SEDIMENT DYNAMICS ON RIVER NETWORKS: INCORPORATING SOURCES, STORES, AND SINKS FROM A SEDIMENT BUDGET INTO A NETWORK-MODELING FRAMEWORK

EXTENDED ABSTRACT

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Many streams and rivers throughout the U.S. have experienced degraded water quality and declines in both number and diversity of aquatic species. These changes are undesirable consequences of an intensification and expansion of human actions on the landscape combined with climatic trends occurring in the last few decades. The Minnesota River Basin (MRB) is no exception. Changes in agricultural management in the MRB, including installation of tile drainage, have reduced surface runoff and erosion from agricultural fields in recent decades. However, increased drainage has also increased streamflow and therefore amplified erosion of streambanks and bluffs. As a result, no net change in suspended sediment loading has been observed, but rather a drastic shift in sediment sources from upland agricultural fields to near-channel river banks and bluffs (Belmont et al., 2011; Schottler et al., 2014). Targeting management actions to ultimately improve ecosystem health and function requires navigating the cascade of changes from streamflow to sediment to river biology.

In the MRB, the locations and rates of erosion and deposition of major sediment sources and sinks (i.e., bluffs, streambanks/floodplains, agricultural fields, and ravines) have been well documented over millennial and decadal timescales (Belmont et al., 2011; Gran et al., 2011a, 2011b, 2013). But robust modeling of watershed sediment dynamics (i.e., generation, transport, and storage of sediment through the entire river network) requires understanding how these features are arranged within the river network, the "skeleton" of the landscape, and how process-based time delays of input, storage, and transport set the system in motion. We investigate the sediment dynamics of the Le Sueur River Basin, the major sediment-generating subbasin of the MRB, using a sediment budget to inform a modeling framework that incorporates simple reach-scale process dynamics into a river network context (Czuba and Foufoula-Georgiou, 2014, 2015). We seek to better understand how fine and coarse sediment moves through an entire river network over decadal to century time scales, given a heterogeneous distribution of sources, transport pathways set by the river network, and underlying process dynamics. We also extend this understanding to discuss implications for watershed scale sediment management and policy.

The network-based modeling framework of Czuba and Foufoula-Georgiou (2014, 2015) focuses on understanding large-scale system functioning and predicting the emergence of vulnerabilities, “hotspots” of change, and system resilience for guiding effective landscape management decisions. Landscapes are too complex to be modeled with fully distributed deterministic models that consider all the small-scale physics and interactions, due to large and unavoidable uncertainties associated with the myriad of relevant processes. Besides, changes in climate, land use, and water management impose non-stationary conditions and also nonlinearities in the system make it sensitive to small perturbations. Instead, the aim of this framework is to capture the most important interactions and amplifications by exploring the system connectivity and its transport pathways including residence times, threshold behavior, and physical transformations. The framework focuses on understanding network transport by: (1) decomposing the landscape into a connected network of elements including river channels, wetlands, agricultural fields, etc., (2) spatially and temporally distributing inputs of water and sediment, and (3) tracking these inputs through individual landscape elements through process-based time delays.

The application of this framework so far has focused on the dynamics of water and sediment on the landscape. The transport of sediment has been reduced to simple time delays as functions of upstream drainage area and channel slope by combining and reducing equations for uniform flow hydraulics, (at capacity) sediment transport, hydraulic geometry scaling, and intermittent sediment-transporting flows (see Czuba and Foufoula-Georgiou, 2014 for the derivation and limitations of mud, sand, and gravel transport time-delay equations). This framework has successfully answered questions as to likely hotspots of fluvial geomorphic change that have been validated with field observations. Specifically, the framework has been used to identify vulnerable reaches of a river network prone to high rates of channel migration by highlighting where bed-material sediment has a tendency to persist and thereby force channel migration through the bar-push mechanism, i.e, more rapid accretion of the point bar along the inner bank forcing erosion of the outer bank (Czuba and Foufoula-Georgiou, 2015).

We apply and advance this framework to capture the dynamics of sediment-size classes of mud, sand, and gravel in the Le Sueur River Basin. Sediment input to the network is informed based on the locations and erosion or deposition rates of bluffs, streambanks/floodplains, agricultural fields, and ravines as well as physically-based process dynamics of sediment generation. Sediment transport closely follows the approach developed by Czuba and Foufoula-Georgiou (2014). The advancement of the framework is in allowing for feedback between the accumulation of mass, geomorphic properties, and sediment transport (via travel time) within a reach. Thus, we now couple geomorphic properties with density-dependent transport, all within a network context. Furthermore, we explore how floodplain storage (via additional storage delays) affects the system dynamics.

As part of this ongoing research, we are exploring: (1) how the heterogeneity of landscape features affects the spatial distribution of sediment impacts, e.g., confined to select reaches near the sources, (2) timescales of movement of sediment through the system, including floodplain storage, that can better inform legacy effects and hysteresis, and (3) the implications of system dynamics for targeting management actions that will most effectively reduce the detrimental impacts of sediment.

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