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Scale dependent importance of spatial heterogeneity in biogeochemical cycling at aquifer-river interfaces

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The transport and transformation of carbon and nitrogen across aquifer – river interfaces are significantly altered along the streambed passage. Recent investigations have substantially improved the understanding of controls on streambed biogeochemical cycling, outlining a critical impact of exchange fluxes, temporal and spatial coincidence of reaction partners and streambed residence time distributions. Still, there is little understanding of the drivers of the widely observed strong spatial and temporal variability of interlinked carbon and nitrogen turnover at aquifer-river interfaces, including hotspots (locations) and hot moments (time periods) of increased reactivity. Previous research, predominantly with a surface water perspective, has mainly focused on the impact of bedform controlled hyporheic exchange fluxes and the chemical transformation of surface solutes transported along a hyporheic flow path. While such studies may explain nutrient turnover in the hyporheic zones of low-order streams in rather pristine headwater catchments, they fail to explain observations of spatially and temporally more variable nutrient turnover in streambeds with higher structural heterogeneity and relevant concentrations of autochthonous carbon and nitrogen.

Here we combine laboratory, field and numerical modeling experiments from plot to stream reach/subcatchment scales to quantify the impacts of variability in physical and biogeochemical streambed properties on hyporheic nutrient (C, N, O) cycling.

At the plot scale, hotspots of biogeochemical cycling have been found to be associated with peat and clay layers within streambed sediments, representing areas of significantly increased residence times and oxygen consumption what results in enhanced microbial metabolic activity and nitrogen removal capacity. We present distributed sensor network based up-scaling methods that allow identification of such features at larger reach scale. Numerical modeling based generalization approaches confirmed that variability in streambed conductivity observed in the field could substantially diversify streambed residence time distributions, creating hotspots with either enhanced anaerobic or aerobic respiration potential.

Small-scale investigations were combined with reach-scale tracer studies to study the impact of sub-reach variability (geomorphology, woody debris) on river respiration and microbial metabolic activity. Novel, in-situ fluorescence sensors have been deployed together with continuous dissolved oxygen monitoring to identify areas of enhanced microbial metabolic activity and stream respiration, revealing that similar to small scale hotspots, biogeochemical turnover can be enhanced significantly around streambed features that enhance hyporheic exchange and residence times.