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Transport of environmental tracers through a karst system with a thick unsaturated zone

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The transport of the environmental tracers tritium (^{3}H), krypton-85 (^{85}Kr) and helium (^{3}He) in a karst system is investigated. Differences between mean tracer ages determined in spring water are explained by slow percolation of water through the thick unsaturated zone reflecting the importance of slow and diffuse unsaturated flow processes in these systems.

Mean tracer ages on the Gallusquelle spring (Swabian Alb) were determined with lumped parameter modeling and decrease in the following order: ^{3}H $>>^{85}$Kr $>^3$He. Since ^{3}H is part of the water molecule it enters a karst system via precipitation, i.e. the mean ^{3}H age is a measure of water flow through the whole karst system, including the unsaturated and saturated zone. The mean ^{85}Kr age and ^{3}H/^{3}He age are measures of time since groundwater recharge arrived at the water table. Therefore our results indicate a long travel time of ^{3}H through the unsaturated zone of the karst system.

The interpretation is supported by a two-dimensional numerical simulation of flow and transport in a fissured matrix block that contains a thick unsaturated zone (ca. 100 m) and is drained by a conduit. Transport simulation is performed in the sense of backtracking, i.e. the flow field is reversed, and the boundary conditions are adapted accordingly. At any position in the model domain, the time required for a water molecule to reach the outlet is estimated corresponding to the "life expectancy" (Cornaton and Perrochet 2006), i.e. the life expectancy on the outlet is zero. The simulation of life expectancy of water in the matrix block shows (1) the importance of heterogeneities for interpretation of groundwater ages, (2) the location of stagnant zones in areas of low hydraulic permeability and/or low hydraulic gradient and (3) that flow through unsaturated fissured matrix blocks may cause a considerable travel time of water through a karst system. The travel time of water from the recharge area to the discharge point for the shown example is about 15 years with a travel time of water through the unsaturated zone of 10 years (Geyer 2008). This result reflects the variation of estimated ages for different tracers sampled at the Gallusquelle spring. Additionally, we demonstrate that depending on boundary conditions, the unsaturated zone of a karst system may provide a large water storage since the porous matrix can be expected to be close to saturation and the volume fraction of fissures and conduits is small.

Literature

Cornaton, F., Perrochet, P. (2006): Ground-water age, life expectancy and transit time distributions in advective-dispersive systems: 1. Generalized reservoir theory. – Advances in Water Resources 29 (9): 1267-1291.

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