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Impact of transient stream flow on water exchange and reactions in the hyporheic zone of an in-stream gravel bar

Nico Trauth, Christian Schmidt, and Jan H. Fleckenstein
Helmholtz Centre for Environmental Research - UFZ, Hydrogeology, Leipzig, Germany (nico.trauth@ufz.de)

Groundwater-surface water exchange is an important process that can facilitate the degradation of critical substances like nitrogen-species and contaminants, supporting a healthy status of the aquatic ecosystem. In our study, we simulate water exchange, solute transport and reactions within a natural in-stream gravel bar using a coupled surface and subsurface numerical model. Stream water flow is simulated by computational fluid dynamics software that provides hydraulic head distributions at the streambed, which are used as an upper boundary condition for a groundwater model. In the groundwater model water exchange, solute transport, aerobic respiration and denitrification in the subsurface are simulated. Ambient groundwater flow is introduced by lateral upstream and downstream hydraulic head boundaries that generate neutral, losing or gaining stream conditions. Stream water transports dissolved oxygen, organic carbon (as the dominant electron donor) and nitrate into the subsurface, whereas an additional nitrate source exists in the ambient groundwater.

Scenarios of stream flow events varying in duration and stream stage are simulated and compared with steady state scenarios with respect to water fluxes, residence times and the solute turn-over rates. Results show, that water exchange and solute turn-over rates highly depend on the interplay between event characteristics and ambient groundwater levels. For scenarios, where the stream flow event shifts the hydraulic system to a net-neutral hydraulic gradient between the average stream stage and the ambient groundwater level (minimal exchange between ground- and surface water), solute consumption is higher, compared to the steady losing or gaining case. In contrast, events that induce strong losing conditions lead to a lower potential of solute consumption.