



Challenges in estimating water transit times in the unsaturated zone

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Stable isotopes of water can provide integrative information about water flow and transport processes. Therefore, they are frequently used to determine transit times of water in different compartments of the water cycle. Of particular importance for groundwater vulnerability assessment are the transit times in the unsaturated zone. However, the transient nature of flow in the unsaturated zone as well as the spatial heterogeneity of physical properties makes it difficult to estimate water transit times. Hence, the application of water isotope approaches is challenged by dynamic and heterogeneous processes in the unsaturated zone and its transitions with the atmosphere and the groundwater. The objective is to summarize these challenges and how they can be solved. One of the major challenges is to determine the correct isotope input concentration of the recharging water which not necessarily equals the isotope concentration in precipitation; particularly in snow dominated regions or if transpiration is a crucial part of the water balance. Further, spatial heterogeneities can be considered by estimating not only mean transit times but transit time distributions of water additionally giving information about dispersivity. Stable water isotopes can also help to quantify preferential flow. Still, all these parameter are only representative for the observation time being analyzed and may change though. Therefore, more advanced approaches giving information about time variable transit time distributions in the unsaturated zone are required in future.