Thermal tracer tests for characterizing a shallow alluvial aquifer

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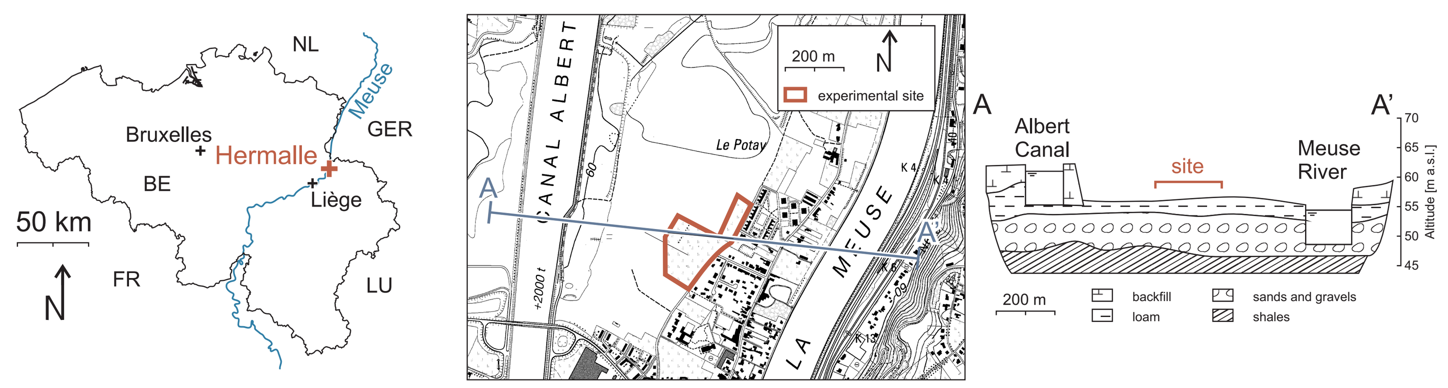
Abstract

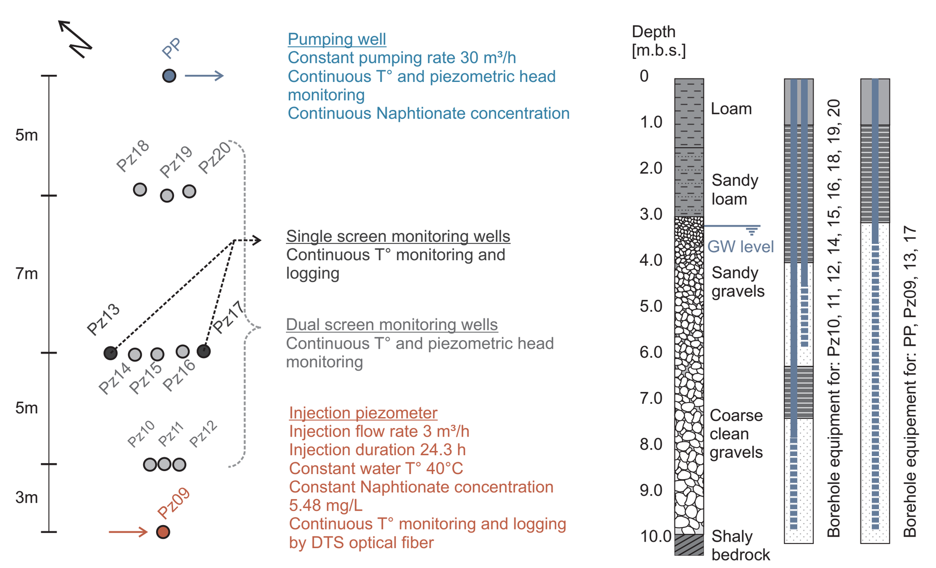
Using heat as an active tracer in different types of aquifers is a topic of increasing interest [e.g. Vanderbohede et al., 2008, Wagner et al., 2013, Read et al., 2013]. In this study we investigate the potential interest for using heat and solute tracer tests for characterization of a shallow alluvial aquifer. A thermal tracer test was conducted in a shallow alluvial aquifer of the Meuse River, Belgium. The tracing experiment consisted in injecting simultaneously heated water and a dye tracer in a piezometer and monitoring evolution of groundwater temperature and tracer concentration in the recovery well and in 3 observation well transects perpendicularly to the main groundwater flow.
Temperature breakthrough curves highlight that heat transfer in the alluvial aquifer of the Meuse River is complex and contrasted with different dominant process depending on the depth leading to significant heat exchange.The breakthrough curves measured in the recovery well showed that heat transfer in the alluvial aquifer is slower and more dispersive than solute transport. This is due to heat diffusion in rocks is large compared to molecular diffusion, implying that exchange between groundwater and aquifer solids is more significant for heat than for solute tracers. Temperature and concentrations in the recovery well are then used for estimating the specific heat capacity with the energy balance approach and the estimated value is found to be consistent with those found in the literature.

Field site and experimental setup

The test site is located 13 km north east of Liège, Belgium, Western Europe, on the alluvial plain of the River Meuse.

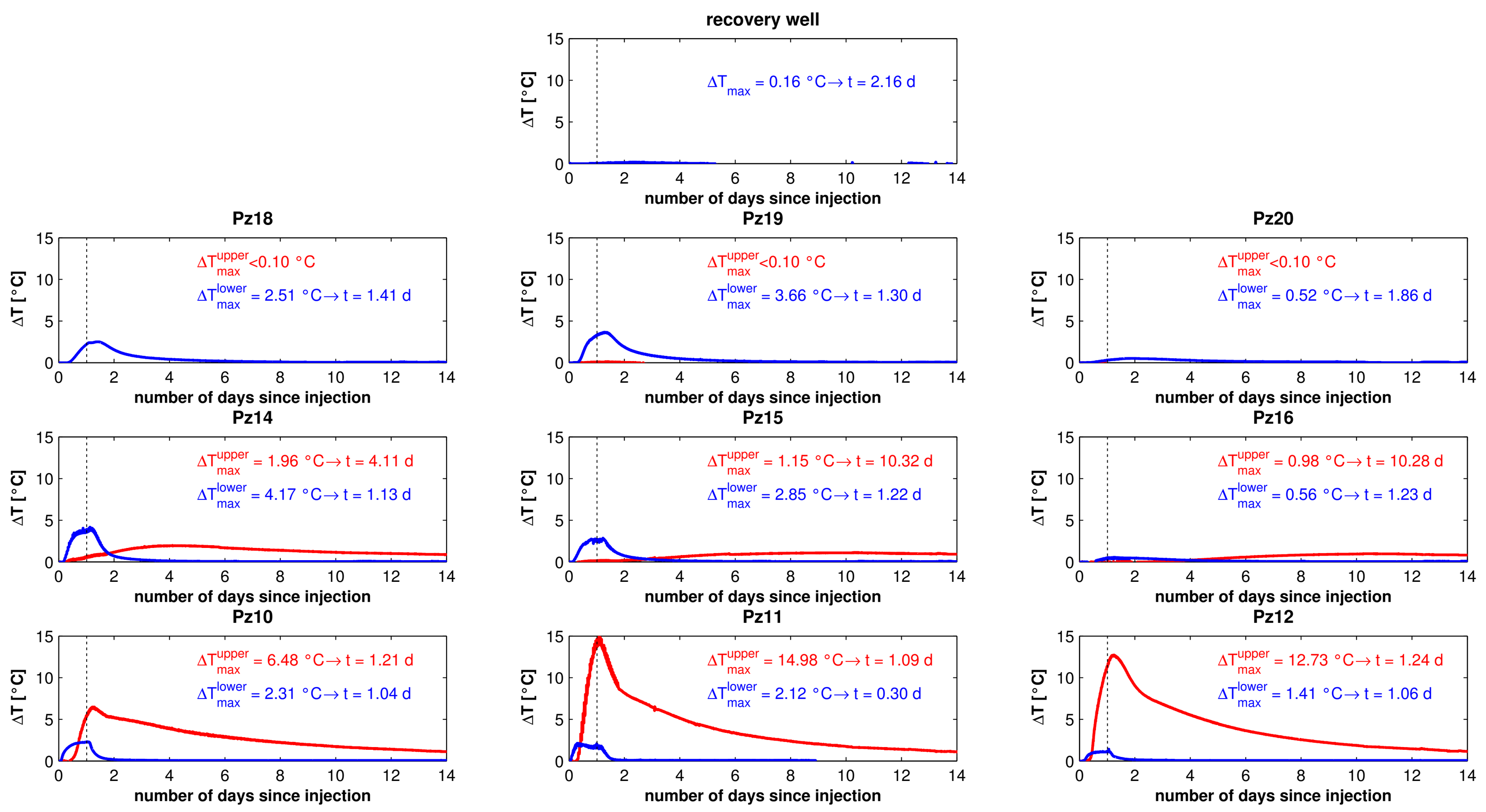


Piezometers at the site are either single-screened in the whole alluvial aquifer made of sandy gravels, or double-screened with an upper screen in the finest part of the aquifer at its top, and a lower screen within the coarse gravels at the bottom of the aquifer. The experimental setup consists in simultaneous injection of heat and chemical tracer from Pz09 and monitoring of their breakthrough at the recovery pumping well (PP).

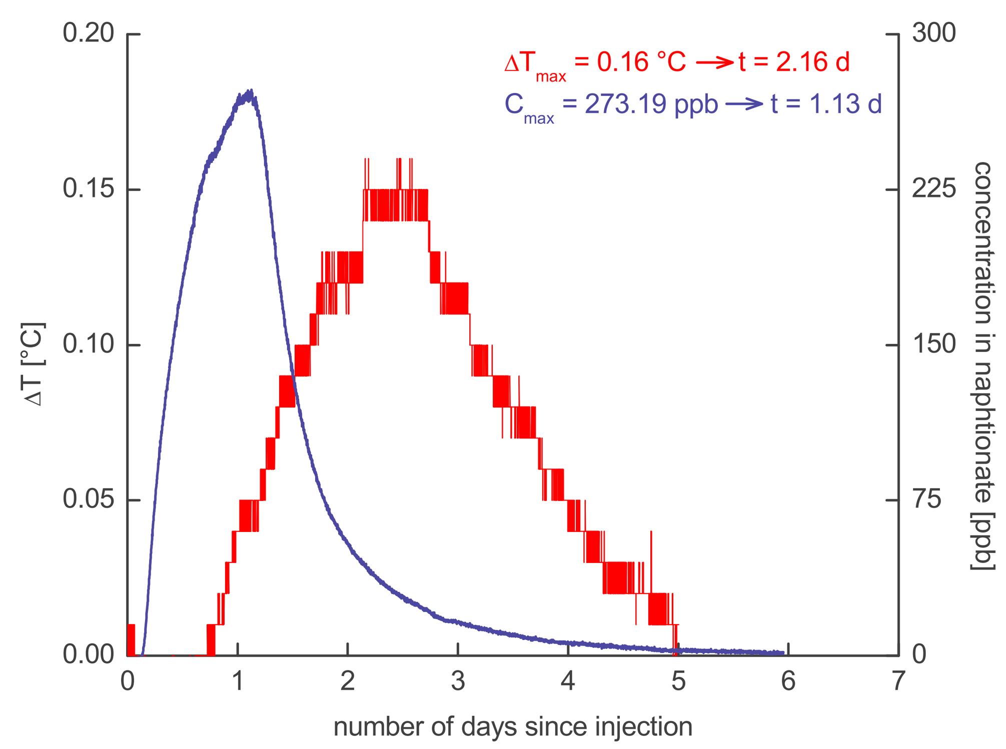


Experimental results

Temperature is continuously monitored at piezometer Pz10 to Pz20 in the lower (blue curves) and in the upper part (red curves) of the aquifer. Temperature breakthrough in other piezometers are contrasted with what would be expected in an ideal layered aquifer and reveal lateral and vertical components of the transport mechanisms. Heat transfer is mainly convective in the lower part of the aquifer and mainly conductive in the upper part.



Heat transfer is delayed and retarded as compared to solute transport.



Estimating the specific heat capacity

(1) The energy balance equation on a volume of porous medium corresponding to the portion of the aquifer investigated by the heat tracer experiment can be written as follows:

$$\dot{M}_{inj} \times c_w \times T_{inj} + (\dot{M}_{ext} - \dot{M}_{inj}) \times c_w \times T_0 - \dot{M}_{ext} \times c_w \times T_{ext} - \dot{Q}_{lost} = M_m \times c_m \times \frac{dT_m}{dt}$$

$$\dot{Q}_{lost} = \dot{M}_{inj} \times c_w \times T_{inj} + (\dot{M}_{ext} - \dot{M}_{inj}) \times c_w \times T_0 - \dot{M}_{ext} \times c_w \times T_{ext}$$

$$C_m = \frac{M_m \times c_m}{V_m} = 2.47 MJ/m^3/K.$$

Estimating the specific heat capacity

(2) Temperature and solute breakthrough curve modeling using a semi-analytical transport model

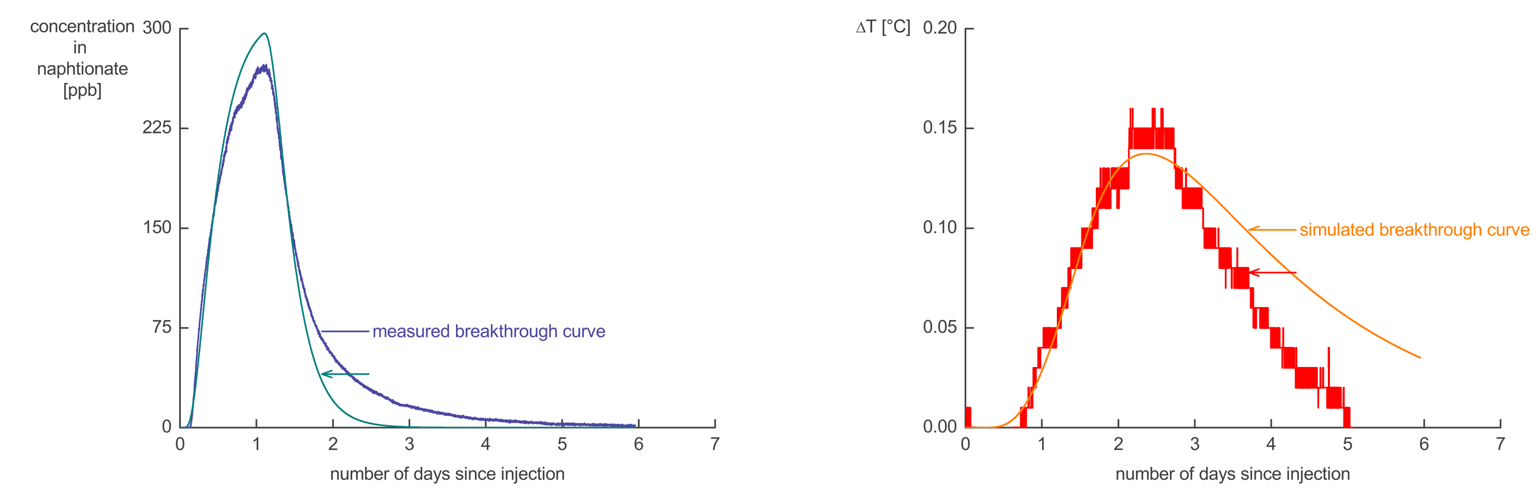


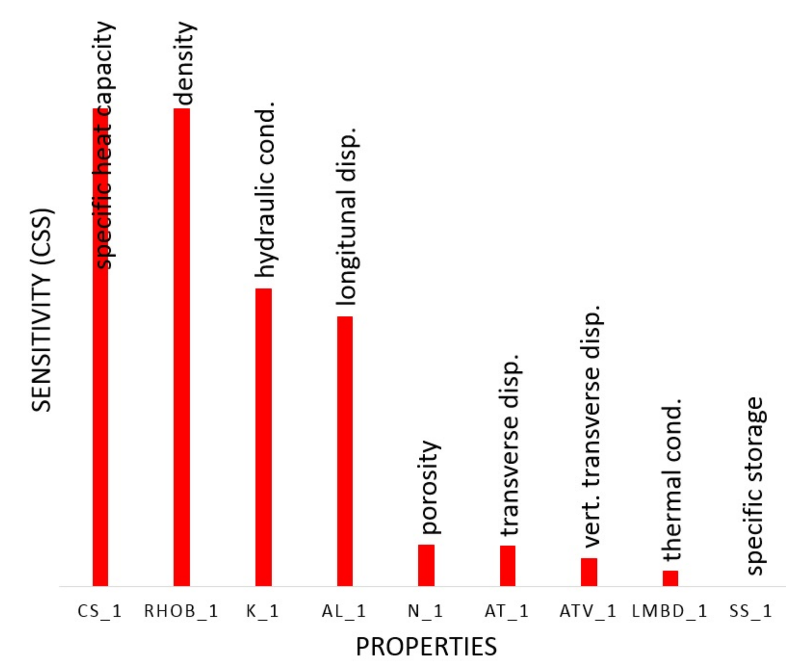
Table: Estimated parameters

	Naphtionate	Temperature
Effective porosity n_e [-]	0.04	from naphtionate
Longitudinal dispersivity α $[m]$	3	from naphtionate
1st order degradation coefficient $[s^{-1}]$	$1.5 \cdot 10^{-5}$	0
retardation factor [-]	1	5

Retardation factor $R = C_m/n \cdot C_w => C_m = 2.30 MJ/m^3/K$

Numerical modelling

To identify which parameters have the most influence on temperature changes, a sensitivity analysis was performed by computing composite sensitivities CSS.



The temperature changes are mostly sensitive to the specific heat capacity, density, hydraulic conductivity and longitudinal dispersivity.

Conclusions

The coupled heat and chemical tracer experiment provides an efficient way of estimating the specific heat capacity of the saturated porous medium in the field using temperature and concentration measurements in the recovery well. Temperature breakthrough in other piezometers are not required for estimating the specific heat capacity. However, these data could be included in the calibration of a complex heat transfer model for estimating the entire set of heat transfer parameters and their spatial distribution by inverse modeling.