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Using a physically-based water flow model to explore the dynamics of transit times and mixing in a small agricultural catchment

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Catchment-scale transit time distributions (TTDs) for discharge and residence time distributions of the water in storage (RTDs) are promising tools to characterize the discharge and mixing behavior of a catchment and can help to interpret the associated solute loads to the stream in a spatially implicit way. TTDs and RTDs are dynamic in time, influenced by dynamic rainfall and evapotranspiration forcing, and changing groundwater storage in the catchment. In order to understand the links between the dynamics of TTDs and groundwater mixing in the small agricultural catchment Schäfertal, in central Germany, a 3D hydrological model was set up for the catchment using the fully coupled surface-subsurface numerical model HydroGeoSphere (HGS). The model is calibrated using discharge and groundwater level measurements, and runs transiently for a period of 10 years from 1997 to 2007. A particle tracking tool was implemented in HGS to track the movement of water parcels in the subsurface, outputting TTDs of channel discharge and RTDs of groundwater storage at daily intervals.

Results show that the mean age of the discharge water is significantly younger than that of the water in storage, indicating a poorly mixed subsurface. Discharge preferentially samples faster flowing younger water originating from the more conductive top parts of the aquifer. Spatial variations of the age of water in storage are observed, highly influenced by aquifer heterogeneity. Computed StorAge Selection (SAS) functions [Rinaldo et al. 2015] show clear shifts in the discharge sampling preferences between wet and dry states: during wet states in winter and spring, discharge has a preference for younger water because the shallow flow paths are active due to high groundwater levels and low evapotranspiration. Conversely, during dry states in summer and autumn, discharge has a preference for older water because the shallow flow paths are inactive due to low groundwater levels and stronger evapotranspiration. Measured nitrate (NO_3) loads in discharge, mainly originating from fertilizer in shallow soils, decrease significantly with decreasing wetness of the catchment. This trend confirms the shifts of discharge sampling preferences between wet and dry states.

Reference:

Rinaldo, A., P. Benettin, C. J. Harman, M. Hrachowitz, K. J. McGuire, Y. van der Velde, E. Bertuzzo, and G. Botter (2015), Storage selection functions: A coherent framework for quantifying how catchments store and release water and solutes, Water Resour. Res., 51, 4840–4847, doi:10.1002/2015WR017273.