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Hot Moments in Cold Spots – Investigating Reactive Transport Patterns at Aquifer-River Interfaces by Heat Tracers and Distributed Sensor Networks

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The mixing of groundwater and surface water in hyporheic zones often coincides with high redox reactivity and chemical transformation potential. Depending on redox conditions and reaction types, hyporheic mixing of groundwater and surface water can lead to either attenuation or enrichment of pollutants or nutrients with diametrical implications for stream and aquifer hydro-ecological conditions.
This study investigates the reactive transport of nitrate and a chlorinated solvent (Trichloroethylene - TCE) at the aquifer-river interface of a UK lowland river. In this study, distributed temperature sensor networks and hydrogeophysical methods, which have been applied for identifying structural streambed heterogeneity and tracing aquifer river exchange, were combined with hydro-chemical analyses of hyporheic multi-component reactive transport.
In stream Electric Resistivity Tomography has been applied to map the complex spatial distribution of highly conductive sandy and gravely sediments in contrast to semi-confining, low conductivity peat lenses.
Reach scale (1km) spatial patterns and temporal dynamics of aquifer-river exchange have been identified by heat tracer experiments based on fibre-optic Distributed Temperature Sensing in combination with 2D thermocouple-arrays and small scale heat pulse injection methods for tracing shallow (25 cm) hyporheic flow paths.
Spatial patterns of hyporheic redox conditions, dissolved oxygen and organic carbon (DOC) content as well as concentrations of major anions, TCE and its decay products have been observed in 48 nested multi-level piezometers and passive DET (Diffusive Equilibrium in Thin film) gel probes.
Our results indicate that patterns of cold spots in 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. These flow-inhibiting structures have been shown to cause semi-confined conditions in the up-welling groundwater, resulting in long residence times and increased redox-reactivity. Anoxic conditions and high DOC contents combined with long residence times underneath peat layers cause highly efficient denitrification rates, reducing nitrate concentrations from > 50mg/l to below the level of detection. In contrast, sandy and gravely areas of fast groundwater up-welling where characterized by only marginal changes in nitrate concentrations. Observation of the reactive transport of the chlorinated solvent groundwater plume into the river suggest that natural attenuation of TCE, which competes with nitrate for DOC as reductive agent, is limited to the semi-confined, anoxic, low nitrate – high DOC groundwater pockets underneath streambed peat lenses.
The investigations supported the development of a conceptual model of aquifer - river exchange and hyporheic reactivity in lowland rivers including temperature traceable “hyporheic super-reactors” of great importance for river restoration, water quality and ecology status.