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Spatial and temporal dynamics of coupled groundwater and nitrogen fluxes through a streambed in an agricultural watershed

D.P. Genereux (1), C.D. Kennedy (2), H. Mitasova (1), and D.R. Corbett (3)

(1) Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC, 27695-8208, USA (genereux@ncsu.edu, helena_mitasova@ncsu.edu), (2) Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, 47907-2051, USA (cdkennedy@purdue.edu), (3) Department of Geological Sciences and Institute for Coastal Science and Policy, East Carolina University, Greenville, NC, 27858, USA (corbettd@ecu.edu)

We studied the spatiotemporal dynamics of the coupled water flux (v) and nitrogen (N) fluxes ($f_N = v$[N], where [N] is the concentration of a dissolved N species) through a streambed in an agricultural watershed in North Carolina, USA. Physical and chemical variables were measured at numerous points in the streambed of a 0.26 km reach: hydraulic conductivity (K) and hydraulic head gradient (J), and concentrations of NO_3^- and other N species in the streambed groundwater, from which water flux (v= *KJ*) and N fluxes (e.g., $f_{NO3} = v[NO_3^-]$) through the streambed were computed, mapped, and integrated over the streambed. The result was a novel set of streambed maps of the linked variables (K, J, v, N concentrations and fluxes), showing their spatial variability and how it changed over a year (based on 7 bimonthly sets of streambed maps). Mean f_{NO3} during the study year was 154 mmol m^{-2} day^{-1}; this NO_3^- flux, together with that of DON (f_{DON} = 17 mmol m^{-2} day^{-1}) accounted for >99% of the total dissolved N flux through the streambed (ammonium was insignificant). Repeat measurements at the same locations on the streambed show significant temporal variability in f_{NO3}, controlled largely by changes in v rather than changes in $[NO_3^-]$. Changes in v were in turn caused by temporal variation in both J and K (i.e., streambed hydraulic conductivity, not only head gradient, changed over time). One of the clearest and most temporally-persistent aspects of spatial variability was lateral variability across the channel from bank to bank. Values of K and v were greater in the center of the channel and lower on the sides. This distribution of K (likely a reflection of sediment dynamics in the channel) apparently focused groundwater discharge toward the center of the channel, exactly where nitrate concentration $[NO_3^-]$ and flux (f_{NO3}) were lowest. CFC age-dating of groundwater in the streambed confirmed that groundwater beneath the center of the channel was generally older than that beneath the sides; lower $[NO_3^-]$ and f_{NO3} in the center were most likely the result of greater groundwater age there and the lower agricultural N use in past decades (not the result of greater denitrification in the center). f_{NO3} was characterized by localized zones of high and low values that changed in size and shape over the study year but remained in basically the same locations (the same was true of K, J, $[NO_3^-]$, though less so for v). 70% of NO_3^- flux occurred through about 38% of the streambed area. Lateral distributions of the physical hydrologic attributes (K,J,v) were highly symmetrical across the channel, while those of $[NO_3^-]$ and f_{NO3} showed higher values on the left side of the channel than right, likely a reflection of different agricultural N use on opposite sides of the stream. Finally, trace gas modeling suggests that about half the nitrate in the groundwater of this watershed "leaves" the groundwater system via groundwater discharge into the stream, and the other half by denitrification. The streambed-based approach taken here offers a number of insights concerning the spatial and temporal dynamics of linked water and N fluxes, and their controls.