Poster #21-75

Mechanistic Models of Hydrologic Exchange Flows in Diverse Hydromorphic Settings

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BER Program: SBR
Project: PNNL SBR SFA
Project Website: https://sbrsfa.pnnl.gov/

This element of the PNNL SFA seeks to develop mechanistic understanding of hydrologic exchange flows (HEFs) and associated biogeochemical processes and develop approaches for representing these processes at system scales. Hydrologic exchange between rivers and subsurface environments is a critical mechanism that shapes hydrobiogeochemical processes in river corridors and watersheds. Because of limitations in field accessibility, computational demand, and complexities of geomorphology and subsurface geology, three-dimensional mechanistic modeling studies to quantify hydrologic exchange flows (HEFs) have been mostly limited to local-scale applications in individual bedforms. Although it is well known that surface flow conditions, riverbed morphology, and subsurface physical properties strongly modulate hydrologic exchanges, quantitative measures of their effects on the strength and direction of such exchanges in complex hydromorphic settings are lacking.

Here, three-dimensional models of coupled river hydrodynamics and subsurface flow and transport simulations in diverse hydromorphic settings are used to study the hydrologic exchange flows and residence time distributions at kilometer scales in order to support the development of reduced-order models at reach and watershed scales. Hydrologic exchange is often simulated by assuming hydrostatic pressure on the river bed as a boundary condition. In this study, the impact to HEFs driven by the non-hydrostatic pressure variations on the riverbed are explored by comparing model results simulated by PFLOTRAN (an open source subsurface flow and transport model) driven by 1) non-hydrostatic pressure simulated using open-source computational fluid dynamics (CFD) software OpenFOAM, and 2) hydrostatic pressure simulated by the 2D Modular Aquatic Simulation System (MASS2) model. Particle tracking is used to quantify residence time distributions (RTDs) within a 7-km river section at the Hanford 100FH area. Model outputs are analyzed in the context of classes of hydromorphic features (previously defined and mapped over the entire Hanford Reach) to quantify the impacts of hydromorphology on HEFs and RTDs for each hydromorphic class. This new understanding is guiding development of reduced-order modeling at reach to watershed scales and the selection of locations for field studies.