Proceedings of the 4th Mini Conference on Noble Gases in the Hydrosphere and in Natural Gas Reservoirs held at GFZ Potsdam, GERMANY, 28.02.-02.03.2007

Groundwater dating with the aid of tracers: strategies, pitfalls and open problems

A. Zuber[1], K. Rozanski[2]

[1]Polish Geological Institute, Carpathian Branch, ul. Skrzatow 1, PL-31560 Krakow, Poland
[2]AGH University of Science and Technology, Al. Mickiewicza 30, PL-30059 Krakow, Poland

Short-term multi-tracing versus time series of tritium

Transient tracers (^{3}H, ^{3}H/^{3}He, ^{85}Kr, CFCs and SF_6) are commonly employed to investigate young waters in phreatic aquifers. Nowadays, two contrasting sampling strategies are in use: (i) several transient tracers are sampled over a short period of time, and (ii) tritium is sampled over extended period of time (up to several years) in addition to other tracers. The first approach is often favoured due to a short duration of projects. In such cases, the piston flow model (PFM) and/or binary mixing model (BM) is usually adopted to interpret the transient tracer data. The tracer age obtained from the PFM, called the apparent age, is regarded as hydrogeological parameter in spite of its inadequacy to yield residence time distributions (RTD) of converging flows in abstraction wells and springs. In contrast, tritium time series obtained in the second approach are adequately interpretable by box or numerical models, which yield RTD functions for individual sampling sites.

For wells abstracting young waters, very wide RTD functions are usually observed, which often lead to mixing between water containing transient tracer(s) with older tracer-free water. Mixing ratios of these two types of water can be obtained from the integration of the RTD functions [1, 2]. Such mixing ratios are time dependent and involve waters of the same chemistry. In practice, it is more important to identify mixing between waters of different origin, usually obtainable from stable isotope and Cl^- data, or of distinctly different ages. For instance, in one of the wells in the unconfined part of Cracow Malm limestones, tritium data yielded the mean age of 40 a for the young component, and 70% of tritium-free water. The presence of that older component was confirmed only by relatively high $^4He_{exc}$ (32×10^{-8} cm^{3}STP/g) [3]. Similarly, in two of the wells in the unconfined part of Triassic carbonates in the Upper Silesia, tritium and $^4He_{exc}$ data also showed two-component mixing of modern water with much older pre-bomb era Holocene water. In both aquifers, $^4He_{exc}$ in other wells with modern waters was very low ($<1\times10^{-8}$ cm^{3}STP/g), though components of the pre-bomb era were present as deduced from the RDT functions found from tritium data.

Disagreement of ages and models

For the ^{3}H/^{3}He method, the zero age is at the water table, whereas for the tritium method, the dating starts already at the ground surface. Consequently, both methods yield different ages. Similarly, the ^{3}H+^{3}He method is applicable only if the water table is very shallow. In other cases, the escape of tritiogenic ^{3}He from the unsaturated zone leads to false ages.

Combined interpretation of ^{3}H and ^{85}Kr is sometimes used to obtain both the age of water and the fraction of pre-modern water [4]. The same approach can be used for tritium combined with other gaseous tracer. However, one should keep in mind that this approach is valid only for shallow water tables. In other cases, ^{3}H yields ages which include the time of travel through the unsaturated zone, whereas for gaseous tracers that time is usually negligibly short. Consequently, interpretation based on the (gaseous tracer)-^{3}H relationship for any specific model (usually PFM, EM or binary mixing model) will lead to false conclusions, as the RDT functions of both tracers

DOI: 10.2312/GFZ.mga.027

differ as being described by different models, such as EM for a gaseous tracer, and the dispersion model or the PFM in line with the EM for ^3H [1, 2].

Hydrodynamic age versus tracer age

Tracer and hydrodynamic ages often distinctly differ due to diffusion of tracers to stagnant water zones, such as the porous matrix in fissured rocks. However, they may also differ considerably in porous aquifers, if the flow patterns change. This stems from the fact that tracer steady state in the system is obtained after a much longer time then a new hydrodynamic steady-state resulting from a change in the withdrawal rate and/or a change in the recharge rate.

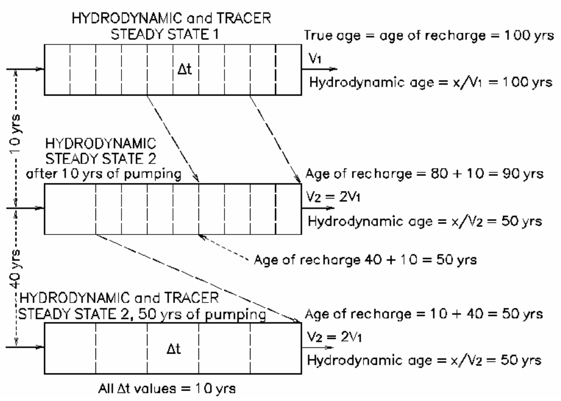

Fig. 1. Schematic model of three stages of piston flow through a column [2].

In the example shown in Fig.1 (upper row) both hydrodynamic and tracer ages are 100 years at the outlet. After 10 years of intensive abstraction a new hydrodynamic steady state is obtained (middle row), but any tracer will exhibit an unsteady age, greater than the flow age. Only after 50 years of withdrawal both ages are again the same, though much lower than those in the pre-exploitation era (lower row).

Much greater age differences may occur, if discharge by seepage changes to recharge as shown in Fig. 2, which roughly presents conditions of some wells described in [1]. Similar situation is also observed in Oligocene sands of the Mazovian basin, central Poland, which are recharged and drained by seepage through Pliocene silts and clays. In the central part, a multi-tracer approach (mainly $\delta^{18}O$, $\delta^{2}H$, ^{14}C and ^{4}He) yielded ages above 10 ka, whereas the hydrodynamic modelling yielded ages below 1 ka [5]. These large age differences can be reconciled if one takes into account that intensive abstraction changed slow drainage rates to faster recharge rates. If the travel time of seepage is of the order of 0.8 ka, tracer ages observed in the Oligocene will remain the same or become even greater for a very long period of time [2].

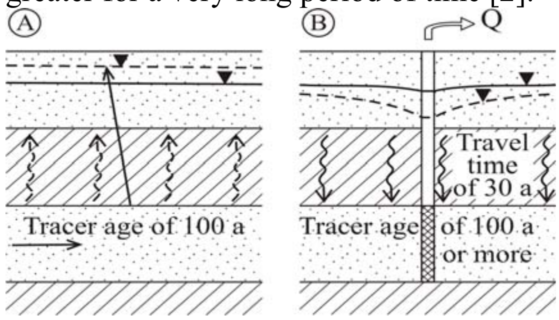

Fig. 2. When the abstraction starts, the hydrodynamic age may significantly decrease whereas the mean tracer age will increase due to back-flow from the aquitard [2].

Acknowledgements

Partial financial support to K.R. through statutory funds of the AGH University of Science and Technology (project No. 11.11.220.01) is kindly acknowledged.

References

[1] A. Zuber, S. Witczak, K. Rozanski, I. Sliwka, M. Opoka, P. Mochalski, T. Kuc, J. Karlikowska, J. Kania, M. Jackowicz-Korczyński M. Duliński. Hydrol. Proc. 19: 2247-2275, 2005.

[2] A. Zuber, W. Ciezkowski, K. Rozanski (Eds), Tracer Methods in Investigations of Groundwaters (in Polish). Technical University of Wroclaw. Wroclaw 2007.

[3] A. Zuber, S.M. Weise, J. Motyka, K. Osenbrück, K. Rozanski. J. Hydrol. 286: 87-112, 2004.

[4] P.G. Cook, A.I. Herczeg (Eds). Environmental Tracers in Subsurface Hydrology. Kluwer Acad. Publ., Boston 2000.

[5] A. Zuber, S.M. Weise, K. Osenbrück, H. Pajnowska, J. Grabczak. J. Hydrol. 233: 174-188, 2000.

DOI: 10.2312/GFZ.mga.027