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Multi-tracer data and groundwater modelling from modern to glacial ages: a case study in southern Poland

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Environmental tracers, including noble gases, are powerful tools for quantifying timescales of groundwater flow. They are also often employed in the process of calibration and/or validation of numerical flow and transport models.

The Bogucice Sands aquifer, southern Poland (Fig. 1) was investigated under EU research project [1]. It constitutes a typical Tertiary structure of deltaic origin, recharged at the outcrops in the south and discharged by upward seepage through the confining cover to Pleistocene sands in the north. Multi-tracer approach involving ^{3}H, ^{3}He, ^{4}He, ^{85}Kr, CFCs, SF_6, $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$, ^{14}C, ^{37}Ar and ^{39}Ar was used to determine groundwater ages by lumped-parameter modelling and to improve the numerical flow and transport models of the system. Heavy noble gases measured by gas-chromatography and mass-spectrometry provided noble gas temperatures (NGT) for selected wells. Among 35 wells sampled for hydrochemistry, 25 were sampled for selected tracers and 15 were repeatedly sampled over the period of several years, mainly for ^{3}H.

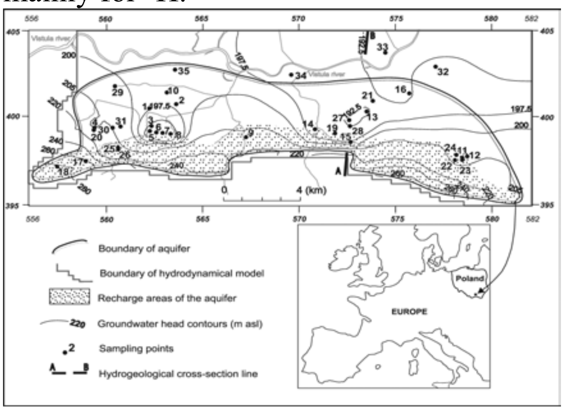

Fig. 1. Simplified hydrogeological map of the investigated groundwater system [2].

The results of tracer study and modelling focussing on the aquifer zone occupied by modern waters were reported in [2, 3, 4]. Within the present work, preliminary results obtained for the zones occupied by pre-modern waters are presented. Some findings from the earlier work are also recalled, especially in comparison with determinations of ^{85}Kr content and $^{3}H/^{3}He$ ratio in some wells.

Spatial distributions of ^{3}H and ^{14}C shown in Fig. 2 allow qualitative assessment of the timescales characterising the studied aquifer. It is apparent that while ^{3}H distribution is strongly influenced by abstraction wells in and close to the recharge area, the ^{14}C distribution still maintains natural pattern, with gradually decreasing ^{14}C content towards the discharge area.

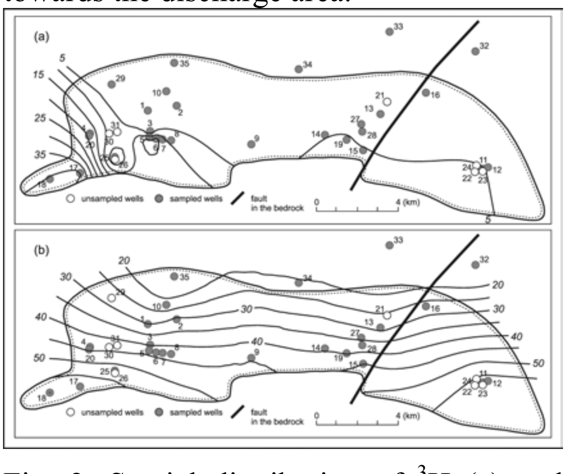

Fig. 2. Spatial distribution of ^{3}H (a) and ^{14}C (b) measured in 2000-2001, with isolines of ^{3}H in TU and ^{14}C in pmc [4].

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Typical ^{14}C contents in modern waters were 35-66 pmc, whereas in wells Nos 32-34 they dropped below 0.5 pmc, with $\delta^{18}O$, $\delta^{2}H$ and NGT values characteristic for recharge under cooler pre-Holocene climate. Assuming that initial ^{14}C content in the system is 42±12 pmc, and that the waters with lowest ^{14}C content have the age of ca. 12 ka, an effective half-life of ^{14}C in the order of 2 ka is obtained [4]. That half-life results from radioactive decay and isotope exchange of ^{14}C with carbonates present in the matrix. Although quartz is the main component of aquifer material, the carbonate content ranges from 3–10% in sands and 25–30% in sandstones. This apparent half-life of ^{14}C was confirmed by ^{40}Ar ages determined for six selected wells. Therefore, the ^{14}C and ^{39}Ar data may serve as calibration tools for the flow and transport model of the system, within the zones containing pre-modern waters.

Wide distributions of water ages, represented by RTD functions, are usually observed in abstraction wells, strongly influencing the concentration of transient tracers and pollutants, particularly in and close to recharge areas. The RTD function obtained for well No 7 represents modern water (^{3}H contents >10 T.U.) whereas that of well No 13 represents practically tritium-free water (Fig. 3). The later was obtained from the transport model by assuming an instantaneous appearance of a conservative tracer over the whole recharge area. Young waters are very often mixtures of water containing tracer(s) with tracer-free water in proportions easily obtainable from the RTD function. These mixing proportions are generally functions of time [2], which means that often used binary mixing models are not time-invariant.

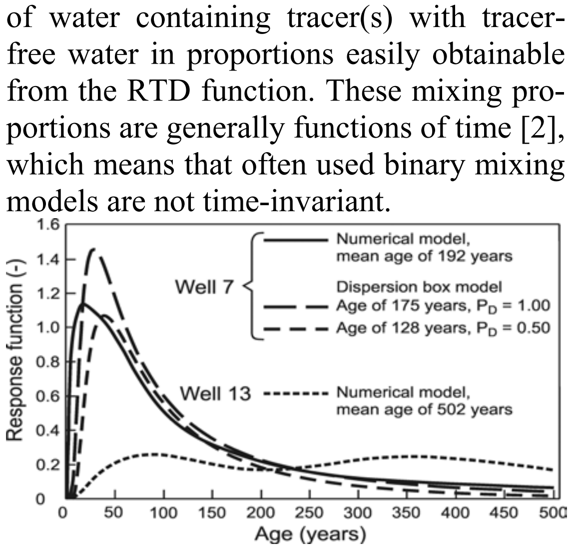

Fig. 3. Examples of RTD functions obtained from numerical and box models [3].

^{85}Kr and $^{3}H/^{3}He$ were measured in two wells in the recharge area, yielding ages of ca. 20 and 35 years, whereas tritium data yielded mean ages of ca. 60 and 160 years, respectively, for models indicating very wide RTD functions extending up to several hundred years. For the well with mean water age of 160 years, $^{4}He_{exc}$ of 1.7×10^{-8} cm^{3}STP/g confirmed the presence of old component. Knowledge of RTD functions obtained either from the interpretation of tritium data, or from numerical modelling, or from both, leads to a better understanding of the aquifer response to existing or potential pollution hazards.

For some wells situated in and close to the recharge area, the simulated concentrations of transient tracers were in disagreement with the measured concentrations, even after recalibration of the numerical models, indicating the need for further improvement of the conceptual model.

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