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Stream discharge events increase the reactive efficiency of the hyporheic zone of an in-stream gravel bar

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Streambed structures such as dunes, pool-riffles or bars enhance the exchange of stream water and solutes with the subsurface, the hyporheic zone. Prior studies have evaluated the factors which control hyporheic exchange and biogeochemical processes for steady state hydrological conditions using numerical models. However, the impact of natural discharge variability on water and solute exchange, creating hydraulically specific conditions for the reactions in the shallow streambed, has received less attention to date.
In our study, we set up a transient flow and reactive transport model to elucidate the impact of single stream discharge events on water exchange, solute transport and reactions within the hyporheic zone of an in-stream gravel bar. The discharge events were varied by their duration and the maximum stream discharge. Temporally varying hydraulic heads were assigned as hydraulic head boundary conditions at the top of the reactive groundwater model MIN3P. A steady ambient groundwater flow field was introduced by lateral upstream and downstream hydraulic head boundaries, resulting in losing, neutral, or gaining conditions in the stream with respect to exchange with groundwater. Stream water borne dissolved oxygen, dissolved organic carbon and nitrate can infiltrate across the top of the modelling domain, where aerobic respiration and denitrification are simulated.
Our results show that water and solute exchange through the hyporheic zone (only stream water that infiltrates into the subsurface and exfiltrates back to the stream) is highly dependent on the interplay between event characteristics and the ambient groundwater level. In scenarios where the stream discharge shifts the hydraulic system to strong and long-lasting losing conditions, hyporheic flow paths are longer and the extent of the hyporheic zone deeper than under base flow conditions and small hydrologic events where gaining conditions prevail. Consequently, stream discharge events may temporarily lead to increased reactive efficiency (the ratio between solute consumption and solute influx) of the hyporheic zone by approximately 2.0 and 3.8 times for aerobic respiration and denitrification, respectively.