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Quantifying the role of immobile water on pollutant fluxes in double-permeable media under dynamic flow conditions

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Sustainable use of water resources and their protection against pollution requires fundamental understanding of filter, buffer and storage functions of groundwater systems. Of particular importance are heterogeneous porous aquifers including zones with mobile and immobile water. Pollutants diffuse from high permeable areas into immobile zones with low permeability. Consequently, pollutants can be stored in such immobile water regions and their residence time in double-permeable aquifers is much longer compared to water residence times. However, it still remains unknown how the heterogeneity of an aquifer and time-dependent variability of the water flow influences the pollutant fate in such systems. The objective of this study was to develop experimental and mathematical methods to understand the role of immobile water zones on the pollutant retention, kinetic ad-/desorption and degradation. In saturated column experiments at three different flow rates multitracer experiments were conducted and 4-Chloronitrobenzene (intermediate in the production of explosives) was used as pollutant.

The columns were packed with an outer cylinder of clay containing mainly immobile water whereas the centre was filled with coarse quartz sand containing mobile water. In the resulting breakthrough curves of the conservative tracers characterized by different diffusion properties, differences were observed in peak concentration and tailing. These differences indicated a mass exchange with immobile water zones driven by diffusion and were depended on the tracers' molecular diffusion coefficient. The mass exchange increased with decreasing flow rates and was quantified for conservative tracers applying a Single-Fissure Dispersion Model (SFDM) to porous media for the first time.

The observed concentrations of the reactive solute 4-Chloronitronbenzen indicated that sorption onto clay minerals enhanced the mass exchange into the immobile water zone. On the other hand sorption and degradation inhibited the back-diffusion from immobile water to mobile water zones. Mathematical models based on analytical and numerical models have to be further developed to describe and quantify these observed processes. A better understanding about the influence of immobile water and dynamic flow conditions on pollutant transport will help to improve prediction of pollutant fluxes and site remediation techniques and management.