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Extended Abstracts

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title: **Quantification of the water flux and transport processes in a heterogeneous aquifer model system with a multitracer approach**

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INTRODUCTION

Several studies have been performed to understand mass transport processes in porous groundwater systems. One common practice for the investigation of heterogeneous groundwater systems is the using of tracer techniques. Many field studies and laboratory experiments have been realised in the past to investigate transport parameters e.g.: main transport path, transport velocities, dispersivities, porosity (Einsiedl and Maloszewski, 2005; Ptak et al., 2004; Seifert and Engesgaard, 2007). To understand reactive transport of contaminants within an aquifer, tracer tests have also been used (Berkowitz, 2002; Cirpka and Kitanidis, 2000; Geyer et al., 2007; Ptak and Schmid, 1996; Reinhard et al., 1997).

To estimate how groundwater systems initially react to contamination, what controls biodegradation and how aquifers recover after contaminant removal, should be investigated in an indoor aquifer model established at the HMGU Institute of Groundwater Ecology in Munich. The aim of the present study in that aquifer model was to clarify how heterogeneous water flow caused by differently conductive porous layers can be quantified.

MATERIALS AND METHODS

Setup of the Indoor Aquifer Model

The experimental aquifer, shown in Fig. 1, has a length of 5 m and a height and width of 0.7 and 0.8 m, respectively. This aquifer model has been filled with quaternary sediment from the Bavarian Alpine Foreland, Germany (grain size between 0 and 4 mm). In addition to the natural sediment, in the middle of the model has been installed a horizontal layer with higher conductivity consisting of homogeneous quartz sand with a grain size of 0.5 to 1 mm. This artificial "heterogeneity" with a thickness of 0.12 m and a length of 0.5 m should focus the water fluxes. The groundwater flow through the model has been designed with a gradient of the water level (i=0.02). The model was fitted with in total 132 water-sampling points made of glass frits, which were connected to stainless steel capillaries and a multi-channel peristaltic pumps. To realise an injection of tracer, one vertical injection well has been installed in the centre of the model closed to inflow (Fig. 1).

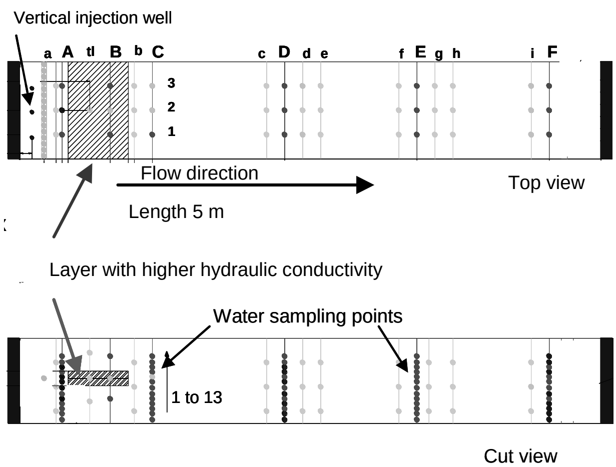

Figure 1. A schematic overview about the Indoor Aquifer Model.

Multi -Tracer Test

For a tracer test, a mixture of potassium bromide (4.4 g) tritium labelled water (activity 170 MBq) has been injected instantaneously as a Dirac-impulse in the vertical injection well. The first multi level well, evaluated in the present study, was installed in the middle of aquifer at the distance of 0.9 m from the injection well. At this vertical section, the water sampling proceeded along the main flow pathway, was performed to calculate the distribution of flow velocity and the longitudinal dispersivity. Further sampling perpendicular to the main flow pathway enabled us to calculate the transversal dispersivity.

Quantifying of tracer test using Multi-Flow-Dispersion-Model

The differences in hydraulic conductivity in vertical cross-section within the aquifer system are expected to cause multiple peaks in the concentrations curves, due to several flow paths with each having a different velocity. To describe the tracer transport in a multi-layered aquifer the multi-flow dispersion model (MFDM) was used. This model assumes that the tracer transport through the system can be approximated by a combination of 1D dispersion advection equations. Each flow path is characterized by a specific volumetric flow rate, mean transit time of water and dispersivity. It is assumed that the mass of tracer injected is divided into several flow paths proportional to the volumetric flow rates along those paths (Leibundgut et al., 2009; Maloszewski et al., 2006). The solution for a fully-penetrating observation well can be written in this case as follows (Maloszewski et al., 2006):

$$C(t) = \frac{\sum Q_i C_i(t)}{\sum Q_i} \quad (1)$$

$$C_i(t) = \frac{M_i}{Q_i t_{oi} \sqrt{4\pi (P_D)_i (t/t_{oi})^3}} \exp\left[-\frac{(1-t/t_{oi})^2}{4 (P_D)_i \, t/t_{oi}} \right] \quad (2)$$

where Q_i [L^3] and M_i [M] are the volumetric flow rate and the mass of the tracer, P_{Di} [-] is the dispersion Parameter, t_{oi} [T] is the mean transit time of the water, for each i^{th} flow path, respectively.

The main assumption for the MFDM is that all i flow paths meet in one vertical observation well. However, the water sampling in the present aquifer-model was realised as a single observation over the depth. To overcome this difficulty each observed single tracer curve has been flux weighted and their sum was used as the outflow concentration curve C(t). The example of the calibration of the mathematical model (MFDM) to the tracer curve is shown in Fig. 2.

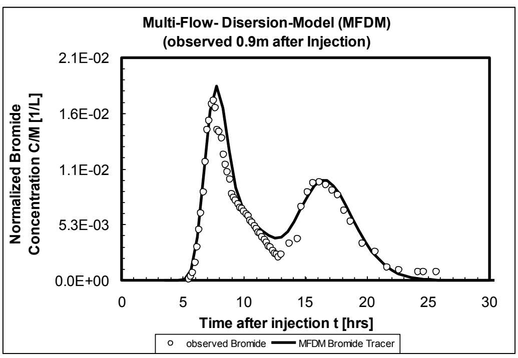

Figure 2. Bromide concentration curves observed (circle) and modelled using the MFDM (solid line).

RESULTS

The application of the MFDM has shown that there seem to be three layers with different velocities and longitudinal dispersivities, each (Table 1).

Table 1. Modelled transport parameters and calculated layer thickness for the different flow paths at a distance from the injection well of 0.9 m (model applied: MFDM).

	Flow path 1	Flow path 2	Flow path 3
Velocity [m/d]	2.72	1.88	1.27
Layer thickness [m]	0.16	0.11	0.39
Longitudinal Dispersivity [mm]	9.0	9.6	8.1

Further evaluation of the fitting parameters has produced the thickness of the layers characterized by different conductivities. The modelling of the flux weighted concentration curve showed that the local "heterogeneity", which was installed in the aquifer-model, could be found and quantified with the MFDM. The calculated thicknesses of the layers agree well with those installed in the indoor aquifer system model (Fig. 3), which validated the mathematical approach used. Modelling of both tracers produced practically the same values of system parameters, which can be considered as additional, indirect validation of the MFDM.

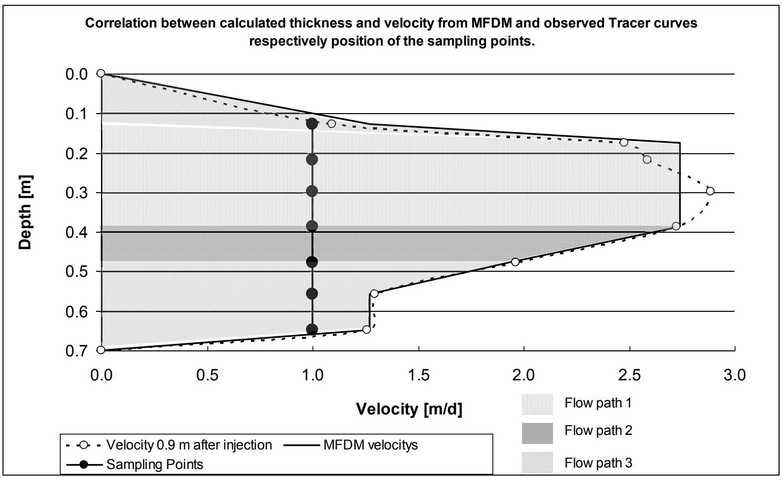

Figure 3. Velocities from the Multi-Flow-Dispersion Model; all three flow paths with the calculated thickness of each flow path.

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