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Influence of varying hydraulic conditions on hyporheic exchange and reactions in an in-stream gravel bar

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In the hyporheic zone (HZ) important biogeochemical transformations occur with crucial impact on nutrient cycling in fluvial systems. Here we investigate the interplay between stream flow and HZ exchange of a natural in-stream gravel bar (ISGB), by using three-dimensional steady state simulations of a coupled surface and subsurface numerical model.

Stream flow is simulated by the open source computational fluid dynamics (CFD) software OpenFOAM. It is sequentially coupled by the hydraulic head distribution to the top boundary of the groundwater model code MIN3P, simulating flow, solute transport, aerobic respiration (AR) and denitrification (DN) in the HZ. The modelling approach is validated to the stream rating curve and the subsurface travel times in the ISGB based on field measurements. Hydraulic conditions are varied by stream discharge, ranging from low discharge, sufficient to allow stream water flow through both stream channels surrounding the ISGB (0.1 m^3/s), to conditions where the ISGB is completely submerged (5.0 m^3/s). Ambient groundwater flow is assigned by constant head boundaries upstream and downstream of the ISGB. By varying stream discharge or ambient groundwater heads the general flow field of the ISGB can be adjusted from losing via neutral to gaining conditions.

Reactive transport scenarios consider stream water as the primary source of dissolved oxygen and dissolved organic carbon. Furthermore, two nitrate sources originated from the stream water and ambient groundwater are included in the model.

Results show that highest hyporheic exchange and longest residence times occur under neutral conditions, where the extent of the hyporheic flow cell is at a maximum. Hence, the stronger the system is gaining and losing, the smaller is the hyporheic exchange flux and the shorter are the residence times in the HZ of the ISGB. AR and DN efficiencies of the ISGB are lowest under gaining conditions because infiltrating solutes are restriced to the hyporheic flow cells and hence to small reactive areas. In contrast, under losing conditions stream solutes infiltrate deep into the HZ and overreach the extent of the hyporheic flow cells, resulting in large reactive areas with highest AR and DN efficiencies.