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How important are biogeochemical hotspots at aquifer-river interfaces for surface water and groundwater quality?

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The mixing of groundwater (GW) and surface water (SW) can have substantial impact on the transformation of solutes transported between aquifer and river. The assessment of biogeochemical cycling at reactivity hotspots as the aquifer-river interface and its implications for GW and SW quality require detailed understanding of the complex patterns of GW-SW exchange fluxes and residence time distributions in particular under changing climatic and landuse conditions.

This study presents combined experimental and model-based investigations of the physical drivers and chemical controls of nutrient transport and transformation at the aquifer-river interfaces of two upland and lowland UK rivers. It combines the application of in-stream geophysical exploration techniques, multi-level mini-piezometer networks, active and passive heat tracing methods (including fibre-optic distributed temperature sensing - FO-DTS) for identifying hyporheic exchange fluxes and residence time distributions with multi-scale approaches of hyporheic pore-water sampling and reactive tracers for analysing the patterns of streambed redox conditions and chemical transformation rates.

The analysis of hyporheic pore water from nested multi-level mini piezometers and passive gel probe samplers revealed significant spatial variability in streambed redox conditions and concentration changes of nitrogen species, dissolved oxygen and bio-available organic carbon. Hot spots of increased nitrate attenuation were identified beneath semi-confining peat lenses in the streambed of the investigated lowland river. The intensity of concentration changes underneath the confining peat pockets correlated with the state of anoxia in the pore water as well as the supply of organic carbon and hyporheic residence times. In contrast, at locations where flow inhibiting peat layers were absent or disrupted - fast exchange between aquifer and river caused a break-through of nitrate without significant concentration changes along the hyporheic flow path. Fibre-optic distributed temperature sensor networks and streambed electric resistivity tomography were applied for identifying exchange flow patterns between groundwater and surface water in dependency of streambed structural heterogeneity and for delineating the location and extend of flow inhibiting structures as indicators of streambed reactivity hot spots.

Results of these surveys indicate that during summer, patterns of cold spots in the investigated streambed sediments can be attributed to fast groundwater up-welling in sandy and gravely sediments resulting in low hyporheic residence times. Contrasting conditions were found at warmer areas at the streambed surface where groundwater – surface water exchange was inhibited by the existence of peat or clay lenses within the streambed.

Model simulations of coupled groundwater and surface water flow indicated that ignoring the increased reactivity in hyporheic streambed hotspots would lead to substantial under- or over-prediction of nitrate fluxes between aquifer and stream with potentially critical implications for river management and restoration.

The investigations supported the development of a conceptual model of aquifer-river exchange and hyporheic reactivity in lowland rivers including temperature traceable hyporheic exchange fluxes at multiple scales and highlighted the necessity to adequately reflect hyporheic hotspot reactivity in coupled groundwater-surface water models for adequate water quality predictions.