

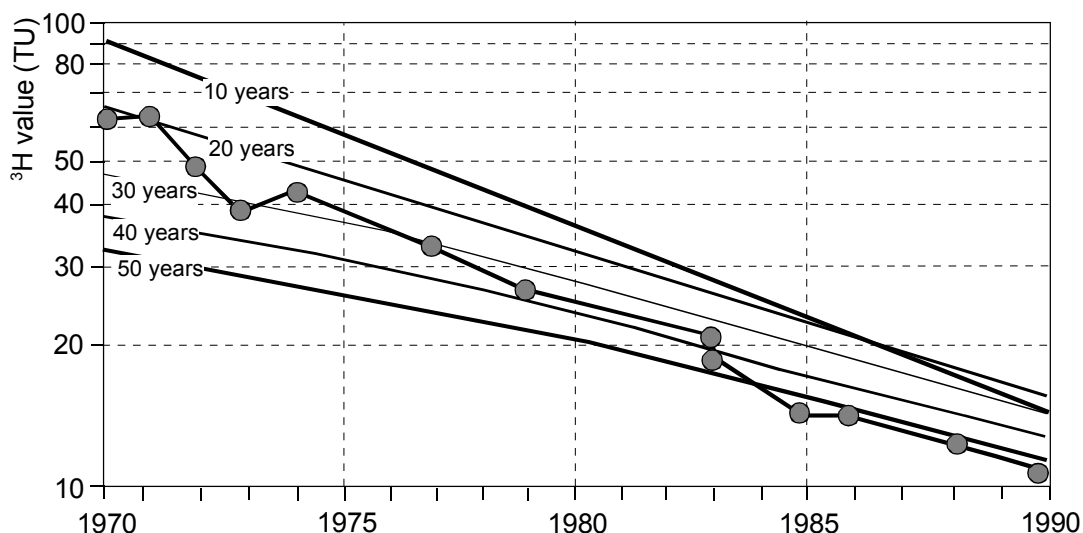
# 7 PLANNING AND PERFORMANCE OF MULTIPLE ISOTOPE STUDIES

In Fig.3.1 (Chapter 3) the most simple geohydraulic conditions are shown, described by the piston-flow model and the exponential model. In nature the conditions are generally more complicated. Young water may be admixed to very old water. Leakage between aquifers may result in mixtures of differently old groundwaters. In such cases measured and modelled isotope data often deviate from each other. To overcome this problem trial and error procedures are applied using different model conceptions (e.g. by applying the MULTI program; Richter et al. 1993). A final agreement between these two values does not mean that the model is a good reflection of natural conditions (Oereskes et al. 1994; Maloszewski and Zuber 1993, 1998).

There are many attempts to express a close agreement between modelled and measured isotope data as a good approximation of the actual situation. An example is the long-term record of the stable isotopic composition of the Fijeh spring in the Antilebanon mountains (Kattan 1996b). Even a slight disagreement shows that a model cannot be applied and a completely deviating geohydraulic constellation may exist. In this case the approximate estimate of a mean residence time is hydrogeologically misleading. The proposed explanation of the deviation between the model and the observed isotopic composition is then unsatisfactory (Fig.7.1).

In order to understand the hydrogeological system two or even more independent isotope determinations are required, combined with hydrochemical analyses. The fact is that the applicability of the model is not proven by an apparent agreement between the model result and the data obtained. As the above mentioned example demonstrates that a long-term monitoring of one isotope instead of multiple isotope analyses may give evidence for such disagreement. On the other hand, it still may not allow to understand the actual geohydraulic situation of the system. Hence serious case studies in isotope hydrogeology usually consist of a wide spectrum of techniques (e.g.  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{36}\text{Cl}$ ,  $^{85}\text{Kr}$ ; Bath et al. 1979; Andrews et al. 1984; Phillips et al. 1989; Verhagen et al. 1991), in order to describe a realistic geohydraulic situation with more than one groundwater component. The occurrence of groundwaters of different age in the same hydraulic system requires independent information on different time scales. That is why *multiple-isotope analyses* are usually essential. An example is the determination of the mean residence time (MRT) of young groundwater by means of the exponential model or any other lump-parameter model (Sect.3.1.2; Volume VI). Using complementary  $^{14}\text{C}$  and  $^3\text{H}$  analyses of the same water samples, two unknowns exist – the

mean residence time (MRT) and the initial  $^{14}\text{C}$  activity  $C_{\text{init}}$ . Time-series of these isotope data yield more accurate and reliable estimates. Moreover, it is recommended to analyse samples of as many as possible sites of the same catchment, in order to check which interpretation model yields the best fit to the data.



**Fig.7.1** Temporal trend of the  $^3\text{H}$  value of groundwater discharged from the Fijeh spring in the Antilebonaon mountains. The discrepancy between modelled (lines) and the measured  $\delta$  values (open circles) shows (Kattan et al. 1996b) that the exponential model cannot be applied to estimate a mean residence time which would be geohydraulically misleading.

Any multiple isotope hydrological study can only develop its full potential if there is a lack of hydrogeological information or the hydrogeological questions are very specific. When planning such an *applied hydrological study* the first question is if there are sufficient funds and time .

In case of a *scientific study* as many as possible isotopic and hydrochemical analyses are to be carried out and The time of sampling should be extended over at least one hydrological cycle of 12 months. The goal is usually to understand the whole system without answering specific hydrological questions. One of the best examples is the most comprehensive multi-isotope study which was conducted in the marly sandstones of southern England (Andrews et al. 1984). The aim was to assess the value of individual environmental isotopes for establishing hydrogeological data. The results confirmed that  $^3\text{H}$  and  $^{14}\text{C}$  activity measurements along with the determinations of the stable isotopic composition of carbon, hydrogen and oxygen provide practically all information of hydrogeological interest to be expected from environmental isotope methods, provided hydrochemical analyses are implemented.

The applied *isotope hydrological studies* usually suffer from the shortness of the period available for sampling and often also from restricted financial resources (Verhagen et al. 1991). On the other hand, the hydrogeologically interesting questions are often well-defined.

The limitations require a thorough planning including all information on the site to be studied:

The *size* of the region and the distance of the sampling sites defines the required age resolution and possible influence of the continental effect on  $\delta^{18}\text{O}$  (Sect.5.2.1.1).

The *morphology* determines whether or not the altitude effect on  $\delta^{18}\text{O}$  (Sect.5.2.1.1) may play a role, allowing a rough estimate of the tracer velocity of groundwater in relation to the required age resolution.

The *sampling sites* may be drilled or dug wells. The pumping rate and the totally abstracted amount of groundwater may be important to estimate if groundwater mining has occurred that may have modified the  $^{14}\text{C}$  ages of groundwater DIC (Sect.5.1.2.3). In the case of springs the fluctuation of the spring discharge during one hydrological cycle may allow to decide whether or not a spot sampling is sufficient or sampling and analysis is required in short distances (e.g. month or weeks).

The *hydrogeological situation* of the study region (unconsolidated sediments, fractured rocks, phreatic or confined aquifers, leaky aquifer systems) allow to resolve what age range of the groundwater has to be expected, how many groundwater components with what estimated age have to be expected in order to decide how many and which isotopes should be analysed.

The *geohydraulic conditions* are reflected by the piezometric surface of the groundwater in different aquifers and allows reliable estimates of the tracer velocity and expected flow directions. Based on this the minimum and maximum distance of the sampling sites can be determined.

The *palaeohydrologic situation* of the study is important to set up the spatial distribution of the sampling sites, this in order to get an impression whether or not steady-state or non-steady-state geohydraulic conditions have to be taken into account in the interpretation of the isotope date (Verhagen et al. 1991).

The *hydrochemistry of the groundwater resources* is important in order to recognise if hydrochemical analyses are indispensable for a hydrochemical correction of the isotope compositions ( $^{14}\text{C}$ ,  $^{13}\text{C}$ ) (Volume I; Clark and Fritz 1997), in order to correct and to calibrate the time scale of groundwater.

Based on this information and on the hydrogeological questions an optimum sampling and analytical program is to be established. The main aims are determining:

- 1) the *age* of the *groundwater* where the determination of relative water ages is sufficient for checking or calibrating the geohydraulic model results. Tracer velocities, groundwater recharge rates, regional aquifer parameters (hydraulic conductivity, total porosity), mixing proportions, or contributions to the groundwater budget can be obtained with

conventional  $^{14}\text{C}$  ages of the groundwater DIC. Palaeoclimatic information to be used for numerical model calibration requires absolute ages. This requires the estimating the initial  $^{14}\text{C}$  activity and thoroughly making hydrochemical analyses in order to exclude or to correct secondary changes of the isotopic composition. This is also necessary if the pollution potential of an aquifer has to be substantiated.

- 2) the *origin* of the *groundwater*, possibly allowing to make mixing balance studies, to localise the recharge areas or to determine and distinguish between the participating groundwater components.

Comparing the estimated costs of sampling and analysis, and possibly of data interpretation, an optimal *multiple-isotope programme* can be set up. The quality finally determines the hydrogeological value of the isotope hydrological contribution.