XA9848337

THE IMPORTANCE OF TRACER TECHNOLOGY IN COMBINED BOREHOLE INVESTIGATIONS

H. ZOJER
Institute of Hydrogeology and Geothermics, Joanneum Research, Graz, Austria

Abstract - *In an experimental field for a waste disposal site, investigations have been carried out applying methods from geology, hydrology, hydrogeology, hydrochemistry, environmental isotope hydrology and tracer technology. All data obtained result to a dynamic drainage model of groundwater. The combined interpretation of borehole data guarantees a high-grade knowledge of groundwater exfiltrating to the surface drainage, which enables proper control measures of the disposal site and an effective groundwater protection.*

1. HYDROGEOLOGICAL BACKGROUND

A proper interpretation of borehole data requires combined investigations that include tracer methods. Conventional data are limited and only available from the geological description of strata, as well as pumping tests, while in some selected cases, only data derived from geophysical logging. In an experimental field, investigated for a potential waste disposal site in Upper Austria, a reasonable number of boreholes have been drilled (Fig. 1). The geological structure is defined by Neogene layers, mostly consisting of extensive sand and clay sequences. In almost all geological units, fissures and joints having widths up to some centimeters appear locally. The main tectonic fractures are directed at WNW-ESE, accompanied by secondary joints indicating tension processes along that fault zones. Therefore, the main pre-conditions for the permeability are controlled by a net of joints and fissures while porosity of the media is of secondary importance for the flow of groundwater.

There is no doubt that permeability, as a main aquifer parameter, gives evidence for the understanding of solute transport phenomena. Investigations of permeability showed values in the magnitude of 10^{-11} and 10^{-3} m/s. The wide scattering of data is due to: a) the intercalation of porous and fissured parts of the aquifer; and b) the different evaluation methods like pumping, flow meter, packer and tracer tests as well as on geophysical borehole logging and soil mechanic indications.

Regular measurements of groundwater level and spring discharge were performed and provide indications on the flow pattern of groundwater (Fig.1), but they must be considered insufficient for the determination of the local catchment. Small seasonal fluctuations of groundwater level have been observed near spring outlets representing the discharge zone and at boreholes with a considerable thickness of the unsaturated zone, thus damping vertical flow processes. However, these effects have not been generally recognized but only as indicators of preferential flow conditions in the recharge area of the aquifer.

2. AQUIFER DYNAMICS

The water cycle implies the concept, that water, infiltrated to the underground, is re-emerging to the surface after a certain turnover time and in an unknown distance from the recharge location. Groundwater circulation is adjusted to the natural drainage [1]. It was therefore essential to determine whether groundwater and the associated dissolved solids of the investigated aquifer are discharging to the local streams (Fig. 1) or farther downstream to the same surface drainage or maybe to a larger stream within the drainage network. For such a conceptual model, the unsaturated zone is of minor importance.

Between infiltration and exfiltration of groundwater there exists a dynamic equilibrium. It is determined by hydraulic as well as by solute parameters resulting to the fact, that in the recharge zone, a dominant downward movement of water molecules and solutes

Figure 1. Location map of boreholes and groundwater contours.

occurs, while in the exfiltration zone the water movement is directed upwards [1]. This is the most important consequence for choosing waste disposals sites, since the knowledge of the hydrogeological conditions for groundwater exfiltration finally allows the control of contaminants and furthermore the setting of measures for the rehabilitation of possible disposal damages.

3. TURNOVER TIME OF GROUNDWATER

The age distribution of groundwater is defined in this case by the tritium content. The investigated area is located between Unterseliger and Pisdorfer Bach (Fig. 1). A rough overview of the data show a large scattering between almost zero and 70 TU. Figure 2 offers an insight to the relation between tritium concentration and groundwater level.

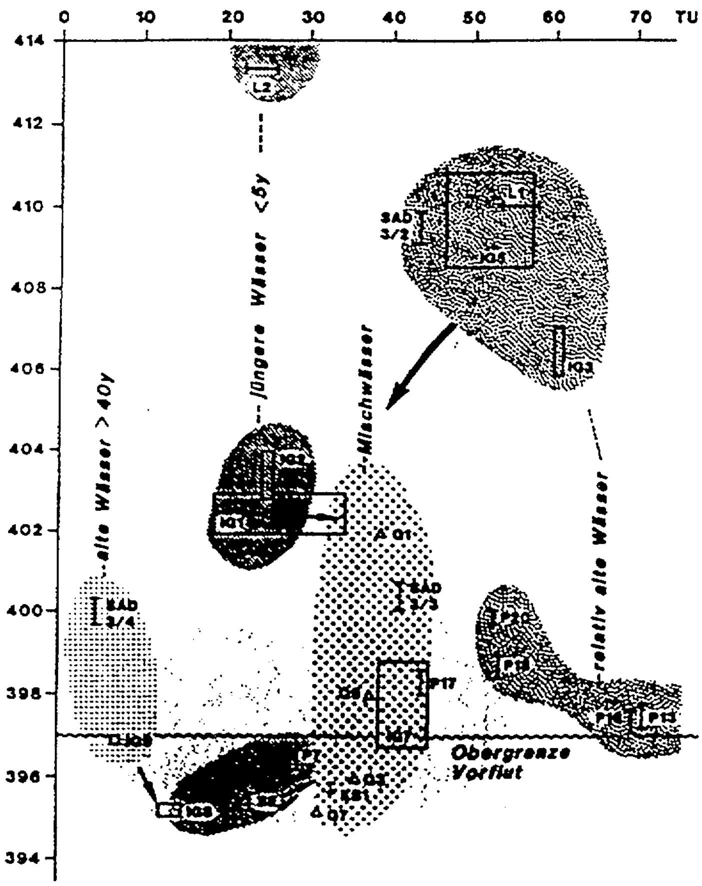

FIG. 2: Relation of groundwater level and tritium content.

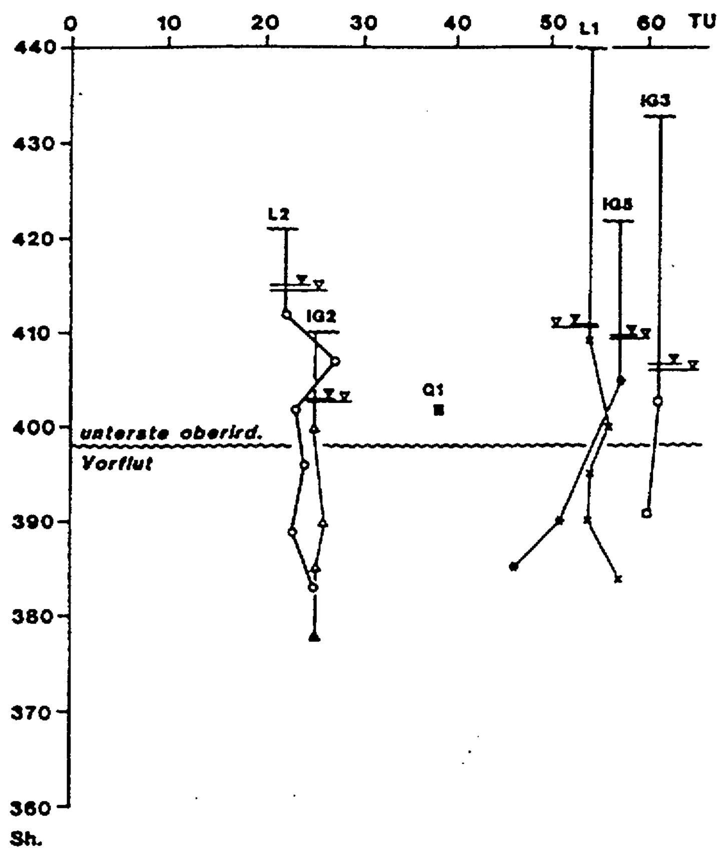

FIG. 3: Tritium profiles in boreholes of upper Unterselig Valley

Considering the fact that the tritium content of precipitation and infiltration water varies at present between 15 and 20 TU, the oldest groundwater, not exceeding 5 to 10 TU, can be easily distinguished having a turnover time of more than 40 years. Such groundwater is exfiltrating along a fractured zone parallel to the Pisdorf Valley to the surface drainage, represented by the boreholes SAD 3/4 and IG 9. In the latter, the sodium content is slightly increased, which points to a deep circulation of groundwater

The youngest groundwater is exposed in boreholes L 2, IG 2, IG 1, P 3 and P 7. In the most cases the groundwater is locally recharged through a very thin zone overlying the groundwater. The groundwater in the southern part (near Pisdorf Valley) is composed by groundwater of different origins and ages, grouped into two as a young/shallow and a deep circulating components.

4. VERTICAL MOVEMENT OF GROUNDWATER

In order to gain optimal results for a dynamic infiltration-exfiltration model a programme of combined borehole investigations has been conducted as follows:

- geophysical borehole logging
- flowmeter measurements
- tracing the whole water column to obtain preferential flow paths
- measurement of filter velocity by one point dilution method
- point-injection of tracers to obtain information on the vertical water movement (downwards or upwards)
- vertical profiles of selected parameters, especially of natural tritium

In the upper part of Unterselig Valley the boreholes L 1, L 2, IG 5, IG 3 and IG 2 have been drilled for distinct measurements. Borehole profiles of tritium are shown in Figure 3. The tritium content of groundwater from the drillings L 2 and IG 2 is varying between 20 and 25 TU and does not considerably change by depth, which obviously indicates to the presence of a young groundwater, infiltrated at the flanks and not circulating very deep. A tracer injected in borehole IG 2 at a depth of 21 m was transported upwards, thus recording clear exfiltration conditions to the surface drainage (Unterseliger Bach). Tritium profiles at L 1 and IG 3 show likewise no changes of the concentration by depth but with a considerable high content of 50 to 60 TU, which corresponds to a mean transit time of 20 to 30 years. Both boreholes are located in the recharge groundwater zone indicated by a slightly downwards movement of groundwater derived from point injections of tracer. The same is supposed for borehole IG 5. However, due to the tritium profile a structuring of groundwater turnover time is remarkable - the upper part of groundwater seems to be older than the lower one. It is evident, that the vertical movement of water in the unsaturated zone is slowed down because of less permeability. On the other hand the borehole is touching in the deeper part of the aquifer a fractured net system which causes a fast groundwater exchange. These processes are confirmed by flow meter measurements.

The boreholes IG 1, P 2, IG 7, P 7 and L 3 are located in the lower part of Unterselig Valley. With regard to the tritium profile (Fig. 4) the groundwater of IG 7 is identified as well mixed in the whole aquifer (^{3}H about 40 TU). In contrast, boreholes IG 1 and P 2 show the same mixed groundwater, but overlain by groundwater of young age, caused by a quick infiltration through a thin unsaturated zone. The very well mixed groundwater at borehole IG 7 shows a downwards movement indicated by a tracer injection about 5 m below groundwater level. That seems to be a very surprising result since the borehole is situated only some 100 m near to the local drainage. It is evident, that groundwater from this area is not exfiltrating along the shortest course to the local surface drainage as indicated by the groundwater contour map (Fig. 1) rather it is discharging much more downstream into the same drainage stream after the junction of Unterseliger and Pistorfer Bach. In borehole L 3 tracer experiments have not been performed, but the tritium profile in Figure 3 proves a young water portion in the

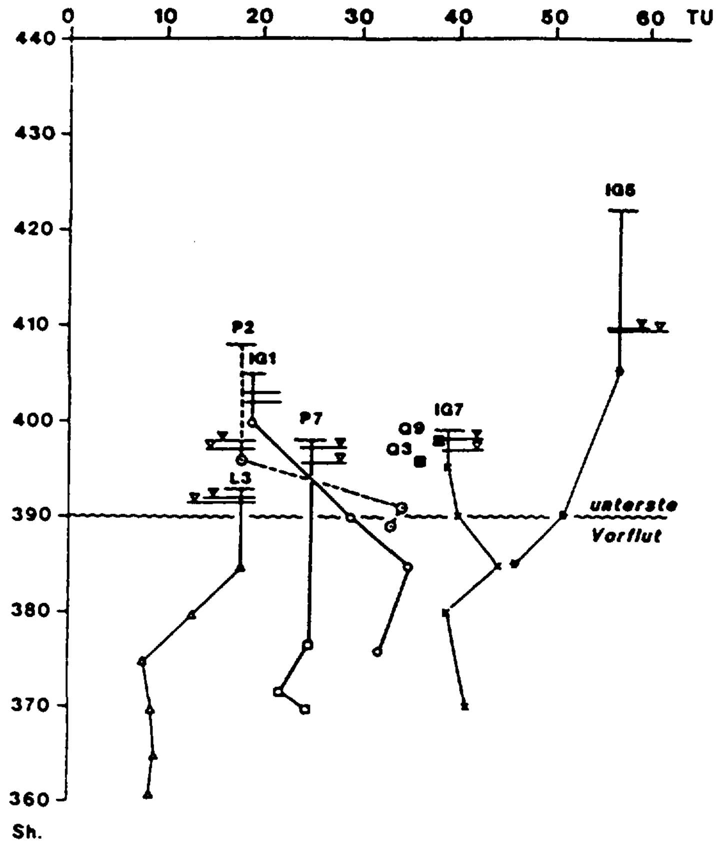

FIG. 4: Tritium profiles in boreholes of lower Unterselig Valley

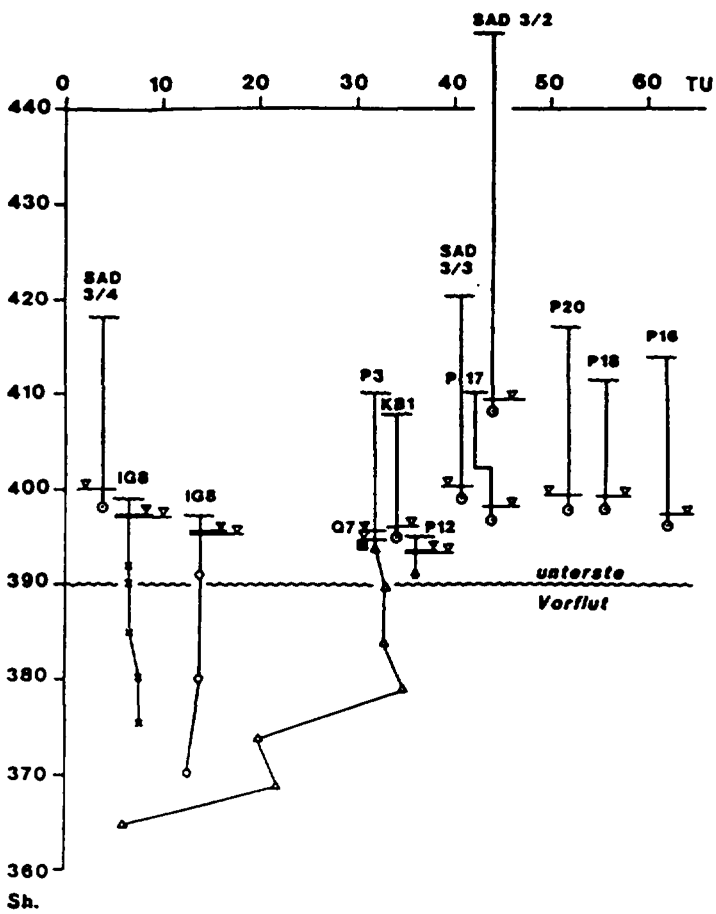

FIG. 5: Tritium profiles in boreholes of Pisdorf Valley

upper section of the aquifer, which is very locally recharged. But deeper than 15 m below groundwater level, a rather old water with a tritium content less than 10 TU has been determined. No upwards movement of groundwater in this borehole can therefore be assumed.

Figure 5 reflects the horizontal and vertical distribution of tritium in the recharge area of Pisdorfer Bach. The immediate function of the local drainage is clearly pronounced, expressed by an upwards water movement in boreholes IG 9, IG 8 and P 3 from tracing experiments. The tritium profile of P 3 indicates furthermore mixing processes of different water portions along the whole borehole.

5. UNDERGROUND DRAINAGE MODEL

The most important results of the investigation are the determination of recharge and discharge zones within the fissured and porous aquifer. They are essential for the hydrogeological assessment of a waste disposal:

a. The groundwater in the proposed disposal area is overlain by a considerable infiltration zone with different permeability, which provides a rather high storage capacity.

b. In the North, groundwater is flowing fast towards Unterseliger Bach, more downstream of the creek the groundwater is mixed from more components of different recharge and age.

c. The steep slope in the South, towards Pisdorfer Bach, is tectonically influenced. Old groundwater indicates a deep reaching circulation. Mixed groundwater from ascending portions and from shallow origin have also been found.

d. The most Eastern boreholes (IG 7, L 3), referring to their location and groundwater pattern, give the impression that they are in exfiltration zone of the nearby local drainage. This is decidedly not the case, based on tritium profiles and tracer tests in boreholes.

e. The exfiltration of groundwater occur farther downstream of the valley field which acts as a "natural barrier" to the neighbouring regions.

6. DISPOSAL SITE ASSESSMENT

Each scientific discipline is developing its own assessment criteria. This is true particularly for hydrogeology considering the term "barrier", which is not solely remaining to the geological view. This term should be extended to "natural barrier" in order to include all interdisciplinary aspects originating from geology, hydrogeology, chemistry and biology. For the field of hydrogeology the knowledge of drainage conditions are of prime importance on which groundwater flow dynamics are adjusted.

With reference to the conventional definition of the term "geological barrier" it is admittedly difficult to come to an overall agreement, since in the investigation area it will not be possible to reach a "geological barrier" in a technically attainable depth. Furthermore it must be noticed that the disposal site is located above a fractured aquifer with a reasonable permeability. Nevertheless a positive hydrogeological assessment can be expressed because the drainage conditions are known and effective with respect to hydraulics and solute transport in groundwater.

For the case of a contaminant intrusion to groundwater, the flow paths can be followed. It is therefore essential to establish proper measures for the control of the disposal site and the protection of groundwater quality. For that reason the development of multi-control systems depending on a very well defined infiltration-exfiltration relationship is necessary.

7. CONCLUSIONS

In order to gain optimal results for a dynamic infiltration-exfiltration model a programme of combined borehole investigations has been realized:

- geophysical borehole logging
- tracing of the whole water column to obtain preferential flow paths
- flowmeter measurements
- measurement of filter velocity by one point dilution method
- point infection of tracers to get information on the vertical water movement (downwards or upwards)
- vertical profiles of selected parameters, especially of natural tritium

All obtained data result to a dynamic drainage model of the aquifer. The dilution tests together with flowmeter measurements show very clearly the preferential flow especially in fissures and fractures indicated by the geological-tectonic structure. Most reasonable results can be derived from the point injection tracer tests and the tritium profiles. Starting from the recent input concentration of some 10 to 20 TU there exists a wide variety of the tritium content in the groundwater by areal distribution and by depth, located between 0 and 70 TU. A grouping of the different groundwater components enables an excellent insight to the dynamics of the groundwater system. In some of the boreholes a rather high and stagnant tritium content by depth (50 - 60 TU) is associated with a slightly downwards movement of groundwater in the borehole, which indicates the infiltration area of groundwater. It is overlain by an unsaturated zone with a reasonable thickness. Other boreholes are characterized by a groundwater stratification of different age, in some cases even old water overlies younger components. According to results of tracer tests and flowmeter measurements, such phenomena are affected by preferential flow conditions along fractures in the deeper part of the aquifer.

The combined interpretation of borehole data guarantees a high-grade knowledge of exfiltration conditions of groundwater to the surface drainage, which enables effective control measures of the disposal site and groundwater protection.

ACKNOWLEDGEMENTS

The author would like to express his gratitude to the Austrian Research and Testing Center Arsenal, which carried out isotope analyses.

REFERENCE

[1]Chapman, D. (Ed.) 1992. Water quality assessments. 585 pp. London: Chapman & Hall.