Geophysical Research Abstracts
Vol. 13, EGU2011-9110, 2011
EGU General Assembly 2011

Hot moments in cold spots - Multi-scale tracing of reactivity hotspots in hyporheic environments

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The mixing of groundwater and surface water in hyporheic zones, with often increased redox-reactivity and chemical transformation rates, can have substantial impact on the transformation of solutes transported over the aquifer-river interface. Depending on redox-status and reaction types, hyporheic mixing of groundwater and surface water can lead to either attenuation or enrichment of pollutants and nutrients with diametrical implications for stream and aquifer hydro-ecological conditions.

Here we present the combined application of distributed sensor networks, in-stream geophysical exploration techniques and multi-scale approaches of hyporheic pore water sampling for investigating multi-component reactive transport of nitrate and a chlorinated solvent (Trichloroethylene - TCE) at the aquifer-river interface of a UK lowland river.

Spatial patterns of hyporheic redox-conditions, dissolved oxygen and organic carbon content as well as concentrations of major anions, TCE and its decay products have been observed in 48 nested multi-level mini piezometers and passive gel probe samplers. The hyporheic pore water sampling identified hot spots of increased nitrate attenuation beneath semi-confining peat lenses in the streambed which appeared to coincide with increased TCE breakdown and decay. The intensity of concentration changes underneath the confining peat pockets has been found to correlate 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.

In order to identify the spatial patterns of reactivity hot spots in the streambed, distributed temperature sensor networks and hydro-geophysical exploration methods have been applied to identify the structural streambed heterogeneity including location and extend of flow inhibiting structures and to trace the exchange flow patterns between groundwater and surface water. At focus areas characterising representative streambed geomorphic features, the complex spatial distribution of highly conductive sandy and gravely sediments in contrast to semi-confining, low conductivity peat lenses has been identified by in-stream ground penetrating radar. Reach scale spatial patterns and temporal dynamics of aquifer-river exchange fluxes have been analysed by heat tracer experiments based on Fibre-Optic Distributed Temperature Sensing (FO-DTS) in combination with 2D thermocouple arrays and a small scale heat pulse injection methods for tracing shallow (25 cm) hyporheic flow paths. Temperature survey results 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. FO-DTS observations of regional groundwater up-welling patterns were complemented by heat pulse injection experiments which provided essential information of the shallow (< 25 cm) aquifer- river exchange fluxes.

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.