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Quantification of the heterogeneity in water transport through the unsaturated zone of sandy soils using environmental isotopes

C. Stumpp, P. Maloszewski, W. Stichler and P. Trimborn
GSF-Institute of Groundwater Ecology, D-85764 Neuherberg, Germany

Dealing with groundwater requires knowledge about the renewable rates, particularly when putting emphasis on risk assessment. Therefore it is necessary to develop methods for determining the water and solute transport through unsaturated zone, and with that estimate the vulnerability of the adjacent aquifer. Conventional mathematical approaches like the Richards Equation combined with the Mualem-van Genuchten model quantify the water transport through the unsaturated zone assuming homogeneous conditions. In reality soils are very complex systems of high heterogeneity. Therefore a new method, which combines mathematical modeling with environmental and hydrological data, was investigated to estimate the heterogeneity of the unsaturated soils by separation of preferential and matrix flows, quantify both fluxes and determine their transit times. Finally the transit time distribution functions were used to construct vulnerability maps of different soils without plants. The model complexity was simplified using a lumped parameter approach that combines an input and output function of environmental tracer contents with hydraulic measurements. This approach, normally used for steady state hydraulic conditions, was earlier compared with more exact numerical modeling of water flow and tracer transport through the unsaturated zone under variable flow conditions showing satisfactory results (Maciejewski et al. 2006; Maloszewski et al. 2006). Assuming a two parallel flow-paths model, which combines dispersion (matrix) and piston (channel) flow, the environmental deuterium (^{2}H) with its seasonal variation in precipitation and in lysimeters outflow was taken to estimate the mean transit times (MTT) as well as the amount of channel and matrix flow and enabled to quantify the heterogeneity of seven fallow, sandy lysimeters installed at the GSF site (L=2m, A=0.125m^2). The calculations were performed using weekly ^{2}H contents in recharge and discharge during an eight year

period (1984-1991).

Under natural atmospheric conditions it was found that preferential (channel) flow varied between 16.6% and 30.3% considering the period 1985-1991. The crucial parameter influencing these amounts is the saturated hydraulic conductivity (K_s). The transit time distribution functions can be depicted in vulnerability maps. Considering their patterns and the soil properties, the investigated soil materials can be put into three groups. Coarser material with low mean water content and high K_s showed short MTT (about 10 weeks), high dispersion parameter $P_D^*(\geq 0.05)$ and channel flow equal or higher than 20%. Finer sand with lower K_s and low mean water contents resulted in MTT of about 30 weeks, P_D^* smaller or equal to 0.03 and a channel flow of 16.6% to 21.1%. The medium grain size shows medium K_s, MTT, P_D^* and mean water content.

It was shown that creating vulnerability maps revealed different patterns that can be explained by the properties of the soils and give information about the soil heterogeneity. Such maps can give a hint when infiltrating water reaches the groundwater. Therefore in a case of an event of loss or damage groundwater drinking resources can be protected in time and purposefully.

Maciejewski S., Maloszewski P., Stumpp C. & Klotz D. Modelling of water flow through typical Bavarian Soils (Germany) based on lysimeter experiments: 1. Estimation of hydraulic characteristics of the unsaturated zone. Hydrological Sciences Journal **51**(2), 2006, in print.

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