ISOTOPE INVESTIGATIONS OF GROUNDWATER MOVEMENT IN A COARSE GRAVEL UNSATURATED ZONE

N. MALI
Geological Survey of Slovenia,
Department of Hydrogeology,
Ljubljana, Slovenia

J. KOŽAR-LOGAR
Jožef Stefan Institute,
Ljubljana, Slovenia

A. LEIS
Institute of Water Resources Management,
Hydrogeology and Geophysics,
Joanneum Research Forschungsgesellschaft mbH,
Graz, Austria

Abstract

The unsaturated zone above an aquifer serves as a water reservoir which discharges water and possible pollution to the saturated zone. This paper presents the application of oxygen-18 and tritium isotope methods in the study of groundwater transport processes in the unsaturated zone of Selniška Dobrava coarse gravel aquifer. The Selniška Dobrava gravel aquifer is an important water resource for Maribor and its surroundings, therefore the determination of transport processes in the unsaturated zone is important regarding its protection. Groundwater flow characteristics were estimated using isotopes and based on experimental work in a lysimeter. Tritium investigation results were compared with the results of long term oxygen-18 isotope investigation. In this paper the analytical approach, results and interpretation of $\delta^{18}O$ and tritium measurements in the unsaturated zone are presented.

1. INTRODUCTION

The processes in the coarse gravel unsaturated zone develop quite differently from those in aquifers with finer unsaturated zone granulation. To define hydrogeological properties in a high permeability coarse gravel aquifer, the lysimeter in Selniška Dobrava was constructed. Since 2001, several isotope investigations have been performed. In the first research period, two tracing experiments have been performed using different tracers and deuterated water as a conservative tracer [1].

The long term isotope investigations with oxygen-18 have been realized to define characteristic behaviours of the unsaturated zone processes which cannot be determined in one hydrogeological period or with single sampling. Previous results show that the environmental isotope oxygen-18 is a suitable tool for the quantification of recharge water movement in the unsaturated zone [2]. Based on the $\delta^{18}O$ signal, tracing water movement in the lysimeter is possible. The oxygen-18 isotope composition signal of the precipitation can be traced in the lysimeter samples with some retardation with time and with diminishing amplitudes with depth. The mean residence time of the water in unsaturated zone was estimated by using lumped parameter models [2–4]. We also tried to determinate the processes in the unsaturated zone with tritium investigations. The research is in progress and some results are presented in this paper.

2. AREA DESCRIPTION

Selniška Dobrava is situated in the northeast of Slovenia near Maribor, the capital of the region. The coarse gravel aquifer lies on the north bank of the Drava River (Fig. 1). The aquifer is recharged by the Drava, by infiltration and seepage from the upper terrace aquifer. The thickest coarse gravel deposit is 50 m thick. The groundwater table is found at an average depth of 25 to 37 m, thus the thickness of the saturated layer along the aquifer axis is 7–14 m, possibly even more in the deepest sections. The hydraulic conductivity of the principal aquifer has been reported as 5×10^{-3} m/s [5]. The research area belongs to the moderate continental climate

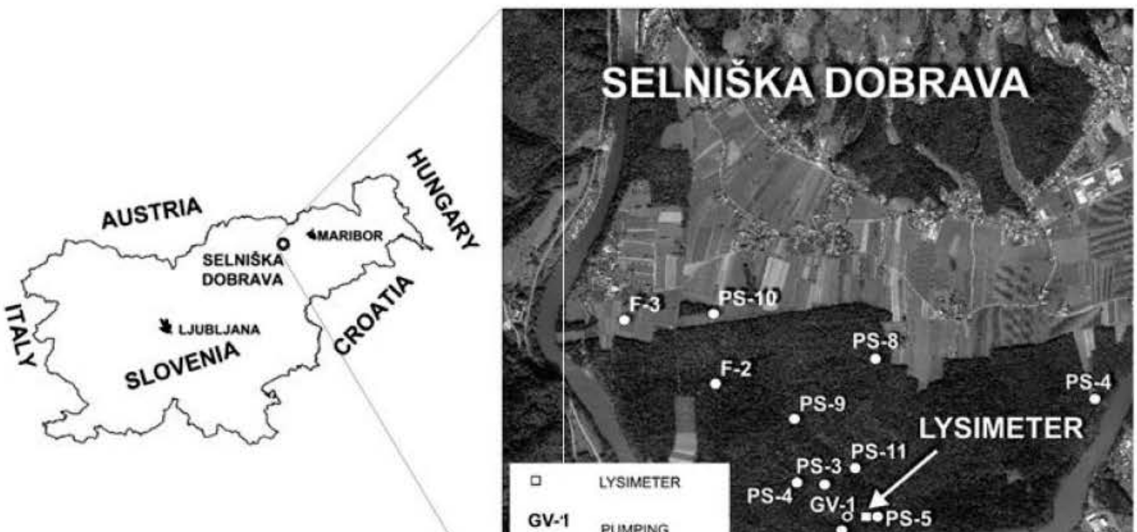

FIG. 1. Study area — location of lysimeter.

of central Slovenia with a typical continental precipitation regime and an average yearly precipitation between 1200 and 1300 mm. The average yearly air temperature lies between 8 and 12° C. In the conceptual model, the lysimeter area is defined as a homogeneous coarse gravel aquifer.

3. METHODS

3.1. Experimental set-up

The lysimeter was designed as a concrete box, dimensions 2 × 2 m, 5 m deep, with 0.2 m thick walls. There are 10 sampling and measuring points (JV-1 to JV-10) positioned according to a randomized design by lysimeter width but at approximately equal distances by depth. Drainage samplers were installed for groundwater sampling in the unsaturated zone. The drains are stainless steel profiles 10 cm × 10 cm, 1.7 m long, with inverse inner perforated profiles and with a water collection system on the end. The closed system was made up of one 400 mL glass bottle and collecting containers. Drains, bottles and collectors were linked with silicone tubes. The precipitation collecting station was used for precipitation sampling at the location. A detailed description of the lysimeter can be found in Refs [1, 2].

3.2. Sampling

Since 2001, over several research (project) periods, samples of groundwater in the unsaturated zone were collected monthly in containers at all ten sampling points (JV-1 to JV-10) at different depths in the lysimeter to determine oxygen-18 isotope composition and, since November 2007, also tritium composition. The water was sampled in plastic bottles of 120 mL volume to determine $\delta^{18}O$ values and in 1 L volume for tritium analysis. Precipitation was also sampled at monthly intervals.

3.3. Measurements

All stable isotope analyses were performed in the laboratory of the JOANNEUM RESEARCH Institute of Water Resources Management, Hydrogeology and Geophysics in Graz, Austria.

Oxygen-18 was measured with a fully automated device for the classic CO_2 equilibration technique coupled to a Finnigan DELTA plus light stable isotope ratio mass spectrometer working in dual inlet mode [6].

Tritium analyses were performed in the Laboratory for Liquid Scintillation Spectrometry of the Department for Low and Medium Energy Physics of the Jozef Stefan Institute in Ljubljana, Slovenia.

The method of electrolytic enrichment was used for sample preparation. Sodium peroxide (Na_2O_2) was added to the sample's distillate with proper pH and conductivity. Electrolytic enrichment ran in the system with 500 mL electrodes (Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, Poland). After a second distillation with $PbCl_2$, the measurements were prepared with 12 mL of scintillation cocktail — Hi Safe 3 or Ultima Gold uLLT, and 8 mL of distilled sample. The samples were stored in Qunatulus 1220 at 18 °C at least 12 hours before measurement. Each sample is counted at least 3 × 100 min to ensure satisfactory low statistic uncertainty. QC samples are measured in the same queue as well.

4. RESULTS AND DISCUSION

Samples for tritium analyses of the unsaturated zone groundwater and precipitation were collected in the period from October 2007 to February 2010. For a detailed observation of groundwater movement in the unsaturated zone, the sampling point JV-8 at 3.4 m below the surface was chosen. The characteristics of the tritium data series was compared with the results of $\delta^{18}O$. Table 1 shows the statistics of monthly measurements of tritium and oxygen-18 in JV-8 and in local precipitation. In both cases the ranges of tritium and $\delta^{18}O$ values are higher in precipitation. Higher tritium content and $\delta^{18}O$ values in precipitation occur in summer time.

The diagrams in Fig. 2 and Fig. 3 show the time series of $\delta^{18}O$ and T compositions of both precipitation and unsaturated groundwater for the sampling point JV-8. Being more complete, the data set of precipitation measurements for Ljubljana was taken for the tritium diagram. Seasonal effects were recognized in both isotope compositions in precipitation. In summertime, the highest tritium content and $\delta^{18}O$ values are detected, and in wintertime, the lowest. The same effect could be traced also in samples from JV-8. The diagrams for both parameters show stronger oscillations in precipitation than in groundwater in the unsaturated zone.

TABLE 1. STATISTICS OF TRITIUM CONTENTS AND $\delta^{18}O$ VALUES

	JV–8 A(TU)	Precipitation A(TU)	JV–8 $\delta^{18}O$(‰)	Precipitation $\delta^{18}O$(‰)
n	22	14	18	24
Mean	9.49	8.10	–8.83	–10.15
Max	10.83	12.90	–7.87	–6.09
Min	7.63	5.16	–10.28	–17.97
Range	3.20	7.74	2.41	11.88

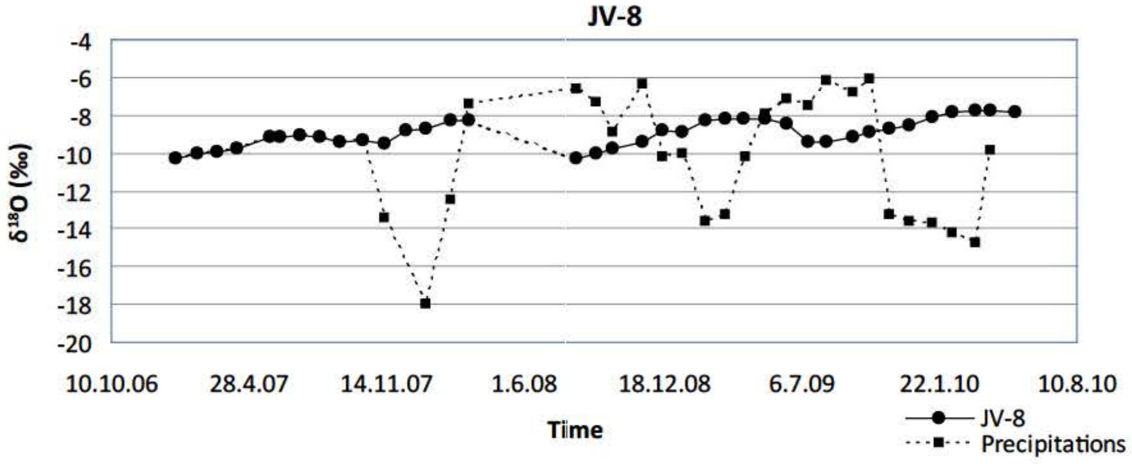

FIG. 2. $\delta^{18}O$ isotope composition plots of monthly sampled water.

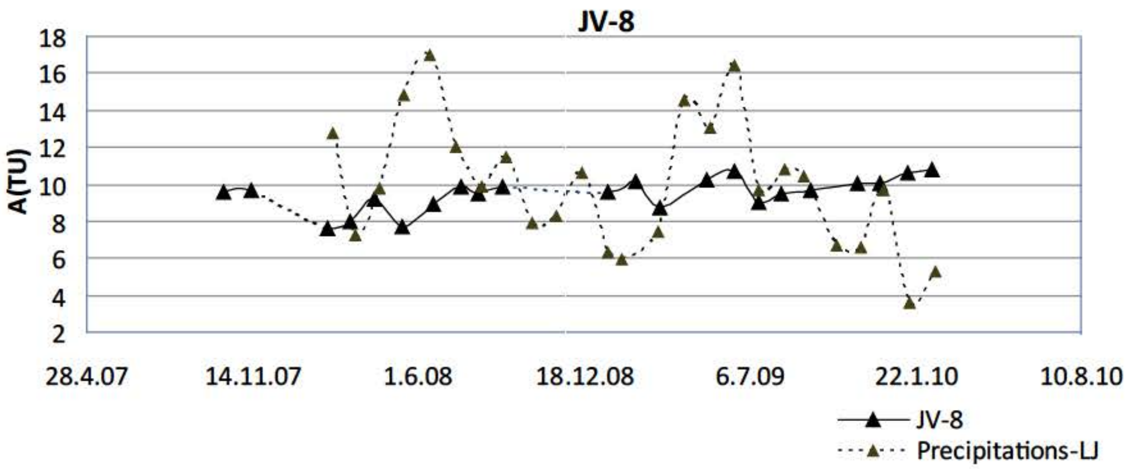

FIG. 3. Tritium content plots of monthly sampled water.

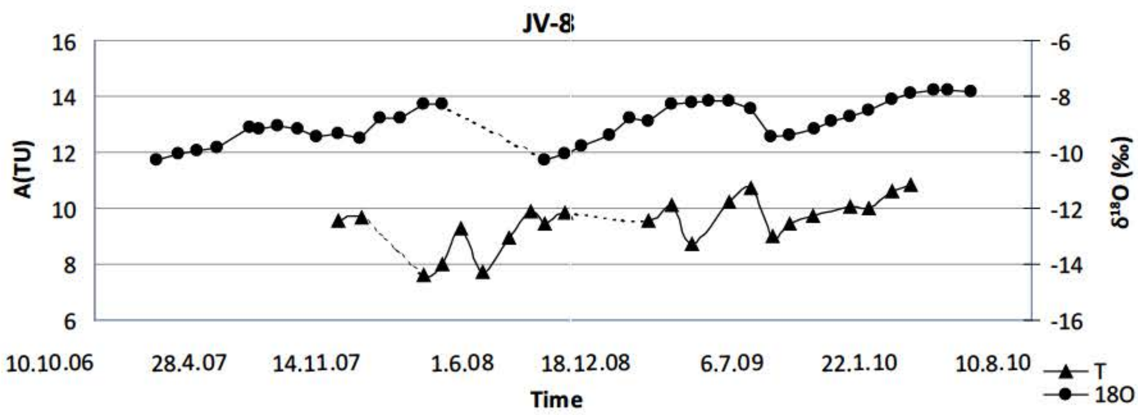

FIG. 4. Tritium and $\delta^{18}O$ isotope composition for JV-8.

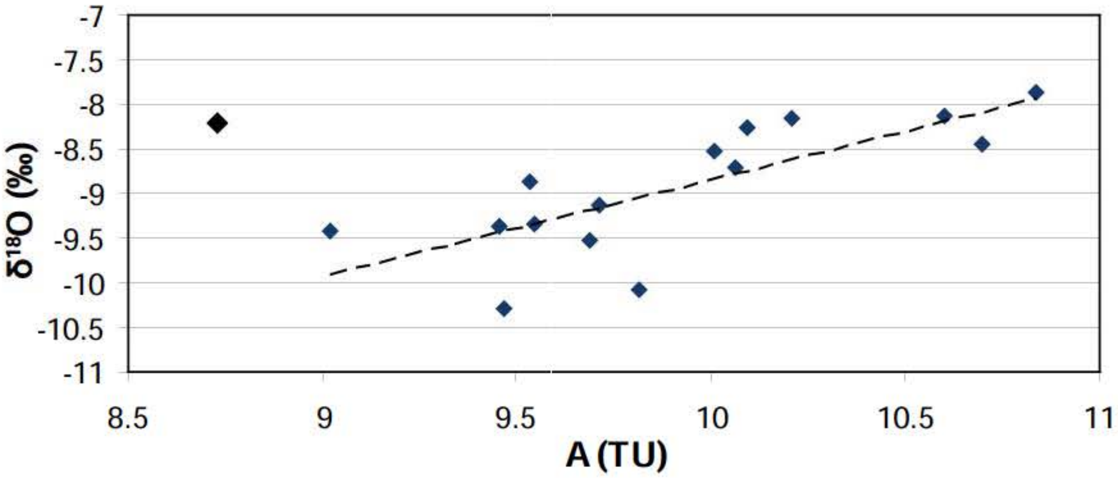

FIG. 5. Relationship between tritium and $\delta^{18}O$ contents.

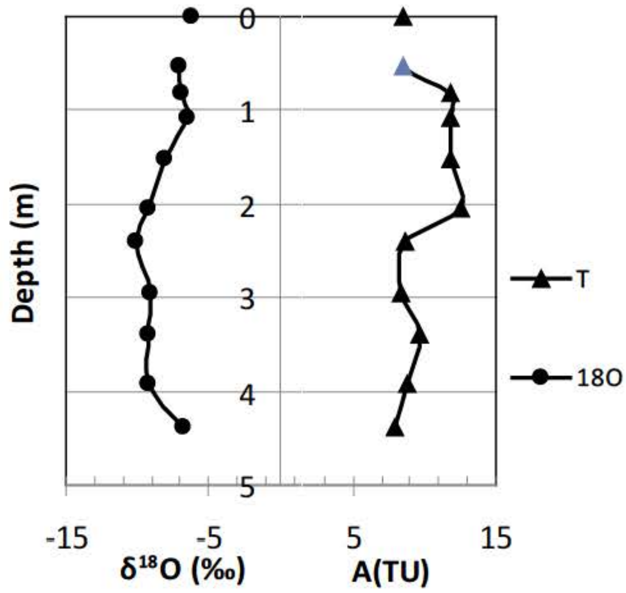

FIG. 6. Depth profile of $\delta^{18}O$ and tritium contents.

Previous oxygen-18 investigations of groundwater movement and the unsaturated zone indicate that peak precipitation values (summer or winter signal) were detected in unsaturated zone sampling point measurements in reduced amplitude with depth. Peak values were also observed to be retarded with depth. Peak (winter) precipitation signal of the $\delta^{18}O$ values in the observed dataset was detected at the observation point JV-8 over 5–6 months. The peak in the precipitation data series is not so significant in the tritium dataset. In Fig. 4. the comparison of both isotope values is presented in a diagram at the same time scale. The diagram of tritium values is not so smooth and clearly formed. The diagram in Fig. 5 shows the dependency of tritium and $\delta^{18}O$ measurements. A correlation between both isotope values is recognizable and a similar behaviour can be assumed.

For a detailed observation of water movement through the unsaturated zone, based on tritium measurements, samples from all observation points were analysed on the 16th of September 2009. The profile of tritium values by the depth on the chosen date is shown in Fig. 6. In the same diagram the $\delta^{18}O$ composition profile on the same date is compared. Both diagrams show that, based on tritium and $\delta^{18}O$ signals, the tracing of water movement in the coarse gravel unsaturated zone is possible. The signal of the positive values (summer) was recognized in sampling points lying in the upper part of the lysimeter, down to 1–2 m depth. In the following part of the profile (2–3 m depth) more negative values were observed. The isotope characteristics of the water in the deepest part of the lysimeter showed more homogenised water.

5. CONCLUSIONS

The aim of this study was to describe transport processes in a coarse gravel unsaturated zone by means of the isotope tritium. Isotope oxygen-18 has already proven a suitable tool for the quantification of recharge water movement in the unsaturated zone, and was therefore chosen for comparison. Results show that based on both signals, the tracing of water movement in the unsaturated zone is possible. Isotope composition signal can be traced in the lysimeter water samples with some time retardation and with diminishing amplitude with depth. The groundwater dynamics in the unsaturated zone are highly dependent on the precipitation rate. Each hydrogeological year has its own characteristics in groundwater dynamics in the unsaturated zone, necessitating more analytical data and hence the need to continue with tritium isotope research. It is difficult to afford an equal number of analyses for the oxygen-18 and tritium isotopes. Based on the existing set of samples from the lysimeter, more tritium analyses for different observation points will be preformed and all the results will be evaluated once more. A more complete and longer dataset of tritium analyses will also be used to estimate the mean residence time with lumped parameter models. The results will be compared with the findings of previous studies of processes in a coarse gravel unsaturated zone at the same lysimeter.

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