Quantifying Stream-Aquifer-Land Interactions along a large dam-regulated River Corridor using Integrated Modeling and Observations

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In this presentation, we will discuss the development and application of an integrated surface and subsurface model for quantifying stream-aquifer interactions in terms of variations in mass exchange rates and groundwater elevations induced by pressure gradient and mass exchange along a large dam-regulated reach of the Columbia River Corridor, as well as their relations to the partitioning of the surface energy budget. The integrated model, named CP v1.0, features the coupling of the Community Land Model version 4.5 (CLM4.5) and a massively-parallel multi-physics reactive transport model (PFLOTRAN). The CP v1.0 model was applied to field scale sites along the Columbia River shoreline and validated against observations from groundwater monitoring wells. Simulations were performed at three spatial resolutions over a five-year period to evaluate the impact of hydro-climatic conditions and spatial resolution on simulated variables.

Results show that CP v1.0 is capable of simulating groundwater-river water interactions driven by river stage variability along managed river reaches, which are of global significance as a result of over 30,000 dams constructed worldwide during the past half century. Our numerical experiments suggest that the land-surface energy partitioning is strongly modulated by groundwater-river water interactions through expanding the periodically inundated fraction of the riparian zone, and enhancing moisture availability in the vadose zone via capillary rise in response to the river stage change. Meanwhile, CLM4.5 fails to capture the key hydrologic process (i.e., groundwater-river water exchange) at the site, and consequently simulates drastically different water and energy budgets. Furthermore, spatial resolution significantly impacts the accuracy of the estimated mass exchange rates at the boundaries of the aquifer, and it becomes critical when surface and subsurface become more tightly coupled with groundwater table within six to seven meters below the surface. Inclusion of lateral subsurface flow influenced both the surface energy budget and subsurface transport processes as a result of river water intrusion into the subsurface in response to elevated river stage that increased soil moisture for evapotranspiration and suppressed available energy for sensible heat in the warm season.

The findings from model simulations were confirmed by observations from three eddy covariance flux towers. Analyses of eddy covariance and collocated soil and groundwater observations suggested that land surface energy fluxes and net ecosystem exchange could vary

significantly as a function of accessibility to groundwater and its connectivity to river water. The coupled model developed in this study can be used for improving mechanistic understanding of ecosystem functioning, biogeochemical cycling, and land-atmosphere interactions along river corridors under historical and future hydro-climatic changes, including river reaches downstream to hydropower dams characterized by highly variable river stage variations. The dataset presented in this study can also serve as a good benchmarking case for testing other integrated models.

Finally, we will briefly review on-going efforts toward building a new integrated watershed modeling framework that explicitly accounts for river corridor processes. Specifically, we will update CP v1.0 to incorporate new developments in subsurface flow and reactive transport (i.e., PFLOTRAN), land surface processes (i.e., CLM or the Energy Exascale Earth System Land Model), and river flow and transport (i.e., the routing model in the Soil and Water Assessment Tool or SWATR) enhanced with hydromorphology-based models of hydrologic exchange and reaction potential (i.e., the physically-based Networks with EXchange and Subsurface Storage or NEXSS). This framework will be used to study cumulative effects of hydrologic exchange flows and river corridor biogeochemistry on watershed-scale nutrient processing by conducting numerical experiments with and without river corridor processes.