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A semi-analytical three-dimensional process-based model for hyporheic dissolved oxygen and nitrogen dynamics in gravel bed rivers

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Dissolved inorganic nitrogen (DIN), naturally a limiting element in pristine watersheds, has received recently great attention because of its increasing concentrations in water bodies due to anthropic activities. DIN concentrations regulate riverine ecosystems and organisms' metabolism with important processes occurring in hyporheic, riparian and parafluvial zones, whose biochemistry is influenced by subsurface flow patterns. Although a large body of experimental evidences confirms this, most of the models used to represent nutrients cycling in fluvial ecosystems lump these processes in a single diffusion-type exchange term. Our contribution to overcome this limitation of the existing modeling approaches is a three-dimensional semi-analytical process-based model that couples hyporheic flow patters with dissolved oxygen and DIN biochemical processes within the streambed sediment. Flow patterns, are obtained analytically, with a few simplifying assumptions, from the streambed topography and solute transport is modeled within a Lagrangian framework chiefly as an advective process with temperature-dependent reaction rate coefficients derived from field experiments. Simplified Monod's kinetics model nitrification-denitrification reactions and biomass uptake of dissolved oxygen and nitrogen. We apply our modeling framework to investigate the role of hyporheic flow induced by alternate bars - an ecologically important and ubiquitous bed form in both regulated and natural streams - on DIN dynamics. We study the effects of alternate-bar size, alluvium depth, hyporheic water temperature and relative abundance of ammonium and nitrate in stream waters. Our results show nitrogen gas emissions from the hyporheic zone increase with alluvium depth in large low-gradient streams but not in small steep streams, whose hyporheic zone shallows near the streambed surface. Conversely, hyporheic water temperature influences nitrification-denitrification processes mainly in small-steep than large low-gradient streams, because of the long residence times, which offset the low reaction rates at low temperatures in the latter streams.