Tracer Test Monitoring Using Wells with Long Screened Intervals: Benefits and Disadvantages

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Introduction

Tracer testing in groundwater provides a means of obtaining much useful information about in-situ mass transport processes in aquifers. However, the high costs associated with installing multi-level monitoring points often make the method prohibitively expensive as a site investigation technique, particularly when resources are limited. Wells with long screened intervals/open boreholes often offer the hydrogeologist a tempting alternative means of monitoring tracer concentrations in groundwater. Nonetheless, test responses in long-screened tracer observation wells often display prolonged tailing, which may be explained as being a consequence of aquifer heterogeneity. This poster presents the results of a study that investigated the origin of prolonged tracer tailing observed in fully-penetrating wells screened in a heterogeous sand and gravel aquifer. The investigation employed a recently developed mobile downhole fluorometer to obtain information about the depths of tracer arrival intervals in an observation well, before considering the consequences of the investigation results results for the development of tracer test invesigation programs.

Test Site Location – Whole Well Sampling

Dornach Test Site

- Tracer test site on Munich Gravel Plain, Germany. (Figure 1)
- Fully penetrating injection and observation wells.

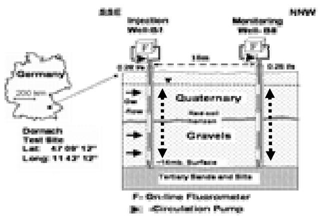


Figure 1. Schematic diagram illustrating the location and instrumentation at the Dornach Test Site, Munich, Germany.

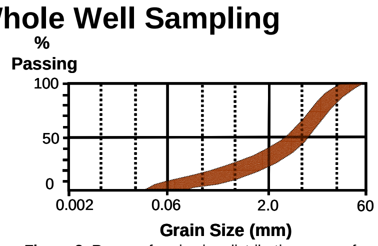


Figure 2. Range of grain size distribution curves for Dornach Aquifer samples. (After Seiler, 1975)

- Aquifer – Heterogeneous Sands and Gravels (Figure 2)
- Tracer injection well and observation well employ continuous circulation technique that mixes water across the entire well screen interval.
- Eight solute tracer tests, each carried out using Uranin (Sodium Fluorescein) over a 24 hour period.

Downhole Fluorometer Investigation Methodology

- Three inch mobile downhole fluorometer can measure Uranin concentrations as low as 0.1ppb.* (Figure 3)
- Meter measured tracer arrivals in observation well B8 in the saturated screened interval at 3-15m below ground surface.
- Programmable pulley system allowed fluorometer to measure tracer concentrations as frequently as every 5 cm.
- Two tracer tests carried out at Dornach under average and high groundwater conditions.
- Repeated cycles measured Uranin concentrations at regular intervals over a 24 hour periods.
- Complimentary single well dilution and vertical flow tests carried out folowing second test.

*Two inch model now available.

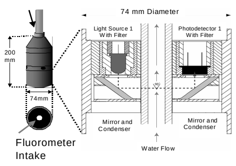


Figure 3: Construction details of downhole fluorometer

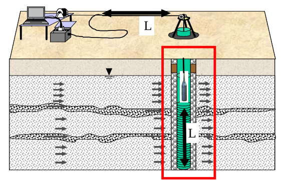


Figure 4: Operation of downhole fluorometer. Pulley draws fluorometer over interval L at ground-surface corresponding to equivalent depth interval in well.

Whole Well Tracer Test Results

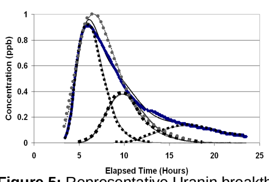


Figure 5: Representative Uranin breakthrough curve observed at B8. Field data in blue; best fit single advection-dispersion term in grey; partial breakthrough curve (dotted) and composite curve (solid) in black.

•Very rapid travel times between injection well and observation well 10m downgradient.

Parameter	Range
First Arrival (Hours after Injection)	2.09-3.13
Time Cmax observed (Hours after injection)	4.25-5.88
Cmax/Co	$1.27 \times 10^{-4} – 3.67 \times 10^{-4}$

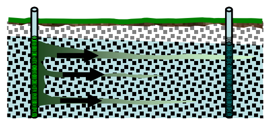


Figure 6: Conceptual model of multiple tracer clouds arriving at long screened well, each giving rise to a partial breakthrough curve.

•Prolonged breakthrough curve tailing cannot be simulated with single advection-dispersion term.
•Can be reproduced with mulitple partial breakthrough curves (Figure 5)
•Suggests that have multiple breakthrough curves, each arriving at different level of screened interval (Figure 6)

Downhole Fluorometer Results

- No Uranin observed in over 50% of screened interval.
- Over 95% of tracer observed between 8.5 and 12.5 mBGS*.
- Peak concentrations consistently observed at 12-12.5mBGS. (Figure 7)
- Trace amount of Uranine (<5%) observed at 4.5 to 5mBGS but no significant influence on overall shape of breakthrough curve.
- Single well tests give consistent response with peak at approximately 8.5-9mBGS. (Figure 8 – below)
- Vertical flow rates and direction varies with depth.

* mBGS: metres below ground surface.

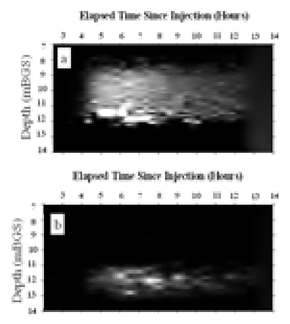


Figure 8: Tracer concentrations observed in B8, in 7mBGS to 14mBGS depth interval in (a) June 2001, (b) August 2002. Whitness proportional to tracer concentration.

Data Analysis /Interpretation 1.

- Vertical flow and single well dilution data show active flow zones where no tracer was observed by downhole fluorometer.
- Downhole fluorometer measurements made during single well dilution tests show a consistent peak at approximetaly 9mBGS.
- Vertical flow measurements indicate that this corresponds to a zone of convergence for upwelling and downflowing groundwater.
- Vertical flow test results indicate that tracer arrived in an intervval at 12-12.5mBGS and was conveyed upwards to the 8.5-9.0 mBGS zone where it re-entered the aquifer, i.e the well acts as a hydraulic short circuit for water flowing at different levels in the aquifer. (Figure 8)

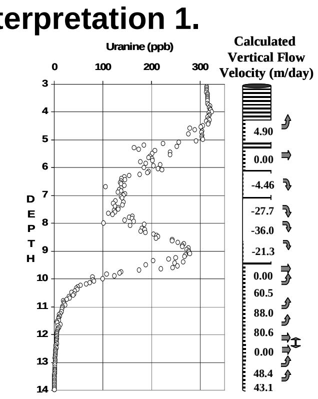
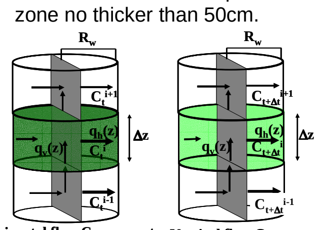


Figure 8: Single well dilution test profile of Uranin concentration in B8 collected measured using mobile downhole fluorometer. Arrows and figures on left hand side of plot are directions and magnitudes (m/day) of vertical flow. (Horiz=horizontal flow). Note tracer arrives at approx. 12mBGS but then flows upward to 9mBGS where it re-enters the aquifer.

Data Analysis / Interpretation 2

- Mass balance model indicates that tracer enters well via rapid-flow zone no thicker than 50cm.



Horizontal flow Component:

$$C^i_{t+\Delta t} = C^i_t - \frac{2q_h(z)\Delta t C^i_t}{\pi R_w}$$

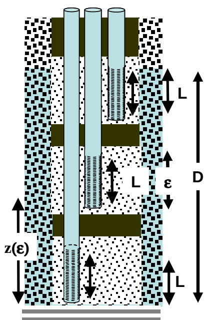
Vertical flow Component:

$$C^i_{t+\Delta t} = C^i_t - \frac{q_v(z)\Delta t (C^{i+1}_t - C^{i-1}_t)}{\Delta z}$$

Concentration at end of time step= Concentration at Start – Loss due to horizontal flow - Loss due to vertical flow.

Figure 9: Schematic illustration of mass balance modelling process. Decline in tracer concentration in a cell of thickness Δz during a time step Δt results from removal by vertical flow across the cell $q_v(z)$ and by Horizontal Flow $q_h(h)$ into the aquifer.

Figure 10: Probability of encountering horizon transporting tracer, P determined as follows:



$$P = \frac{(L+\varepsilon)}{(D-L)} \times n$$

when

$$L < \frac{D-\varepsilon}{2};\ L < z(\varepsilon) < (D-L)$$

where
"L" is piezometer screen length
"D" is aquifer thickness
"ε" is the thickness of the tracer-bearing horizon.
"n" is the number of piezometers installed.

Using the approach shown in Figure 10, the probability of four one metre long piezometers encountering a 50cm-thick horizon in 12m of aquifer is calculated at approximately one in two (54.5%).

Discussion / Conclusions

The results of the investigations carried out at the Dornach Test Site indicate that the groundwater flow velocity in the underlying sand and gravel aquifer varies with depth. The prolonged tailing observed in the breakthrough curves generated from data collected at B8 during the whole well investigations suggested that tracer may have been arriving at multiple horizons with contributions from each horizon producing a partial breakthrough curves. However, tracer concentration profiles measured in B8 using a mobile downhole fluorometer showed this not to be the case, but rather that over 95% of the tracer arrived in a single horizon that could be no thicker than 50cm. The probability of encountering this horizon by installing four one metre long piezometers was calculated to be approximately one in two. This result highlights the potential of failing to encounter horizons that may be important in transporting contaminants, when studying systems using multiple level samplers. This in turn raises the issue of whether expenditure on the installation of these sophisticated groundwater monitoring systems may be the best use of financial resources, particularly where project budgets are tight.

Acknowledgements

This work was partially supported by the Swiss National Science Foundation (Grant Number: FN-20-061370.00). The authors wish to express their gratitude to Roberto Costa of the University of Neuchâtel Geomagnetism Group, who designed and built the downhole fluorometer programmable pulley system, and to Michel Stökl of GSF Neuherberg whose assistance during all tracer tests was greatly appreciated.