Using fluid electrical conductivity logging to determine tracer test input functions for a radial flow test in the chalk

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Key questions

• Can the way that tracer leaves an injection borehole have a significant effect on the breakthrough curve?

•Can logging in the injection borehole give us useful information?

Tracer tests are a used to measure transport properties

Chalk is a dual-porosity medium where fast flow occurs in fractures while matrix flow is close to negligible. Solute transport is strongly retarded due to diffusion of solutes between the fractures and the matrix. A log-log late-time-slope (LTS) of -1.5 in tracer breakthrough curves (BTCs) is indicative of Fickian matrix diffusion. It has been suggested that LTSs of less than -1.5 are indicative of multiple mass-transfer rates and/or multiple flow-pathways.

A radially convergent tracer test was carried out in the Chalk outcrop of Berkshire, UK. Tracer was injected into two boreholes lying 32 m (PL10A) and 54 m (PL10B) from the abstraction hole (BBA). The BTC from PL10A was uni-modal and had a first arrival time of 14 min. The BTC from PL10B exhibited two distinct peaks and a first arrival time of just 4 min (see Figure 1). Both BTCs in Figure 1 show LTSs <-1.5, which could indicate multiple flow paths. In the case of PL10B, this hypothesis seems further supported by the presence of multiple peaks. In this poster, we show that the non -1.5 slopes at PL10B is due to the tracer test input functions (the way in which the tracer leaves the injection well into the aquifer). This is also the case for PL10A, but the results are not shown here. Note that the tracer injection procedure took around 10 minutes, which is comparable with the first arrival time at the abstraction borehole.

Determining the input functions

The methodology for working out the tracer test input functions is:

1. Identify possible flow horizons from integrated geophysical data (temperature, upflow, fluid electrical conductivity (FEC), etc.) (see Figure 2);
2. Estimate flow rates at flow horizons by fitting a dilution test model to the FEC logs (see Figure 2e);
3. The tracer test input functions are then obtained as a mass flux by multiplying modelled concentrations at outflowing horizons by their respective outflow rates (see Figure 3).

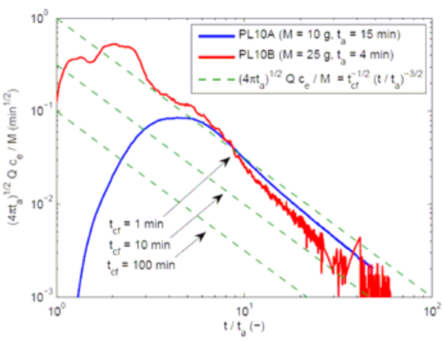

Figure 1. Plot of observed tracer concentrations at the Bottom Barn abstraction well. *t* is time after injection, t_a is the advective travel time, $t_{cf} = (a/\Phi_m)^2/D_A$ is a characteristic fracture diffusion time, *M* is the mass of injected tracer, *Q* is the abstraction rate, *a* is a fracture aperture half-width, Φ_m is a rock matrix porosity, D_A is the apparent diffusion coefficient of the tracer.

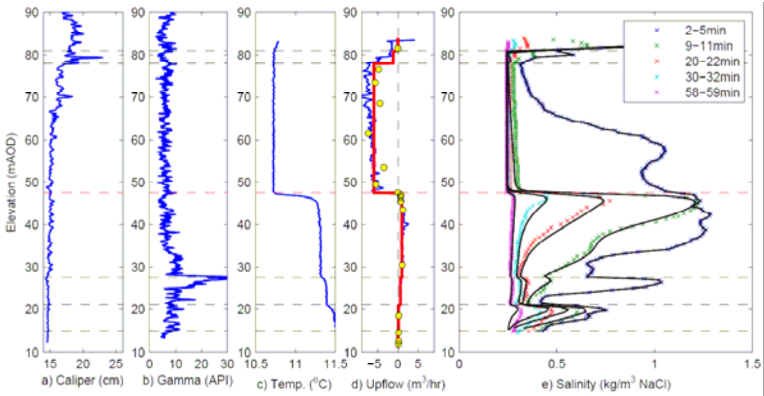

Figure 2. Geophysical logging in PL10B whilst pumping the Bottom Barn abstraction well. Subplot (d) shows upflow estimated from the impeller flowmeter (the blue line), the heat-pulse flowmeter ('o' markers) and from numerical inversion of the FEC logs (the red line). Subplot (e) shows the fluid electrical conductivity (FEC) logs recorded after the tracer injection. FEC logs shown are down runs with start and finish times of each run as indicated in the legend. The black solid lines shown in Subplot (e) are the FEC logs generated from the numerical model. The black and red horizontal dashed lines across all the subplots show the elevations of the inflowing and outflowing flow horizons respectively, used for numerical inversion of the FEC logs.

Idealised input functions

It is not possible to recover the entire tracer input function because we only have knowledge of times after the first FEC logs, which were taken several minutes after the tracer injection. However, we can develop a complete, idealised tracer input function by assuming that the tracer concentration in the injection tube was perfectly uniform and released instantaneously. Under such conditions, the initial concentration profile in the injection well is inversely proportional to the borehole cross-sectional area. If we then apply the flow-fields seen in Figure 2d and run the dilution test models forward, the corresponding idealised tracer input functions are obtained (see green lines in Figure 3). The BTCs at the BBA can be modelled by convoluting the idealised input functions with the single fracture model (SFM) described by Maloszewski and Zuber (1985). Calibrated BTCs are also plotted alongside the observed data in Figure 3. Although the multiple peaks at PL10B did not come through, the shape and late-time slope are superbly represented. The model requires the calibration of just two parameters, t_a and t_{cf} .

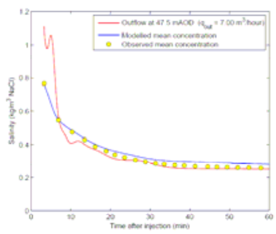

Figure 3. Plots of outlet and mean concentrations for PL10B.

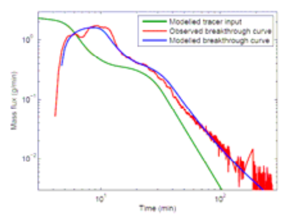

Figure 4. Plots of modelled tracer input for PL10B, the observed PL10B tracer BTC at BBA and the modelled BTC obtained by convoluting the SFM (with t_a =4.5 minutes, t_{cf} = 13.7 minutes, 100% mass recovery) with the tracer input function.

Conclusions

FEC logging and dilution test modelling showed that tracer travelled through two pathways from PL10A and just one pathway from PL10B (see red dashed lines in Figures 2). The multiple peaks seen in the PL10B BTC were probably due to peaks in the release of tracer from the injection well caused by the diluting effects associated with borehole cross-sectional area irregularities and/or the tracer injection procedure itself. The ability of the SFM to model the non -3/2 log-log late-time-slopes (see Figure 4) suggest that these were caused by the way in which the tracer left the injection wells.

Find out more…

Mathias, S. A., A. P. Butler, D. W. Peach, and A. T. Williams (2007), Recovering tracer test input functions from fluid electrical conductivity logging in fractured porous rocks, *Water Resour. Res.*, 43, W07443, doi:10.1029/2006WR005455.

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