union, co-financed by the European Social Fund.”

The research was partly supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP-4.2.2.A-11/1/KONV-2012-0043 ‘ENVIKUT’.

The research was partly supported by the IAEA’s Coordinated Research Project entitled Estimation of Groundwater Recharge and Discharge Using the $^3\text{H}/^3\text{He}$ Dating Technique.

The authors thank Isotoptech Co Ltd. for their contribution in the field sampling and isotope analyses.

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Received at: 14. 02. 2015

Revised at: 01. 07 2015

Accepted for publication at: 19. 08 2015

Published online at: 22. 09. 2015