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Spatio-Temporal Dynamics of km- to Reach-Scale Hydrological Exchange Flows along a Large Dam-Regulated River Corridor

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This element of PNNL SFA seeks to study how the hydrological exchange flows (HEFs) at the river water and groundwater interface are impacted by the dynamics of river flow and the heterogeneity in hydrogeologic properties in dynamic river corridor systems. We used a combination of field observations and high-resolution 3D numerical simulations (PFLOTRAN) to understand the complex spatial and temporal dynamics of HEFs from the km- to reach-scale (10s of km) along the regulated river corridor of the Hanford reach. The spatially distributed hourly data acquired from a monitoring well network at the Hanford site are used to define the initial and boundary conditions of groundwater aquifer, as well as for calibrating and validating numerical models. The drilling logs of the wells and river bathymetry were used to conceptualize the hydrogeologic formations of the domain, which show substantial variability in aquitard topography within the Hanford river corridor. Spatially distributed river elevations simulated by the MASS1 model at an hourly time step were used as spatially-variable pressure boundary condition at the river. Heterogeneity in the riverbed conductance is parameterized based on the river substrate. Multiple numerical tracers are introduced at selected segments of river boundary to track the contribution of river water in the groundwater system from different locations of the river. Particle tracking is run by continuously releasing particles along the shoreline to reveal exchange pathways and estimate the distributions of river water residence time.

At the km-scale, the exchange pathways exhibit strong heterogeneity along the river shoreline within a given flow window as impacted the physical heterogeneity in riverbed substrate and in the aquifer. The riverbed permeability (or conductance) and its spatial heterogeneity are identified as the most sensitive parameters of the HEF model. The exchange patterns also vary substantially across different flow regimes. Consequently, the residence time distribution of river water in the groundwater system is characterized by long tails and multiple modes. The relationship between the residence time distribution and frequency of flow variation and physical heterogeneity is being developed. The km-scale model provided the foundation for building the reach-scale HEF model that encompasses multiple hydromorphic features of the entire reach, which is under active development. The HEF studies at both the km and reach scales and the subsequent studies on river corridor biogeochemical processes will fill in a critical need in bridging the gaps between hydromorphic-scale process understanding and robust predictions of the watershed hydrobiogeochemical function.