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Use of a mixing model to investigate groundwater-surface water mixing and nitrogen biogeochemistry in the bed of a groundwater-fed river

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The dynamics of groundwater and surface water mixing and associated nitrogen transformations in the hyporheic zone have been investigated within a gaining reach of a groundwater-fed river (River Leith, Cumbria, UK). The regional aquifer consists of Permo-Triassic sandstone, which is overlain by varying depths of glaciofluvial sediments ($\sim$15 to 50 cm) to form the river bed. The reach investigated ($\sim$250m long) consists of a series of riffle and pool sequences (Käser et al. 2009), with other geomorphic features such as vegetated islands and marginal bars also present. A network of 17 piezometers, each with six depth-distributed pore water samplers based on the design of Rivett et al. (2008), was installed in the river bed in June 2009. An additional 18 piezometers with a single pore water sampler were installed in the riparian zone along the study reach. Water samples were collected from the pore water samplers on three occasions during summer 2009, a period of low flow. The zone of groundwater-surface water mixing within the river bed sediments was inferred from depth profiles (0 to 100 cm) of conservative chemical species and isotopes of water with the collected samples. Sediment cores collected during piezometer installation also enabled characterisation of grain size within the hyporheic zone.

A multi-component mixing model was developed to quantify the relative contributions of different water sources (surface water, groundwater and bank exfiltration) to the hyporheic zone. Depth profiles of 'predicted' nitrate concentration were constructed using the relative contribution of each water source to the hyporheic and the nitrate concentration of the end members. This approach assumes that the mixing of different sources of water is the only factor controlling the nitrate concentration of pore water in the river bed sediments. Comparison of predicted nitrate concentrations (which assume only mixing of waters with different nitrate concentrations) with actual nitrate concentrations (measured from samples collected in the field) then allows patches of biogeochemical activity to be identified.

The depth of the groundwater-surface water mixing zone was not uniform along the study reach or over the three sampling periods, varying from <10 to 50 cm in depth. The influence of factors such as the strength of groundwater upwelling, channel geomorphology, substrate composition (permeability) and river discharge on the extent of groundwater-surface mixing have been investigated. During the three field campaigns conducted, groundwater nitrate concentrations (100 cm) were higher than surface water nitrate concentrations (3.7 ± 0.4 mg N/L versus 2.0 ± 0.03 mg N/L; $p < 0.001$; $n = 27$), indicating that throughout the reach investigated groundwater will supply nitrate to the overlying water column unless nitrate attenuation occurs along the upwelling flow path. Actual (measured) pore water nitrate concentrations often differed from concentrations predicted using the mixing model, which suggests that biogeochemical transformations also affected nitrate concentrations in the hyporheic zone. The initial field data suggested that there were regions of both nitrate production and nitrate consumption in the subsurface sediments, and that these zones may extend beyond the depths commonly associated with the hyporheic zone.

This research demonstrates that a multi-component mixing model can be used to identify possible hotspots of nitrate production or consumption in the bed of a groundwater-fed river.

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