7 OUTLOOK TO FURTHER APPLICATIONS

This volume refers to results demonstrating the necessity of a combined use of isotopic, hydrochemical and hydrogeologic methods to understand the dynamics of groundwater systems and to assess man's impact on water fluxes and quality. This field is expanding and isotopic tools are developing to conquer new fields of applications.

Microbial activities in groundwater are more pronounced than recognised till now. They contribute to self-purification or natural attenuation processes quite efficiently and may help to assess the resilience or elastic response of subsurface waters to pollution. They thus play an important role in defining sustainable measures of groundwater protection.

Microbial disintegration processes also lead to isotope fractionation, as is well known from the reduction of nitrogen or sulphur. In some cases isotopic investigations may play a significant role in recognising the reaction space in an aquifer where reduction reactions take place as, for instance, in biofilms or in the matrix pores with very low hydraulic conductivities. In these cases measurement of the redox potential in the groundwater suggests oxidative conditions while the N and S isotopes point to reduction processes taking place in a turnover space with low water quantities.

A quite similar field of application of stable environmental isotopes has been started recently by using ^{13}C, ^{14}C, by Vengosh et al. (1991, 1994) and Eisenhut & Heumann (1997) using ^{11}B, by Hiscock et al. (1997) using ^{15}N-isotopes, and by Hallas & Trembaczowski (1998) using ^{34}S-isotopes, as finger prints of eother synthetic or natural chemicals applied near groundwater resources. As far as they do not undergo coupled fractionation and microbial disintegration, they can be utilised to localise their access to and behaviour in the subsurface. It is evident that such investigations should be linked to species related chemical analysis.

Recent investigations (Rau 1999) also proved that the combined evaluation of stable isotope results might lead to a better understanding, if conceptual hydrogeologic models are appropriate or need modification. This should not only control isotope-based model concepts but should also become introduced in numerical hydraulic modelling.

There are many types of mathematical models to simulate and predict water flow and the related behaviour of pollutants in the unsaturated and saturated zone. Some of these are little parameterised and allow lump assessments, others are highly parameterised and mostly suffer from a lack of direct field data. Instead the missing field data must be provided by statistical extrapolation. First attempts to link isotopic data to numerical models (Andres & Egger 1983) are promising. The advantage of introducing environmental isotope results in numerical models is illustrated by the following. Most hydraulic data represent both instantaneous information on the spot. Since advanced hydraulic models on flow and pollutant transport are multi-parameterised, the calibration of such models can be fitted in different ways by respective parameter variation. In case of extrapolation of these calibrated models to other boundary conditions they may fail, because parameters have not be adequately used to calibrate the model. Therefore, environmental isotope results may be used for model calibration and add time- and space- integrative views to the evaluation.

Groundwaters have an isotopic and chemical stratification, that originates from (i) the type of groundwater flow, (ii) the half-life of radioactive environmental isotopes used, (iii) the impact of climate changes on the isotopic and chemical input functions, or (iv) the time-related exchange processes (e .g. ion exchange). Under certain conditions such changes may not be documented in water level changes but expressed in chemical and isotopic changes (Sect.2.1.3). In systems with small turnover times this stratification has usually no significance; in slowly moving systems, however, strategies of groundwater management will change the flow regime over a long period of time. The rate and direction of such changes can be monitored by changes in the isotopic or chemical composition of the water, and be evaluated by appropriate mathematical models. Especially the combination of monitoring of non-reactive tracers and mathematical modelling leads to an early-warning assessment, supporting measures to avoid access of pollutants or arising soil/rock mechanical problems (subsidence) which are mostly irreversible.