Hydrologic and thermodynamic drivers seasonally shift floodplain soils between two redox states

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Physical and hydrologic heterogeneity within the critical zone remains a challenge for modeling soil biogeochemical cycling and solute transport, particularly as models bridge processes from molecular to catchment scales. This is especially important when reactive transport models are employed to predict the fate of contaminants during monitoring and remediation. For instance, at a former uranium ore processing site at Riverton, WY, the floodplain soils exhibit physically and chemically heterogeneous properties from the millimeter to meter scale. We observe that low permeability zones enriched in organic carbon (OC) disproportionately impact biogeochemical cycling and contaminant mobility. Springtime saturation of the soil triggers the onset of reducing conditions, which mobilizes iron and associated nutrients, initiates denitrification, and can drive reductive immobilization of sulfide-hosted and redox-active contaminants. Ebbing late-summer water tables expose formerly water-saturated sediments to air oxidizing the accumulated reduced species, and again influences contaminant mobillity.

To develop responsive numerical representations of key biogeochemical processes we characterize redox transitions in seasonally saturated soil over a full snowmelt-driven runoff-to-drainage cycle. Pairing porewater and soil compositions with hydraulic head and gradients, we observe coincident shifts in water level, groundwater velocities, redox potential, and contaminant concentrations. As spring runoff saturates the aquifer, a reducing front propagates through the soil profile, reaching a maxiumum within six weeks of saturation at a level maintained for another twelve weeks. Significantly, full reoxidation is not achieved until ten weeks after the water table returns to base flow. This suggests that accumulation of reduced species (e.g. iron sulfide minerals) serves as a redox buffer as the soil drains and is exposed to air. These results show in new detail that seasonal saturation drives rapid redox transitions and dramatic elemental cycling with important consequences for C, N, P, and contaminant cycling.