Rifle Floodplain Water Table Dynamics: Biogeochemical Cycling and Uranium Mobility

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Coupled-process modeling is used to build a systematic understanding of the interplay of hydrology, geochemistry, and biology controlling the cycling of carbon, nitrogen, oxygen, iron, sulfur, and uranium in a shallow aquifer-vadose zone-river hydrologic system situated in a floodplain of the Colorado River in Rifle, Colorado, USA and the site of Berkeley Lab's Subsurface Biogeochemistry Genomes-to-Watershed SFA. For most of the year, the floodplain aquifer is generally deficient in oxygen and nitrate. During the snowmelt-driven water table rise and fall in early summer, oxygen and nitrate in the previously unsaturated vadose zone is mixed into groundwater near the water table. The temporal and spatial variation of the biogeochemical response to this event provides an opportunity to characterize process and property interactions responsible for observed behaviors. Some of these behaviors can be linked to distinct zones that reflect the prehistory of the site, including the preferential deposition of organic material and, more recently, the management of uranium mill tailings. Naturally reduced zones have sediments higher in organic carbon and iron sulfides that are linked to faster oxygen consumption, more sulfate and nitrate reduction, and chemolithoautotrophy. Three-dimensional variably-saturated flow and multicomponent biogeochemical reactive transport modeling is used as a systematic framework for interpreting the impact of different material zones, processes responsible for maintaining anoxic conditions, the response to the seasonal water table peaking event, and the redox cycling required to sustain the seasonal behaviors. The biological modeling includes functional representation of fermenters, aerobes, nitrate reducers, sulfate reducers, and chemolithoautotrophs (e.g., microorganisms catalyzing the oxidation of reduced iron, sulfur, and nitrogen). The modeling results are consistent with the oxidation and mobilization of iron, sulfur, and uranium in the background aquifer and NRZs. The mobilization of uranium during the seasonal water table peak is consistent with the oxidation of monomeric U(IV) by biogenic nitrite, and the leaching of surface-complexed U(VI) in the vadose zone. Omics and isotope fractionation have been particularly useful in conceptualizing processes where the absence of measurable concentrations of rapidly-consumed substrates can be problematic.