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Emergent Archetype Hydrological-Biogeochemical Response Patterns in Heterogeneous Catchments

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What can spatiotemporally integrated patterns observed in stream hydrologic and biogeochemical signals generated in response to transient hydro-climatic and anthropogenic forcing tell us about the interactions between spatially heterogeneous soil-mediated hydrological and biogeochemical processes? We seek to understand how the spatial structure of solute sources coupled with hydrologic responses affect observed concentration-discharge (C-Q) patterns. These patterns are expressions of the spatiotemporal structure of solute loads exported from managed catchments, and their likely ecological consequences manifested in receiving water bodies (e.g., wetlands, rivers, lakes, and coastal waters). We investigated the following broad questions: (1) How does the correlation between flow-generating areas and biogeochemical source areas across a catchment evolve under stochastic hydro-climatic forcing? (2) What are the feasible hydrologic and biogeochemical responses that lead to the emergence of the observed archetype C-Q patterns? and; (3) What implications do these coupled dynamics have for catchment monitoring and implementation of management practices? We categorize the observed temporal signals into three archetypical C-Q patterns: dilution; accretion, and constant concentration. Each type can exhibit either a relatively constant variance (homo-scedastic) or decreasing variance with increasing Q (hetero-scedastic). We introduce a parsimonious stochastic model of heterogeneous catchments, which act as hydrologic and biogeochemical filters, to examine the relationship between spatial heterogeneity and temporal history of solute export signals. The core concept of the modeling framework is considering the types and degree of spatial correlation between solute source zones and flow generating zones, and activation of different portions of the catchments during rainfall events. Our overarching hypothesis is that each of the archetype C-Q patterns can be generated by explicitly linking landscape-scale hydrologic responses and spatial distributions of solute source properties within a catchment. The model simulations reproduce the three major C-Q patterns observed in published data, offering valuable insight into coupled catchment processes. The findings have important implications for effective catchment management for water quality improvement, and stream monitoring strategies.