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Impact of meander geometry and stream flow events on residence times and solute transport in the intra-meander flow

Muhammad Nasir Mahmood, Christian Schmidt, and Nico Trauth
Helmholtz-Centre for Environmental Research - UFZ, Leipzig, Germany

Stream morphological features, in combination with hydrological variability play a key role in water and solute exchange across surface and subsurface waters. Meanders are prominent morphological features within stream systems which exhibit unique hydrodynamics. The water surface elevation difference across the inner bank of a meander induces lateral hyporheic exchange within the intra-meander region. This hyporheic flow is characterized by considerably prolonged flow paths and residence times (RT) compared to smaller scales of hyporheic exchange.

In this study we examine the impact of different meander geometries on the intra-meander hyporheic flow field and solute mobilization under both steady state and transient flow conditions. We developed a number of artificial meander shape scenarios, representing various meander evolution stages, ranging from a typical initial to advanced stage (near cut off) meander. Three dimensional steady state numerical groundwater flow simulations including the unsaturated zone were performed for the intra-meander region. The meandering stream was implemented in the model by adjusting the top layers of the modelling domain to the streambed elevation and assigning linearly decreasing head boundary conditions to the streambed cells. Residence times for the intra-meander region were computed by advective particle tracking across the inner bank of meander. Selected steady state cases were extended to transient flow simulations to evaluate the impact of stream discharge events on the temporal behavior of the water exchange and solute transport in the intra-meander region. The transient stream discharge was simulated for a number of discharge events of variable duration and peak height using the surface water model HEC-RAS. Transient hydraulic heads obtained from the surface water model were applied as transient head boundary conditions to the streambed cells of the groundwater model. A solute concentration source was added in the unsaturated zone to evaluate the effect of transient flow conditions on solute mobilization.

Our preliminary results indicate that residence times ranging from 0.5 to 250 hours are influenced by meander geometry, as well as the size of the intra-meander area. In general, we found that larger intra-meander areas lead to longer flow paths and higher mean intra-meander residence times (MRTs). The shortest RTs were observed near the meander neck in all scenarios, a feature most predominant in more developed meander resulting shorter MRTs. Transient modelling results show that fluctuations in stream hydraulic head influence the transport and zonation of the solute concentration in the intra-meander area with higher and longer stream discharge events leading to stronger mobilization and removal of solutes dominated mainly around meander neck area.