Quantifying Reach-scale Dynamics of Groundwater-Surface Water Exchange and Land-Atmosphere Interactions along the Columbia River Shoreline through Model-Data Integration

PNNL SBR SFA (Laboratory Research Manager: Charlette Geffen)

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Lateral flow and transport between groundwater and river water through the subsurface interaction zone (SIZ) is a major pathway for energy, water, solute, and gas transfer between terrestrial and aquatic systems. Groundwater – surface water exchange is significant at multiple scales, but has been poorly quantified along large river reaches and has not been adequately resolved in Earth System Models (ESMs). Through an active collaboration among scientists at PNNL, SNL, LBNL, and WSU, the PNNL SBR-SFA has established a reach-scale research framework integrating high-fidelity computational tools with extensive surface and subsurface characterization and monitoring to assess the importance of SIZ at the reach scale. Specifically, the framework includes: (1) an integrated land surface and subsurface model enhanced with SIZ processes [i.e., CLM-PFLOTRAN] that is capable of quantifying water and solute exchanges in the SIZ and its impacts on land-atmosphere exchanges; (2) a computational fluid dynamics (CFD)-based approach for benchmarking hyporheic flow patterns under various flow conditions; (3) monitoring of land-atmosphere exchanges of water, energy, and CO2 fluxes along the reach and across upland, riparian zone, and wetland locations; (4) characterization of surface/subsurface water conditions and groundwater-surface water exchange using in-situ boat-based observations.

A 7-km reach along the Columbia River shoreline has been selected to demonstrate the capability of this framework. Along the reach, subsurface and riverine facies are defined based on geo-stratigraphic and hydrodynamic attributes and their flow and transport properties are used for integrated simulations. A series of CFD simulations are first performed to understand hyporheic flow patterns and exchange rates under various flow conditions, which are validated by ground- and boat-based measurements. Idealized simulations are then conducted to isolate the roles of geomorphological features such as river bathymetry, islands and bars in modulating hyporheic flow patterns and exchanges. Lastly, CLM-PFLOTRAN simulations, benchmarked by the CFD simulations, are being performed for a period of five years (2010-2015) spanning high and low flow conditions to quantify the inter-annual variability of hyporheic exchange and its role in modulating land-atmosphere interactions. The research framework, capable of quantifying hyporheic and land-atmosphere exchanges through model-data integration, establishes a solid foundation for better understanding the spatial and temporal dynamics of biogeochemical cycling and biogenic gas generation in the SIZ, and their impacts on and regulation by the changing water cycle and climate. Subsequent research will integrate a multi-scale facies definition (e.g., Hou et al) to extend the integrated modeling approach to the 75 km Hanford Reach, a typical scale relevant to ESM development in DOE projects.