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Towards a Holistic Model for Simulating Sediment Dynamics at Watershed Scales: Partitioning of Sediment Sources and Uncertainty Quantification

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The challenge remains to understand watershed sediment source dynamics for planning and evaluating mitigation measures on anthropogenic activities such as intensive agriculture, which exacerbates soil erosion from the landscape. To this end, our research aims to develop a cross-scale model, capable of simulating sediment transport from the plot scale to the watershed scale while effectively capturing the important feedback effects across the scales. Our approach combines numerical modeling with physical observations and measurements to not only provide a tool capable of mimicking cause and effect relationships, but also capable of quantifying uncertainty related to source dynamics predictions.

We present herein a key component of the cross-scale model that quantifies source partitioning and the associated uncertainty. This component is based on a Bayesian un-mixing framework and is particularly useful for watersheds characterized by considerable spatiotemporal heterogeneity. The Bayesian un-mixing framework utilizes two key parameters, namely α and β, that explicitly accounts for spatial origin attributes and the time history of sediments delivered to the watershed outlet, respectively. These parameters are treated probabilistically so as to account for variability in source erosion processes, as well as the delivery times and storage of eroded material within the watershed. The use of Markov Chain Monte Carlo simulations for determining posterior probability density functions in the framework allows uncertainty in source contribution estimates to be quantified naturally as part of the solution process.

We demonstrate the utility of the Bayesian un-mixing framework in a predominantly agricultural watershed in the US Midwest known as the Clear Creek Watershed, IA, which is part of the Critical Zone Observatory for Intensively Managed Landscapes (IML-CZO). Stable isotopes of Carbon and Nitrogen are used as tracers since they have been found to be appropriate for the watershed. The framework is shown to predict trends in mean source contributions and uncertainty that are in agreement with observations from other studies. Terrestrial sources are seen to dominate sediment contributions early in the growing season when the land cover is low and the hydrological forcing is relatively higher. Instream sources become dominant later in the growing season as the land cover becomes more extensive and well established. The benefits of the framework are further highlighted in its ability to capture changes in uncertainty over the growing season. The results show a clear reduction in uncertainty for periods where connectivity between the landscape and the watershed outlet is greatest such that there is considerable amount of material transported to the collection point at the outlet. On-going studies utilizing the framework are expected to shed some more light on connectivity effects as well as the effects of various landscape attributes on both intra- and inter-seasonal sediment source dynamics.