

## Application of isotope hydrology to groundwater problems in engineering geology

P.J. Leggo, C.D. Warren & D. Blakeway

**ABSTRACT:** Research on the natural variation of the isotopic species of hydrogen and oxygen has led to a firm understanding of the physical processes involved in the isotopic fractionation of these elements in water. Although much use has been made of artificially introduced chemical tracers to investigate flow patterns and characterise the groundwater, this method commonly suffers from bulk dilution and additional problems that limit its applicability to many investigations in engineering geology. Such limitations are avoided in the use of stable isotopic measurements as it is the variability in the isotopic species of the water molecule itself that are used as the characterisation parameters providing a 'fingerprint' for each particular water sample.

In this paper background details of stable isotopic fractionation are summarised and two recent case histories presented to demonstrate its application to groundwater studies, on a small scale, commonly met in many civil engineering situations, namely investigation of possible leakage from a reservoir and identification of the source of water contained within a large landfill. By the seasonal variations in the isotopic values, trends in groundwater isotopic composition can be identified and interpreted within the often limited geological and hydrogeological constraints of the site so as to provide conclusions as to the origin of the groundwaters.

### Introduction

In recent years increasing use has been made of the distribution of the various isotopic species occurring naturally in water, particularly where the introduction of chemical tracers suffers from the problem of bulk dilution (Siddle *et al.* 1984), or may be considered unacceptable if the reservoir or groundwater source is for consumer use. Interpretation of isotopic data can provide information on source of water, flow path, velocity, mechanism of recharge, chemical mixing and the age of the water. Isotopes commonly measured in water include the stable isotopes of oxygen, hydrogen and carbon, usually expressed as relative isotopic ratios  $^{18}\text{O}/^{16}\text{O}$ , D/H (D refers to deuterium or  $^2\text{H}$ ) and  $^{13}\text{C}/^{12}\text{C}$  respectively, and the radioactive isotopes of tritium ( $^3\text{H}$  or T) and carbon ( $^{14}\text{C}$ ).

Research on the natural variation in the isotopic composition of hydrogen and oxygen has led to an understanding of the isotopic fractionation of water that occurs during the meteoric cycle. In general the isotopic fractionation of hydrogen and oxygen occurs during every phase transformation and the meteoric cycle has been likened to a giant multi-stage distillation column (Epstein & Mayeda 1953). It is well established that fractionation patterns produced by evaporation and condensation of water in the lower atmosphere are preserved in precipitation and their accurate measurement provide parameters which can be used for the characterisation of water. Due to the higher vapour pressure of  $\text{H}_2^{16}\text{O}$  relative to

$\text{HD}^{16}\text{O}$  and  $\text{H}_2^{18}\text{O}$ , water vapour becomes enriched in the lighter molecule during evaporation and similarly during condensation the liquid phase becomes enriched in the heavy species. In this way repeated evaporation and condensation leads to progressively lighter isotopic values in the vapour phase.

The degree to which any particular rain is isotopically fractionated is a function of many variables but the main controlling influence of air temperature has been known for some years. (Dansgaard 1964). The isotopic composition of rain is also controlled, to various degrees, by such factors as: physiographic relief, latitude, inland distance and rainfall amount, and worldwide studies have shown that seasonal variations in air temperature can be directly correlated to systematic variations in isotopic composition. Thus rainfall at colder temperatures, higher altitudes and latitudes, and greater distance from the ocean will be characterised by isotopically light  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values (see below for terminology). The dependence of  $\delta^{18}\text{O}$  values on altitude has been found to be from  $-0.13$  to  $-0.3\%$  per hundred metres (Evans, 1982). Such isotopic effects produce variations often orders of magnitude greater than analytical variance and can be used to characterise water from differing environments.

### Isotope hydrology

In order to characterise the water so as to provide some clue to its source, one first has to measure the

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