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Tracking channel-floodplain sediment exchange with conservative and non-conservative geochemical tracers

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Fine sediment is routed through landscapes and channel networks in a highly unsteady and non-uniform manner, potentially experiencing deposition and re-suspension many times during transport from source to sink. Developing a better understanding of sediment routing at the landscape scale is an intriguing challenge from a modeling perspective because it requires consideration of a multitude of processes that interact and vary in space and time. From an applied perspective, an improved understanding of sediment routing is essential for predicting how conservation and restoration practices within a watershed will influence water quality, to support land and water management decisions. Two key uncertainties in predicting sediment routing at the landscape scale are 1) determining the proportion of suspended sediment that is derived from terrestrial (soil) erosion versus channel (bank) erosion, and 2) constraining the proportion of sediment that is temporarily stored and re-suspended within the channel-floodplain complex. Sediment fingerprinting that utilizes a suite of conservative and non-conservative geochemical tracers associated with suspended sediment can provide insight regarding both of these key uncertainties.

Here we present a model that tracks suspended sediment with associated conservative and non-conservative geochemical tracers. The model assumes that particle residence times are described by a bimodal distribution wherein some fraction of sediment is transported through the system in a relatively short time (< 1 year) and the remainder experiences temporary storage (of variable duration) within the channel-floodplain complex. We use the model to explore the downstream evolution of non-conservative tracers under equilibrium conditions (i.e. exchange between the channel and floodplain is allowed, but no net change in channel-floodplain storage can occur) to illustrate how the process of channel-floodplain storage and re-suspension can potentially bias interpretation of sediment fingerprinting results. We then apply the model to explain measurements of meteoric Beryllium-10, Lead-210, and Cesium-137 associated with suspended sediment in two very different rivers, one incising (Le Sueur River, south-central Minnesota, USA) and the other aggrading (Root River, southeastern Minnesota, USA) in response to base level fall and rise, respectively. The Le Sueur River exhibits a remarkably narrow range of tracer concentrations in source areas, which include agricultural fields, alluvial banks, and bluffs. Suspended sediment samples collected immediately above and below the 30 km long incising reach show a systematic shift in terrestrial sources in the downstream direction, indicated by changes in Beryllium-10 concentrations. The Root River indicates a more variable erosion history, with significant variability of Beryllium-10 concentrations in source areas (agricultural fields, forested hillslopes, and alluvial floodplains and terraces) and inverted Beryllium-10 depth profiles (higher concentrations at depth, suggesting unsteady erosion and significant storage of legacy sediment). Both rivers show a systematic disparity in normalized concentrations of conservative versus non-conservative tracers, indicating that significant storage and re-suspension occurs in both systems as the sediment is routed through the channel-floodplain complex.