On the magnitude and frequency of sediment transport in rivers

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ABSTRACT

What flow or range of flows is most responsible for transporting sediment and maintaining sediment continuity in a river over human time scales? This question has inspired scores of studies analyzing the magnitude and frequency of sediment transport (MFA) in rivers and has been a part of the ongoing debate regarding process vs. form-based approaches to stable channel design (Figure 1). MFA in rivers is of general scientific and management interest as it influences channel form, water quality, aquatic habitat, and channel restoration design considerations.

The research presented in this dissertation asks the following overarching question: What influences how much and how often sediment is transported in a river? In this dissertation, I consider relationships between the drivers of sediment transport at a point in a river (flow regime, sediment size, and channel form) and metrics describing sediment yield, which integrate the relationship between flow regime and transport over time (Figure 2). To study this question, I use theoretical and empirical approaches in a spectrum of stream types from fine bed streams dominated by suspended load transport to gravel and cobble streams dominated by bed load transport. I find that, for example, the frequency of the most effective discharge decreases and the range of flows most responsible for sediment yield increases with increasing flow regime variability. As river bed material becomes coarser, a more narrow range of less frequent flows becomes most effective in sediment transport.

The river management and restoration community has given much effort to predicting the bankfull discharge, $Q_{bf}$, and associated channel geometry at $Q_{bf}$ for the purposes of channel study, classification, and design. In a study comparing various $Q_{bf}$ predictors in coarse and fine bed rivers, I find that the discharge associated with 50% of cumulative sediment yield based on the flow record—$Q_{s50}$, the half yield discharge—predicts $Q_{bf}$ better than most other predictors, especially in fine-bed rivers. Other predictors include the most effective discharge, $Q_{eff}$, and the 1.5-year return interval flood.

Using statistical methods to quantify the uncertainty in the sediment load-discharge relationship as well as the empirical flow frequency distribution, I develop methods to propagate uncertainty in estimations of $Q_{eff}$ and $Q_{s50}$. In an examination of the influence of flow regime non-stationarity on sediment yield metrics, I find that in urbanizing watersheds with increasing trends in flow variance, estimates of $Q_{eff}$ and $Q_{s50}$ increase dramatically compared to those based on the entire flow period of record. Finally, I estimate $Q_{eff}$ and $Q_{s50}$ using empirical, sediment load data-driven models and physically-based models driven by one-dimensional flow-depth relationships evaluated at a cross section. Physically-based models that match the slope of the sediment load-discharge relationship performed well. This is the case with total load models for fine bed sites, but generally not the case for bed load models used on coarse bed sites.
**Figure 1** Conceptual diagram of lognormal stress (flow) distribution (a), power law sediment rating curve (b), and sediment yield curve (c), which is the product of (a) and (b). Adapted from Wolman and Miller [1960].

**Figure 2** Conceptual diagrams of sediment yield metrics plotted on sediment yield density (a) and cumulative probability (b) curves. The shaded areas delineate the bounds of the cumulative 50% of sediment yield centered on $Q_{eff}$ (orange) and $Q_{50}$ (blue). The applied stress or discharge value associated with the peak of the sediment yield curve (a) is termed the most effective discharge, $Q_{eff}$. The discharge associated with 50% of cumulative sediment transport (b) is termed the half-yield discharge, $Q_{50}$. 

Figure 3 A visual abstract presented as a “Wordle”. This image is generated from the text of this dissertation wherein font size and weight are a function of the frequency at which the word appears in the text.