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Hillslope Responses to Snowmelt: Approaches for Constraining Predictions of Subsurface Flow and Transport Distributions, and their Downgradient Contributions to Surface Waters

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Major segments of hydrologic and elemental cycles reside underground, where their complex dynamics and linkages to surface waters are obscure. Field measurements are being used to develop conceptual, algebraic, and numerical models for delineated seasonal dynamics of subsurface flow and transport along a lower montane hillslope in the Rocky Mountains (Colorado, USA), where precipitation occurs primarily as winter snow and secondarily as summer rainfall, and discharges into the East River, a tributary of the Gunnison River. Hydraulic and geochemical measurements down to 10 m below ground surface supported application of transmissivity feedback to describing subsurface flow and transport through three zones: soil, weathering shale, and saturated fractured shale. From water mass balance, groundwater flow was predicted to depths of at least 85 m. Snowmelt during the high snowpack water year (WY) [2]017 sustained flow along the weathering zone and downslope within the soil, while negligible shallow downslope flow occurred during the low snowpack WY[2]018. We introduce subsurface concentration-discharge (C-Q) relations as a framework for explaining hillslope contributions to C-Q patterns observed in rivers, and demonstrate their calculations based on transmissivity- predicted flow rates and measured pore water specific conductance (SC) and dissolved organic carbon (DOC) concentrations. Comparisons with SC in the East River show that major ions in the hillslope pore waters, primarily from the weathering and fractured shale, are about 6 times more concentrated than in the river, indicating solute loads are disproportionately high, even while flow from this site and similar regions are small. The methodology developed here can be applied to transect in different representative environments within watersheds in order to link their subsurface exports to river C-Q responses. A [2]-D reactive transport model that can resolve lateral fluxes through the unsaturated and saturated zones of the lower montane hillslope has been developed using TOUGHREACT. Simulation results show distinct spatial and temporal signatures in hydrologic budgeting across the transect. In particular, greater evapotranspiration rates and higher soil water storage are obtained in the floodplain as compared to upslope regions. Moreover, upslope regions show more sensitivity to seasonal variations and changes in snowmelt timing than the floodplain. Future modeling efforts will focus on quantifying the role of changing winter precipitation regimes on hillslope and riparian contributions to dissolved carbon and nitrogen exports to the river.