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Modeling preferential flow and its consequences on solute transfer in a strongly heterogeneous deposit

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The understanding of the fate of pollutants in the vadose zone is a prerequisite to manage soil and groundwater quality. Water infiltrates into the soil and carries a large amount of pollutants (heavy metals, organic compounds, etc.). The quality of groundwater depends on the capability of soils to remove pollutants while water infiltrates. The capability of soils to remove pollutants depends not only on their geochemical properties and affinity with pollutants but also on the quality of the contact between the reactive particles of the soil and pollutants. In such a context, preferential flows are the worst scenario since they prevent pollutants from reaching large parts of the soil including reactive zones that could serve for pollutant removal. The negative effects of preferential flow have already been pointed out by several studies. In this paper, we investigate numerically the effect of the establishment of preferential flow in a numerical section (13.5m long and 2.5m deep) that mimics a strongly heterogeneous deposit. The modelled deposit is made of several lithofacies with contrasting hydraulic properties. The numerical study proves that this strong contrast in hydraulic properties triggers the establishment of preferential flow (capillary barriers and funneled flow). Preferential flow develops mainly for low initial water contents and low fluxes imposed at the soil surface. The impact of these flows on solute transfer is also investigated as a function of solute reactivity and affinity to soil sorption sites. Modeled results clearly show that solute transport is greatly impacted by flow heterogeneity. Funneled flows have the same impacts as water fractionation into mobile and immobile transfer with a fast transport of solutes by preferential flow and solute diffusion to zones where the flow is slower. Such a pattern greatly impacts retention and reduces the access of pollutants into large parts of the soil. Retention is thus greatly reduced at the section scale and breakthrough at the lower boundary condition of the domain is enhanced. The heterogeneity of flow and the global retention efficiency are linked over a large range of hydric and hydraulic conditions. This study clearly demonstrates numerically the need to account for the effect of soil heterogeneity and induced preferential flow on solute transfer.