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Combining active and passive heat tracing technologies for identifying aquifer-river exchange flow patterns at multiple scales

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Accurate understanding of spatial patterns and temporal dynamics of aquifer-river exchange fluxes is crucial for approximating the implications of streambed reactivity hot spots and hot moments for the attenuation and reactive transport of multiple groundwater and surface water contaminants.

This study presents the conjunctive use of three alternative distributed heat tracing technologies for the estimation of exchange fluxes of groundwater and surface water at an exemplary UK lowland river at multiple spatial and temporal scales. The two passive ehat tracing methods utilise a temperature anomaly signal caused by the seasonally variable temperature difference between groundwater and surface water for their analyses.

A Fibre-optic Distributed Temperature Sensor (FO-DTS) network was deployed in a double-loop along the streambed surface to identify spatial patterns of groundwater up-welling in a 300 m stream reach and discriminate between up-welling hotspots and locations with low aquifer-river connectivity and long streambed residence times. The looped sensor network provided detailed information on spatial patterns of streambed temperature anomalies identifying locations of intensive groundwater up-welling, which coincided with enhanced concentrations of local groundwater born pollutants as chlorinated solvents and nitrates, as well as locations with streambed hydro-facies controlled inhibition of groundwater up-welling and increased streambed residence times, coinciding with increased attenuation rates.

Nested thermo-couple sensor networks were installed in streambed clusters along consecutive pool-riffle-pool sequences in order to provide high-resolution (15 min) long-term (> 1 yr) pore-water temperature data. Cross-correlation functions, lag time calculations of maximum correlations in diurnal temperature oscillations as well as simulated oscillation dampening functions provided additional understanding of streambed topography driven, small-scale superficial exchange flow patterns between groundwater and surface water.

In order to investigate if locations with inhibited groundwater up-welling were characterised by increased surface water infiltration and small-scale lateral streambed fluxes compared to groundwater up-welling hot spots, an active heat pulse sensor (HPS) was deployed at locations identified by FO-DTS. HPS is based on tracing the three-dimensional dispersion of a defined heat pulse signal injected into the streambed at 32 connected thermocouples, allowing for an approximation of 3-D flow vectors at plot scale. HPS applications at representative locations confirmed that locations with inhibited groundwater up-welling coincided with increased rates of superficial surface water down-welling and enhanced lateral flow and residence times in near-surface streambed sediments.

The conjunctive use of the three heat-tracing technologies in a nested streambed application lead to a comprehensive understanding of multi-scale aquifer-river exchange fluxes with substantial implications for reactive contaminant transport and attenuation in groundwater, surface water and at the aquifer-river interface.