Geologic and hydrodynamic effects on shallow groundwater-surface water exchange and chemical fluxes to an estuary

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ABSTRACT

Fluxes of nutrients and other chemicals from aquifers to coastal waters can have adverse impacts on ecosystems. While solute concentrations may change along groundwater flowpaths toward the sea, they can also be modulated near the point of discharge in the shallow benthic zone below the sediment-water interface. This benthic reactivity depends on the supply of reactants from both groundwater and surface water and the duration of contact in the mixing zone. These factors are closely tied to physical processes: fluxes from above and below, as well as mixing and residence time in the benthic zone. We characterized heterogeneity in benthic exchange and associated solutes in the Delaware Inland Bays (USA), which are impacted by severe eutrophication. The spatial and temporal variability in benthic fluxes resulting from surface water hydrodynamics and sediment heterogeneity was simulated by linking hydrodynamic circulation models with mathematical solutions for benthic exchange forced by current-bedform interactions, tides, and waves (Figure 1). Total fluxes driven by the three mechanisms were similar, but mechanisms were dominant at different locations and times. Storms were an important factor, increasing wave-driven exchange by orders of magnitude. The spatial distribution of permeability, including near-surface sediments and larger-scale geologic features (paleochannels), also strongly controlled submarine groundwater discharge and benthic exchange rates. High-resolution measurements from a hand resistivity probe, groundwater sampling, and measurements of biogeochemical parameters in transects across paleochannel features and interfluves within the estuary were used to characterize stratigraphic effects on both the nature of the physical exchange processes and solute concentrations and fluxes. By modifying patterns of groundwater flow, discharge, and mixing between fresh groundwater and saline surface water, stratigraphic features influence the geochemistry in the subsurface and near the sediment-water interface, affecting rates and patterns of chemical fluxes to coastal waters. For example, at this site, more than 99% of the groundwater-borne nitrate flux to the Delaware Inland Bays occurs within interfluve portions of coastline, and more than 50% of the ammonium flux occurs at the paleovalley margin (Figure 2).

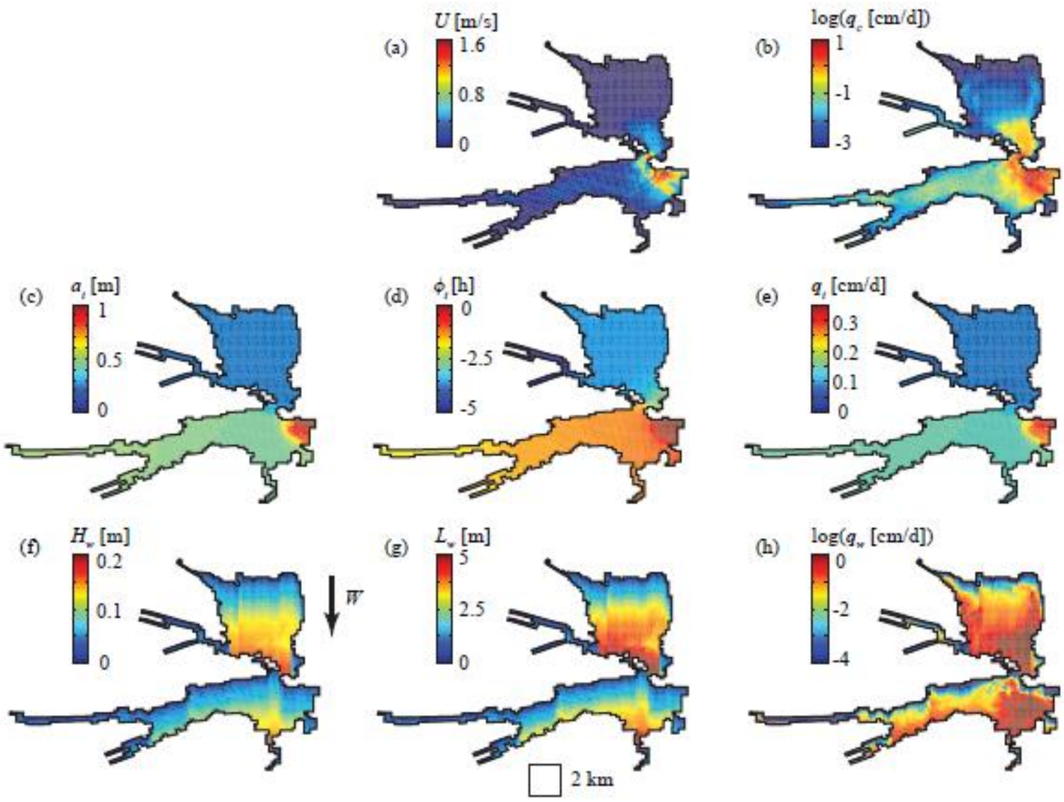

Figure 1. Simulated surface water hydrodynamics and benthic fluxes with constant M2 tide and steady uniform wind of 5 m/s from the North. Averages are taken over one tidal cycle. a. Current speed. b. Benthic flux due to current-bedform interactions, where bedform wavelength is 50 cm and height is 2 cm throughout the estuary. c. Tidal amplitude. d. Phase of tide relative to open ocean (negative values indicate a phase lag). e. Benthic flux due to tidal pumping. f. Significant wave height. g. Wavelength. h. Benthic flux due to wave pumping. From Sawyer et al. (2013)

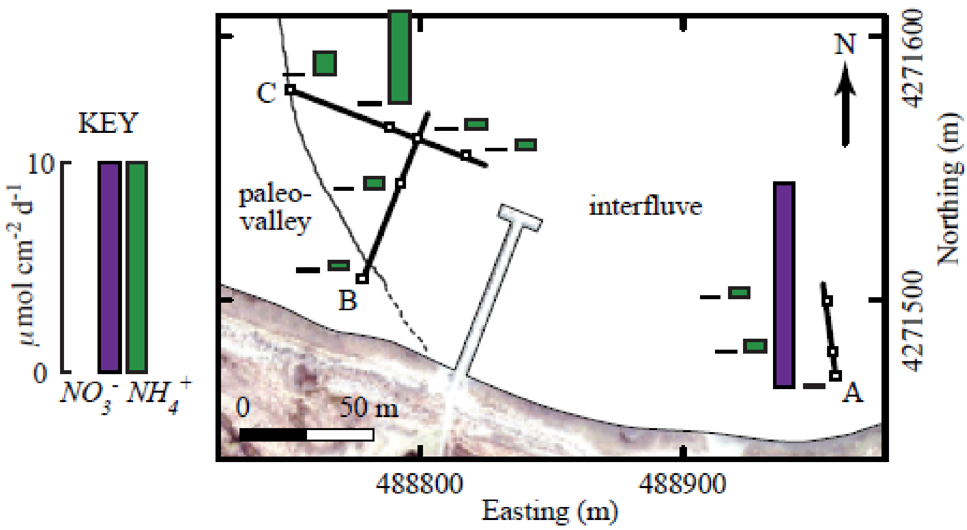

Figure 2. Calculated NO_3^- and NH_4^+ fluxes across the sediment-water interface. Scale bar is shown at left. Fluxes were calculated based on 1-D advection and dispersion calculated from seepage meter measurements and fitted dispersion coefficients for salinity profiles along transects A-A', B-B', and C-C'. From Sawyer et al., in press.

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