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SLAC Groundwater Quality SFA: Hydrologically Driven Biogeochemical Processes Controlling Water Quality

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A growing body of evidence highlights the importance of capillary fringe wet-dry cycling to groundwater quality in the upper Colorado River Basin (CRB), one of Earth's most over-allocated watersheds. Increasingly frequent drought is perturbing the timing and intensity of wet-dry cycles, creating a need for mechanistic understanding of water cycle-biogeochemistry linkages to support water quality prediction. Our research shows that wet-dry cycling in organic-enriched capillary fringe sediments creates transiently reduced zones (TRZs) at sites across the upper CRB. Ebbing summer water tables expose sediments that were formerly water-saturated to air, driving biogeochemical reactions that release organic carbon, nutrients and contaminants. Springtime re-saturation of sediments initiates a new suite of biogeochemical processes, which again have the potential to mobilize nutrients and contaminants. In this fashion, water and biogeochemical cycles intimately intertwine to control nutrient and contaminant behavior. At present, mechanistic understanding of the interdependencies between hydrology, biogeochemistry, and nutrient/contaminant transport within the capillary fringe is poor.

Here we present three sets of field observations that frame the new SLAC *Groundwater Quality* SFA and shed light on mechanisms of hydrologic-biogeochemical coupling in TRZs: (i) Downward as well as robust *upward* transport of water couples biogeochemical activity in the unsaturated zone, capillary fringe, and saturated zone throughout the year at the Riverton, WY site. Riverton is a model for saturated-unsaturated zone interactions, and these findings indicate that biogeochemical groundwater quality models must account for such vertical exchange processes; (ii) The intensity of reducing conditions in TRZs is thresholded by organic carbon and moisture content; and (iii) A reactive pool of iron in TRZs cycles between mackinawite and goethite during wet-dry redox cycles, providing an engine to periodically release or trap associated organic matter, nutrients, contaminants, and colloids. These findings suggest a new conceptual model wherein capillary fringes function as biogeochemical hot zones throughout the year, and nutrient and contaminant mobility is tightly coupled to iron cycling. The model predicts that solutes and nutrients accumulate in the soil zone during the summer and are flushed downward in spring, stimulating biogeochemical redox activity and mineral precipitation/dissolution in underlying saturated sediments. The mission of the SLAC Groundwater Quality SFA is to test this model through laboratory and field research, and to develop fine-scale quantitative process representations that can be incorporated into larger-scale models. We are initially focusing on modeling linkages between hydrology and redox conditions. Nutrient and contaminant mobilization will be understood within this framework.