SLAC Floodplain Hydro-Biogeochemistry SFA: Spatiotemporal Response of Soil-Gravel Bed Connectivity to Hydrological Transitions in an Intermountain Floodplain Aquifer

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Project Abstract: Riparian environments in the Intermountain West are often characterized by extensive interfaces between basal gravel/cobble alluviums and overlying fine-grained soils, which exhibit sharp redox and solute concentration gradients that mediate subsurface water quality. The biogeochemical function of these interfaces results from a tight coupling between hydrological and biogeochemical processes. In particular, the hydraulic connectivity between the gravel bed and the soil dictates the direction and intensity of solute exchanges, and consequently the capacity of the floodplain system to act as a sink or as a source for redox-sensitive nutrients or contaminants (*e.g.* Fe, C). Yet, the spatial evolution of this connectivity and its response to hydrological shifts remain poorly understood.

Our combined field and numerical modeling work on our field site of Slate River, CO, highlights the ways in which the gravel bed controls floodplain hydrology. Due to its large volume and hydraulic conductivity, the gravel bed acts as a preferential flowpath for regional subsurface flow in the down-valley direction, and shows a strong connection with surface water with fast response to hydrological shifts. In contrast, the overlying riparian soils correspond to a hydraulic transition zone between the gravel bed and the surface water, that accommodates smaller-scale hydro-geomorphological features such as the presence of a beaver pond. During snowmelt, rapidly rising water tables in the gravel bed impede downwards surface water infiltration and increase water residence times in the soil. During baseflow, declining water tables in the gravel bed drive more surface water into the soil and through the soil-gravel bed interface. Our work also indicates that the mostly downward flow direction at the soil-gravel bed interface may occasionally reverse, for instance in the return flow areas downstream of beaver dams, or in the distal areas from the stream where evapotranspiration becomes dominant over lateral surface water recharge. These results highlight how hydrologic dynamics and hydraulic connectivity help mediate intermountain floodplain function.

SLAC Floodplain Hydro-Biogeochemistry SFA: Colloid Dynamics at Floodplain Soil-Gravel Bed Interfaces

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Project Abstract: Subsurface interfaces are ubiquitous in floodplain environments and sustain a multitude of biogeochemical processes, including the formation and release of reactive, mobile colloids. Colloids are known vectors of micronutrient, contaminant, and organic matter transport and are suspected to be important export agents from floodplains to stream water. However, few studies have documented the impact of seasonally-variable field hydrological and geochemical dynamics on redox-active colloid occurrence, and transport in riparian floodplains.

We used a combination of cascade filtering, advanced analyses of field samples, lab-based column experiments, and reactive transport modelling (RTM) to characterize the fate of Fe-rich colloids at our floodplain field site of Slate River, CO. Cascade filtering revealed the presence of Fe-rich colloids in the riparian anoxic soil water, whose abundance and composition vary with season and depth, suggesting a strong link to hydrological and biogeochemical dynamics. Cryo-EM and TEM-EDS imaging showed mono-dispersed and nano-assemblages of spherical colloids in the 10-50 nm range containing Fe, O, Si, C, and Ca. Mössbauer spectroscopy indicated a poorly crystalline ferrihydrite-like phase, coated with organic matter and Si. Fe-EXAFS further verified ferrihydrite and Fe(II)- and Fe(III)-organic matter interactions. We therefore conclude the colloids are primarily composed of nanosized ferrihydrite spheres that are stabilized by organic matter, Si, and bridging cations (e.g., Ca). The fact that these Fe(III)-rich colloids existed in primarily anoxic zones is striking. We postulate that the Si-organic matter coating provides a primary protective layer against reduction, but its efficiency depends on the biogeochemical and hydrological conditions. In spring, porewater flow velocity was low in the anoxic soil, due to rising water table, and a higher abundance of Fe(II)-rich colloids was observed. We hypothesize that longer residence times coupled with high organic matter levels, contribute to the formation of the reduced, nanosized colloids. At baseflow, in summer and autumn, increased downward infiltration appears to flush the colloids into to the gravel bed, where relatively high (1.5 m/day) flow velocities may transport them to the river. Furthermore, findings from our column experiments coupled with reactive transport simulations suggest that organic matter-bearing colloids may substantially alter the biogeochemical functioning of the gravel bed itself.

SLAC Floodplain Hydro-Biogeochemistry SFA: Hydrological and microbiome dynamics drive shifts in subsurface geochemistry and oxic-anoxic interfaces in floodplain soils

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Project Abstract: Subsurface microbial communities in floodplain soils drive major biogeochemical cycles (e.g., C, N, S) and control the fate and transport of many metals and contaminants (e.g., Fe, Mn, Zn). Each year floodplains experience seasonal rise and decline of the water table that determines nutrient and other inputs to the subsurface, as well as the oxygen penetration depth. Within the soil column, the boundary depth between oxic and anoxic conditions is therefore controlled largely by floodplain hydrology. Snowmelt-induced flooding and other precipitation further contribute to shifts in the depth of this oxic-anoxic interface. Thus, it is critical to define connections between seasonal hydrology and changes in microbial community composition (and function), as these are not yet well understood.

In our study site along the Slate River, CO, we observe two types of interfaces, namely: (1) an oxic-anoxic interface within the fine-grained layer, as well as (2) a deeper physical interface where soils/sediments shift to a coarse cobble layer. This cobble layer is more directly connected to the river, with oxygenated groundwater moving through it, thus forming a secondary oxic-anoxic interface deeper in the soil column. Using these two interfaces as a guide, we investigated microbial community composition across multiple depths (~10-30 cm resolution) and time points from 2018-2021 at two Slate River floodplain sites. This spatiotemporal analysis consistently revealed phylogenetically- and metabolically-diverse populations of bacteria and archaea, including methanogens and methanotrophs, sulfur-oxidizing and -reducing taxa, ammonia-oxidizing archaea, and iron-cycling bacteria. These communities showed a striking depth distribution across oxic-anoxic boundaries; for example, within the *Archaea*, ammonia-oxidizing *Thaumarchaeota* were abundant in shallow oxic soils, whereas methanogens and *Bathyarchaeota* were found exclusively in deeper anoxic soils. We also investigated the impact of hydrologic perturbations on subsurface microbial communities and geochemistry, through field inundation experiments as well as the coincidental construction of a beaver dam at one site in 2019. The resultant flooding caused microbial community shifts that are reflected in observed geochemistry, as well as modeled oxygen penetration depth. Further analyses, including genome-resolved metagenomics and metatranscriptomics, will be employed to examine floodplain microbiome dynamics at an even finer scale and connect both hydrology and geochemistry to specific biogeochemical processes.