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River Chemistry Predominantly Controlled by Climate

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Global biogeochemical cycles are regulated by reaction rates and fluxes from the land to rivers. The response of river chemistry to short-term weather conditions have been extensively studied, yet their long-term patterns and drivers at the continental scale have remained poorly understood. Here we compile and analyze chemistry data from 506 minimally-impacted rivers (412,801 data points) in the contiguous United States to identify its patterns and predominant control [1]. Despite distinct sources and diverse reaction characteristics, a universal pattern emerges for 16 major solutes (including carbon, nutrients, and geogenic solutes) at the continental scale. Their long-term mean concentrations (C_m) decrease with mean discharge (Q_m), with higher concentrations in arid climates and lower concentrations in humid climates, indicating overwhelming regulation by climate compared to local material characteristics such as lithology. To understand the C_mQ_m pattern, a watershed biogeochemical reactor model was solved by bringing together hydrological and biogeochemical theories. The derivation of long-term, steady-state solutions lead to a power law form of C_mQ_m relationships. The model illuminates competing processes that determine mean concentrations: solute addition by external input and production by soil biogeochemical and chemical weathering reactions, and solute export (or removal) by mean discharge, the water flushing capacity dictated by climate and vegetation. In other words, watersheds mostly function as reactors that accumulate solutes in arid climates, and as transporters that export solutes in humid climates. With space-for-time substitution, these results indicate that in places where river discharge dwindles in a warming climate, solute concentrations will increase, threatening water quality and aquatic ecosystems even without human perturbation. Solutes fluxes however will likely decrease at lower discharge, which could have important implications for global biogeochemical cycles.

[1] Li, Stewart, Zhi, Sadayappan, Ramesh, Kerins, Sterle, Harpold, Perdrial. Climate controls on river chemistry. Earth's future. doi: 10.1029/2021EF002603