Flood Plain Modeling: Hydrological, Biogeochemical, and Microbial Controls on Carbon and Nitrogen Fluxes

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2-D and 3-D reactive flow and transport modeling was used to address the principal controls on carbon and nitrogen cycling in the Rifle and lower East River, Colorado flood plains. The objectives of this work are to: (1) quantify the impact of biogeochemical hot spots (e.g., hyporheic zones, reduced minerals) and hot moments (e.g., river water/ground water fluctuation) on carbon and nutrient fluxes at flood plain/watershed scales, and (2) understand the role of including microbial complexity in reaction networks.

At the Rifle site, the modeling group has led to the development of a 2-D genome-informed reactive-transport model to investigate the impact of localized biogeochemically reduced zones (referred to as naturally reduced zones or NRZs) as well as hot moments on vertical and lateral carbon fluxes. The 2-D model was based on a site-specific reaction network that was informed by genomic studies which explicitly accounted for the previously identified chemolithoautotrophic processes at the site. Importantly, the 2-D modeling efforts suggested that the genome-informed reaction networks and representation of hotspots and hot moment significantly improved prediction of carbon cycling at the Rifle flood plain.

At the lower East River Watershed study site, our efforts have focused on evaluating the importance of hyporheic zone interactions on carbon and nitrogen cycling. Upwelling of nutrient-rich water and downwelling of higher pH and dissolved oxygen rich-water can lead to distinct biogeochemical gradients within the hyporheic zone. To understand the impact of hyporheic exchanges on hydrological and biogeochemical fluxes at the meander scale, we integrated a genome-informed reaction network (similar to the Rifle site model) with a high-resolution, 3-D reactive transport solver - PFLOTRAN. 3-D modeling results demonstrate that the intra-meander hyporheic flow paths and biogeochemical reactions cause the lateral redox zonation, which considerably impact the carbon and nitrogen fluxes into the stream system. Also, the meander-driven hyporheic flow paths enhance denitrification because of relatively longer residence times of nitrate in the organic carbon-rich sediments.

The work also includes the development of scaling constructs based on high resolution 2-D and 3-D reactive transport modeling to capture explicitly the scale-dependence of the hydrological and biogeochemical fluxes across the important subsystem compartment of the floodplain, with inputs from both the upstream river system, adjacent hillslopes, and the deeper shale bedrock compartments.