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Geophysical controls of aquifer-river exchange flow patterns in a UK lowland meandering river.

Rebwar Dara, Stefan Krause, and Michael Rivett

University of Birmingham, School of Geography, earth and Environmental sciens, Life and Environment, Birmingham, United Kingdom (rnd291@bham.ac.uk)

Abstract

The deposition of fine particles (clay and silt) and organic matters in alluvial sediments can substantially reduce the permeability of streambed sediments and extend towards the wider floodplain. The resulting hydraulic conductivity patterns within the streambed and floodplain have been shown to control both location as well as intensity of hyporheic exchange in many lowland rivers.

The aim of the study is to investigate the variability in streambed permeability fields in an unprecedented spatial resolution and quantify the impacts on controlling hyporheic exchange fluxes in the River Tern, a UK lowland meandering stream. Geophysical surveys were conducted deploying Ground Penetrating Radar (GPR) in conjunction with geological information derived from core logs and bank exposures for mapping shallow subsurface structural heterogeneity. The GPR survey deployed a pulse EKKO pro equipped with a shielded 250 MHz antenna. For the floodplain survey, GPR profiles of 12 NE-SW and 6 NW- SE orientation profiles were taken creating a raster of approximately 10 m. The riparian terrestrial GPR surveys were accompanied by a longitudinal in channel GPR survey for which the antenna was deployed on a floating device. At locations identified to be representative for the range of streambed hydrofacies identified by GPR in investigated stream reach, multi-level mini-piezometer networks were installed in the streambed for monitoring groundwater-surface water exchange fluxes, and conducting dilution tracer tests for quantification of residence time distributions at the aquifer-river interface.

Quasi-three-dimensional GPR profiles from closely spaced grids of 2D GPR data of floodplain deposits indicated a range of different radar facies and helped to delineate the type and extend of high and low conductive materials. The results of longitudinal GPR survey along a 240 m section of the river channel revealed that areas rich in low conductivity layers such as organic peat and clay lenses were characterized by low amplitude non-continuous distortion and attenuation of GPR reflections. Highly conductive gravel and sand drift deposits were indicated by strong, subhorizontal, undulating and localized sets of dipping reflections in the GPR survey.

Vertical hydraulic gradients (VHG) distinguished at streambed piezometers showed positive values throughout the observation period, indicating groundwater upwelling into the river. Hotspots of increased VHG were observed in piezometers installed in permeable sections where strong groundwater upwelling was predominant and in impermeable sections where the screen section located below low conductivity layers.

Push-pull dilution tracer experiments within and around low conductivity peat and clay lenses revealed that these layers substantially inhibit groundwater upwelling, resulting in enhanced streambed residence and reaction times and significant reduction in nitrogen and dissolved oxygen concentrations. The increase in residence time and the related depletion in the volume of dissolved oxygen facilitated the development of conditions necessary for nitrate reduction. In contrast, preferential flow paths and short residence times in highly conductive drift deposits resulted in no significant changes in nitrate concentrations along hyporheic flow paths. The revealed impact of strongly heterogeneous physical streambed properties on hotspots of enhanced residence time and biogeochemical turnover highlights the value of GPR-based of high-resolution streambed monitoring.