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When Does the Dominant Discharge Concept in Rivers Apply?

A Sediment Yield Perspective

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1 Overview

What flow or range of flows is most responsible for transporting sediment and maintaining continuity in a river? This question has inspired scores of *magnitude and frequency of sediment transport analysis* (*MFA*) studies and is central to defining dominant discharge.

I consider how the **Sediment Yield Spread** of a given river is influenced by the size of its bed material and the variability of its flow regime. Sediment Yield Spread quantifies the relative width of the range of flows responsible for the middle 50% of cumulative sediment yield in a river.

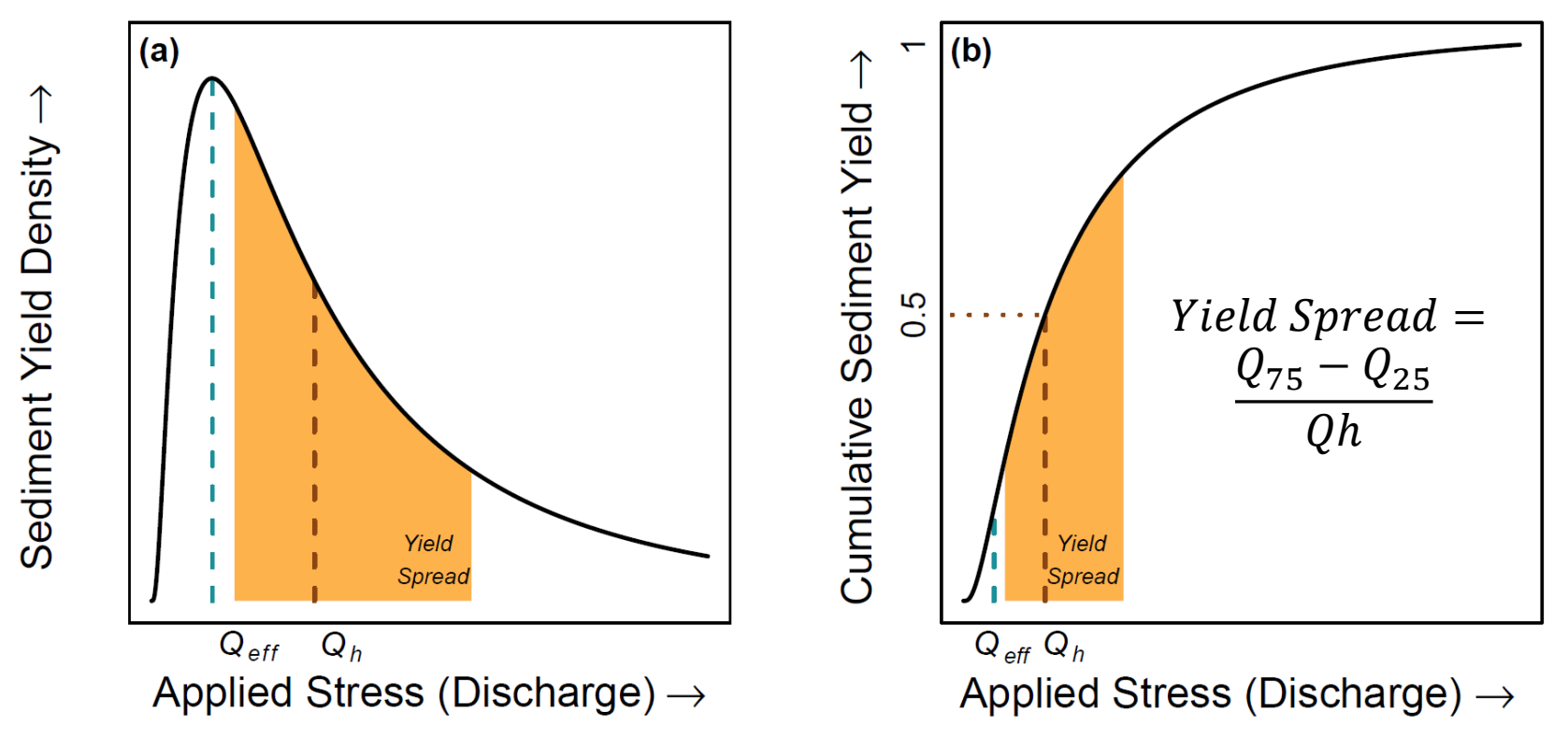


Figure 1. Conceptual diagram of the "Yield Spread" metric on the magnitude-frequency of sediment transport curve (a) and the cumulative sediment yield curve (b). They represent how much sediment is transported by what magnitude flow across the flow regime. Q_{25}, Q_h, and Q_{75} are the discharges associated with a cumulative 25%, 50%, and 75% of sediment transported over the flow record.

2 Methods

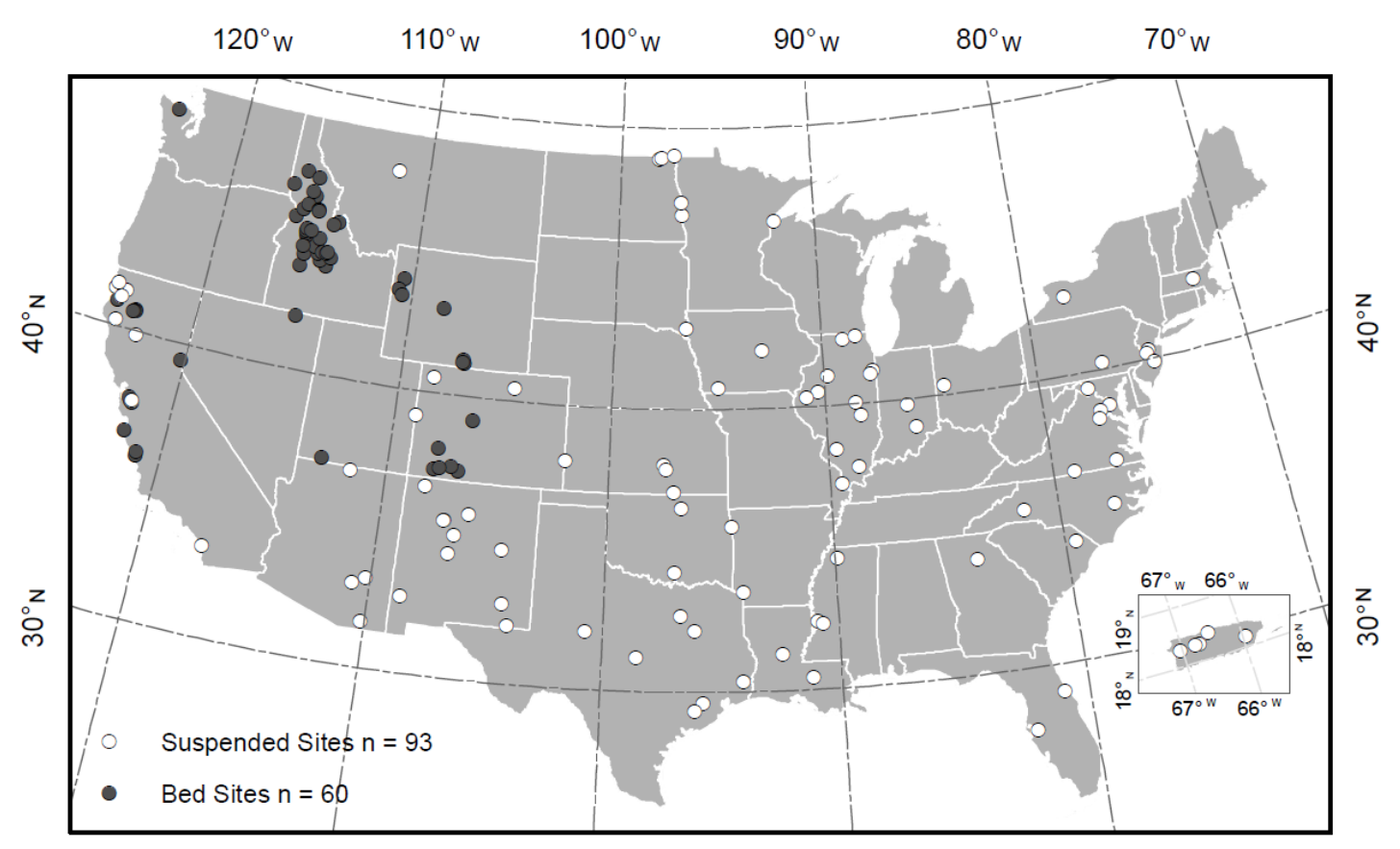


Figure 2. Map of sites with extended flow records, limited flow regulation, and bed material load data used in the magnitude-frequency analysis.

I conducted magnitude-frequency analysis on 153 stream sites with existing bed material load data collected near a stream gage. I stratified these sites by coarse bed, bed load-dominated and fine bed, suspended load-dominated rivers. We used a bias-corrected, log-linear regression to create a power law sediment rating curve of the form $Q_s = \alpha Q^{\beta}$ (Figure 3, top left) We created an empirical probability density function (PDF) of the daily flow record by numerically-differentiating the empirical cumulative distribution function (CDF) following Orndorf & Whiting (2000) (Figure 3). Sediment yield metrics such as the most effective discharge (Qeff), the half-yield discharge (Qh) along with Yield Spread are calculated from these curves (Figure 3, bottom row).

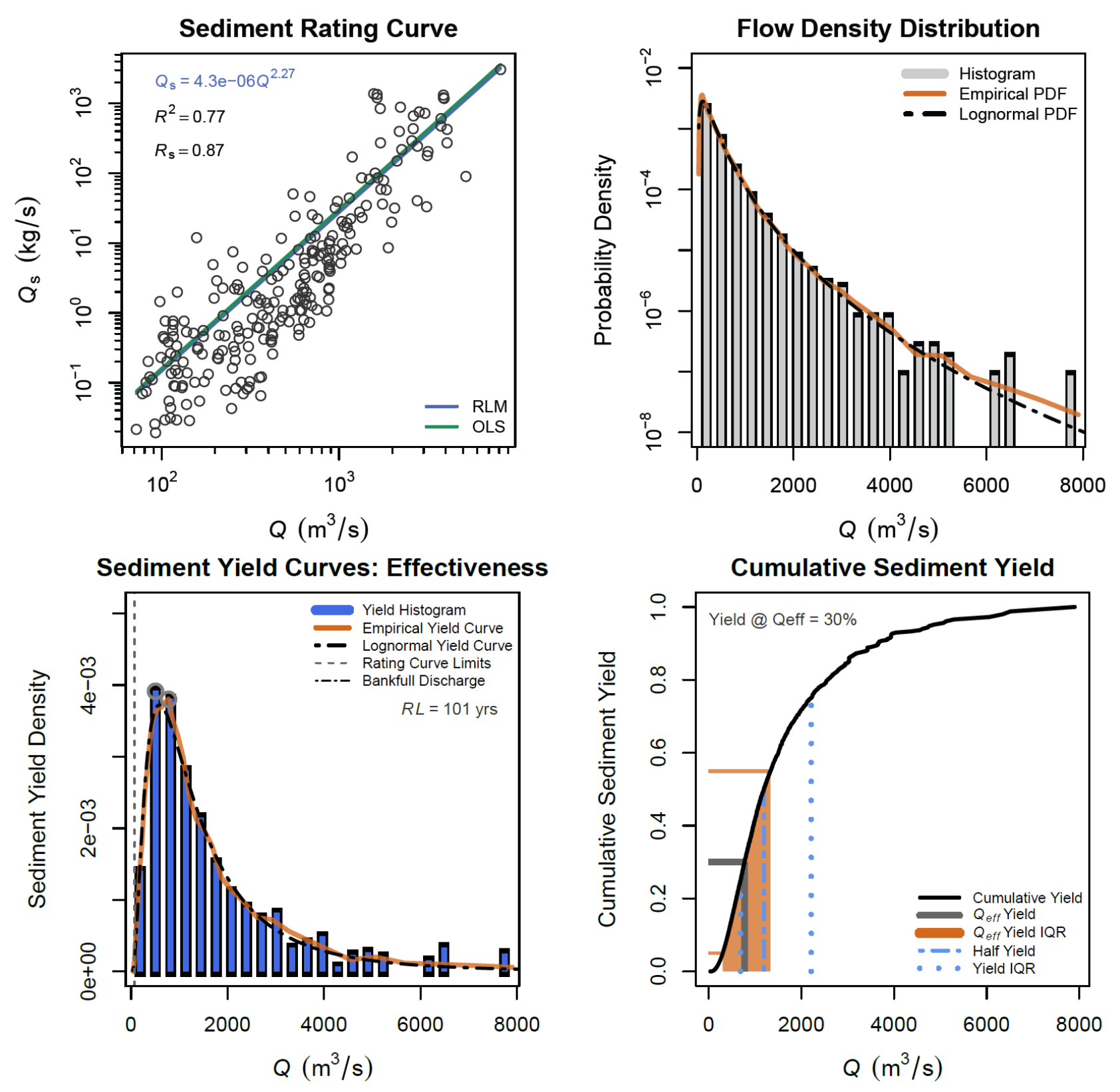
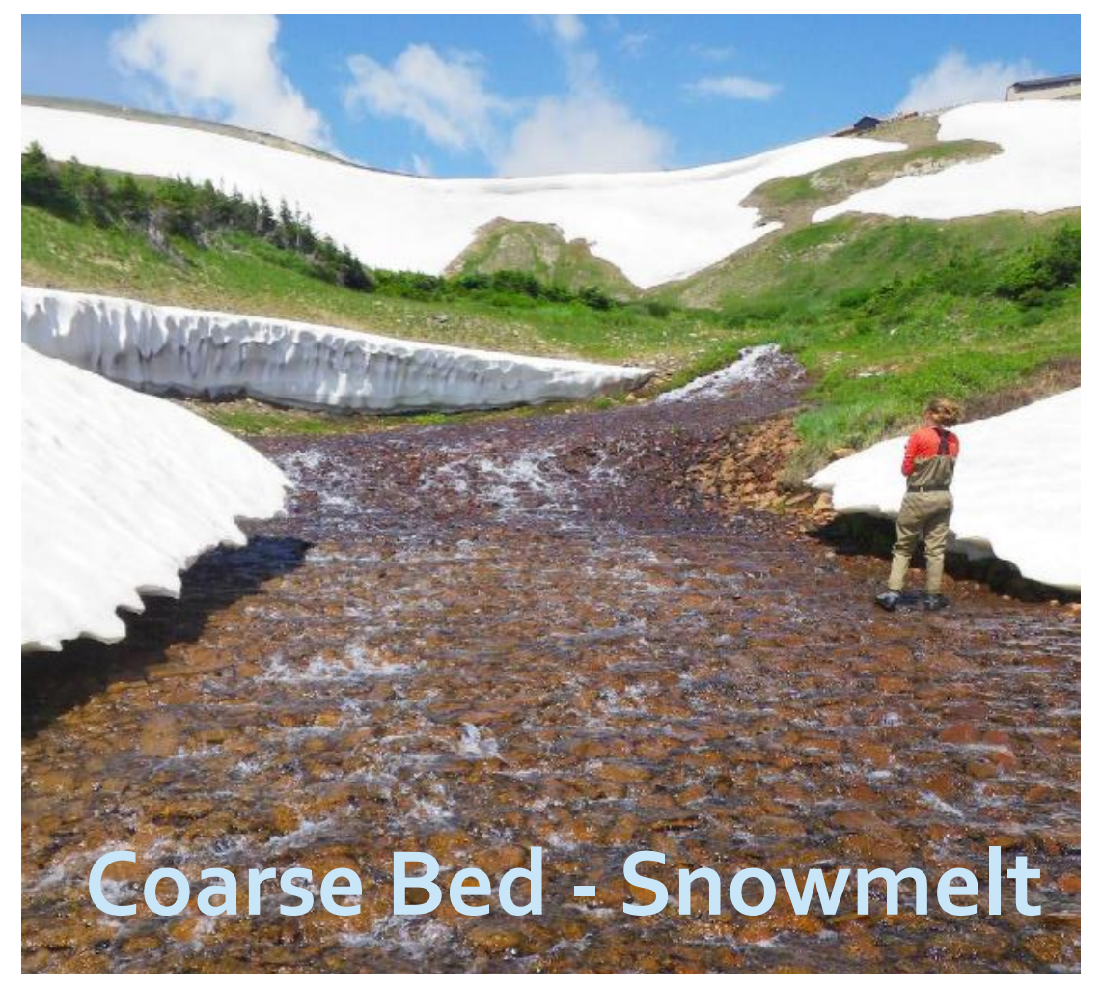


Figure 3. Example of sediment transport magnitude-frequency analysis for a fine bed site using suspended sand load data.

3 Defining Dominant Discharge

The dominant discharge is a theoretical value that, if held steady over time, would result in the same observed channel form and slope under the existing sediment supply quantity and caliber. It is defined in a number of ways, recently reviewed by Blom et al. (2017). The variability of the flow regime along with the size of the bed material are two primary factors that influence the range and magnitude of flows responsible for sediment continuing in a river.

Rivers with coarse bed material typically transport the majority of their sediment load at discharges at or near bankfull where the threshold for entrainment is passed (Phillips & Jerolmack, 2016). Rivers with finer bed material transport their sediment load over a much broader range of discharges. **Sediment continuity in fine bed rivers relies on flow ranging from well below bankfull to well above**.


Coarse Bed - Snowmelt


Fine Bed - Convective

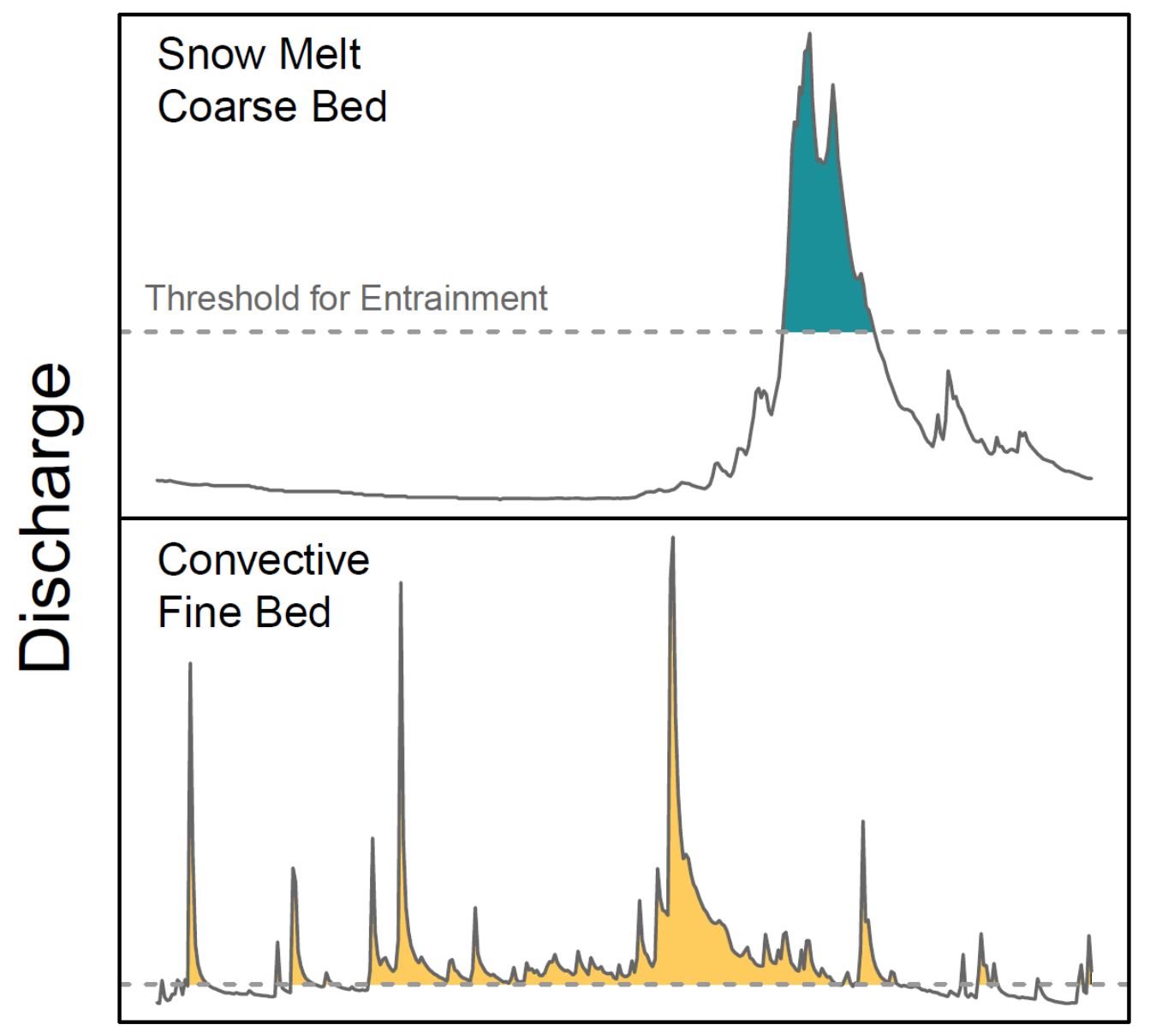


Figure 4. Conceptual diagram of the magnitude and frequency of sediment transporting flows in coarse-bed snow-melt-driven rivers (top), and fine bed, convective prepetition-driven rivers (bottom).

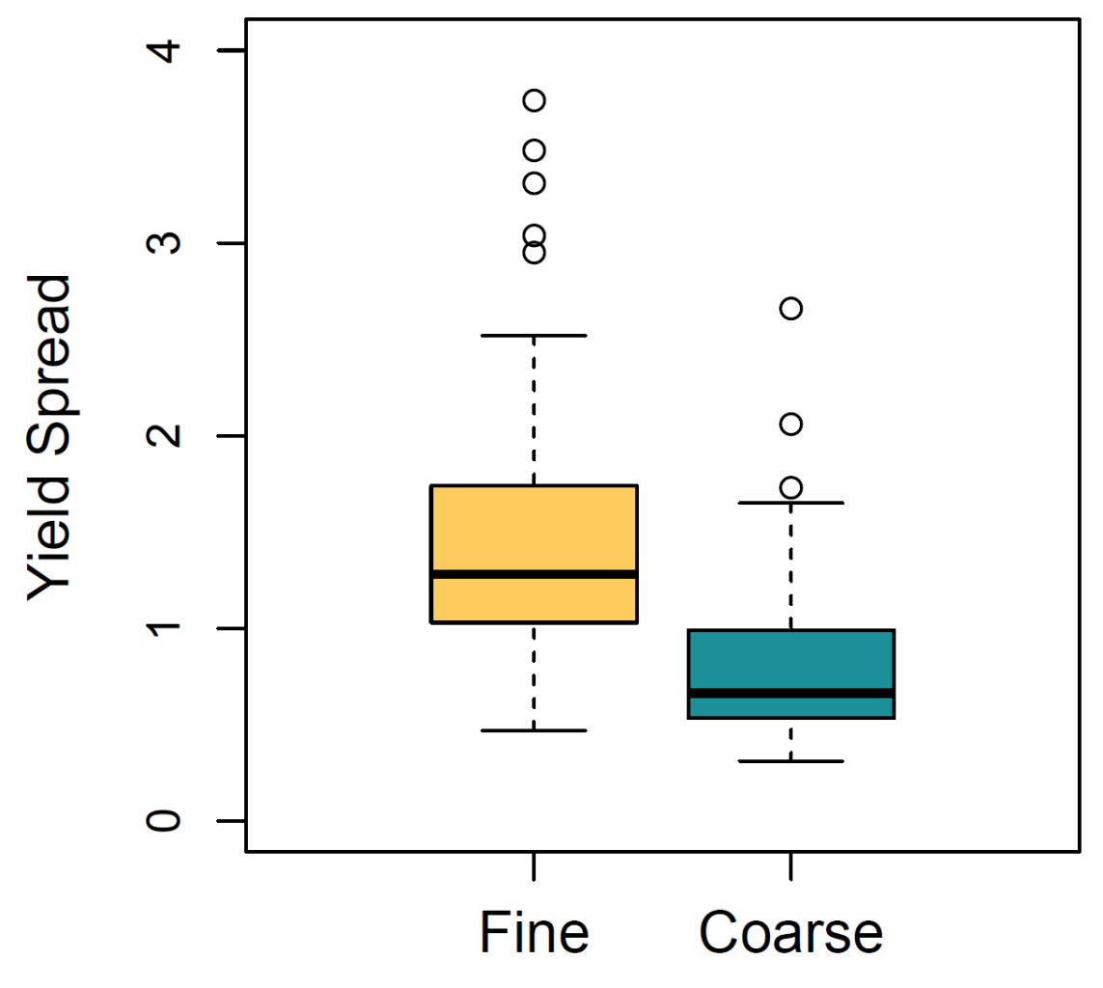


Figure 5. Boxplots showing the distribution of *Yield Spread* values for fine and coarse bed sites.

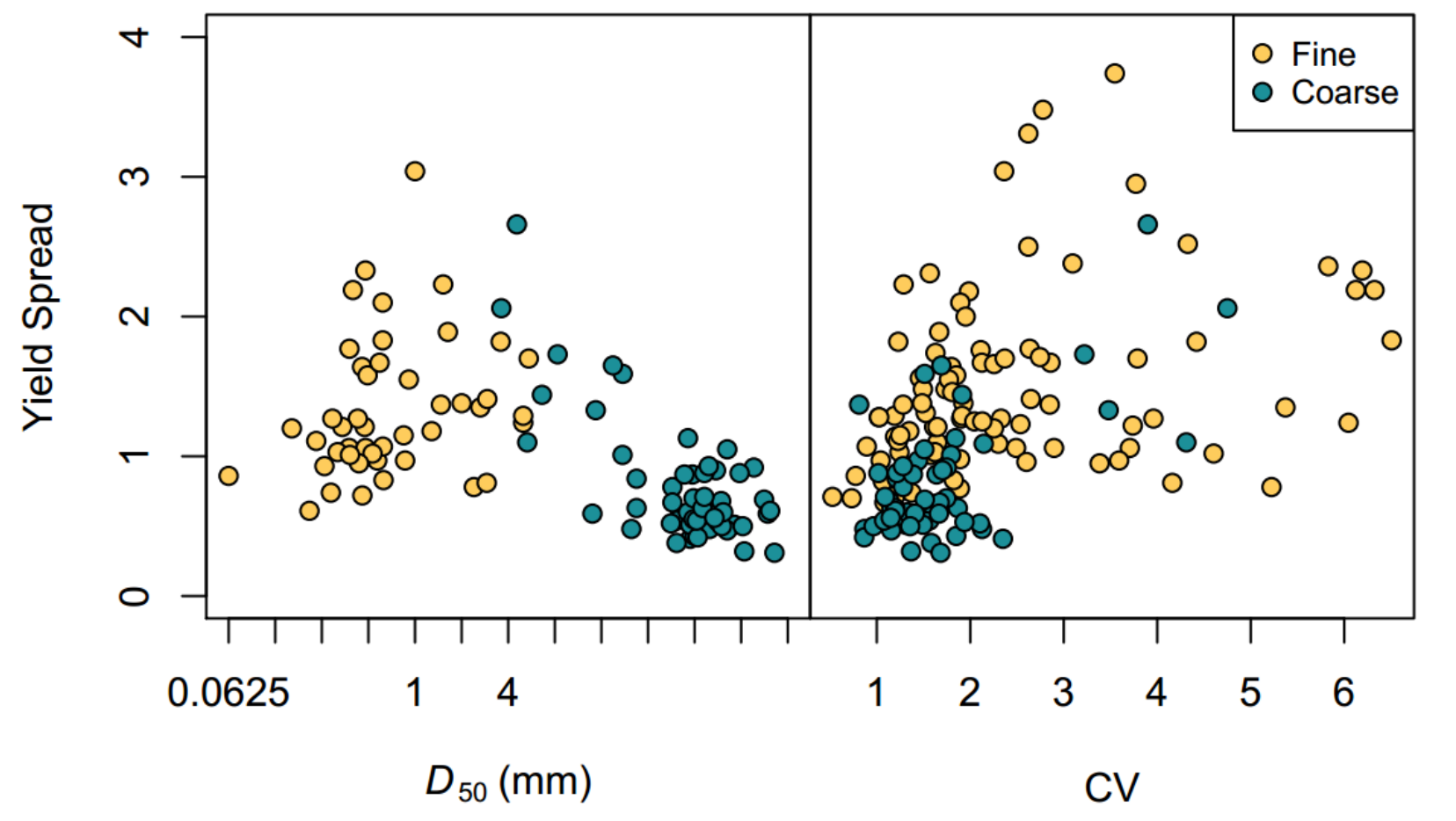


Figure 6. *Yield Spread* as a function of bed material *D*50 (left) as well as flow variability ($CV = s/\bar{x}$, right).

***Yield Spread* increases** with *D*50 in fine bed rivers and then decreases with D50 in coarse bed rivers, with a peak in the coarse sand to the very fine gravel range. Note that the *D*50 of fine bed sites increases with flow variability.

4 Linking Sediment Yield with Dominant Discharge

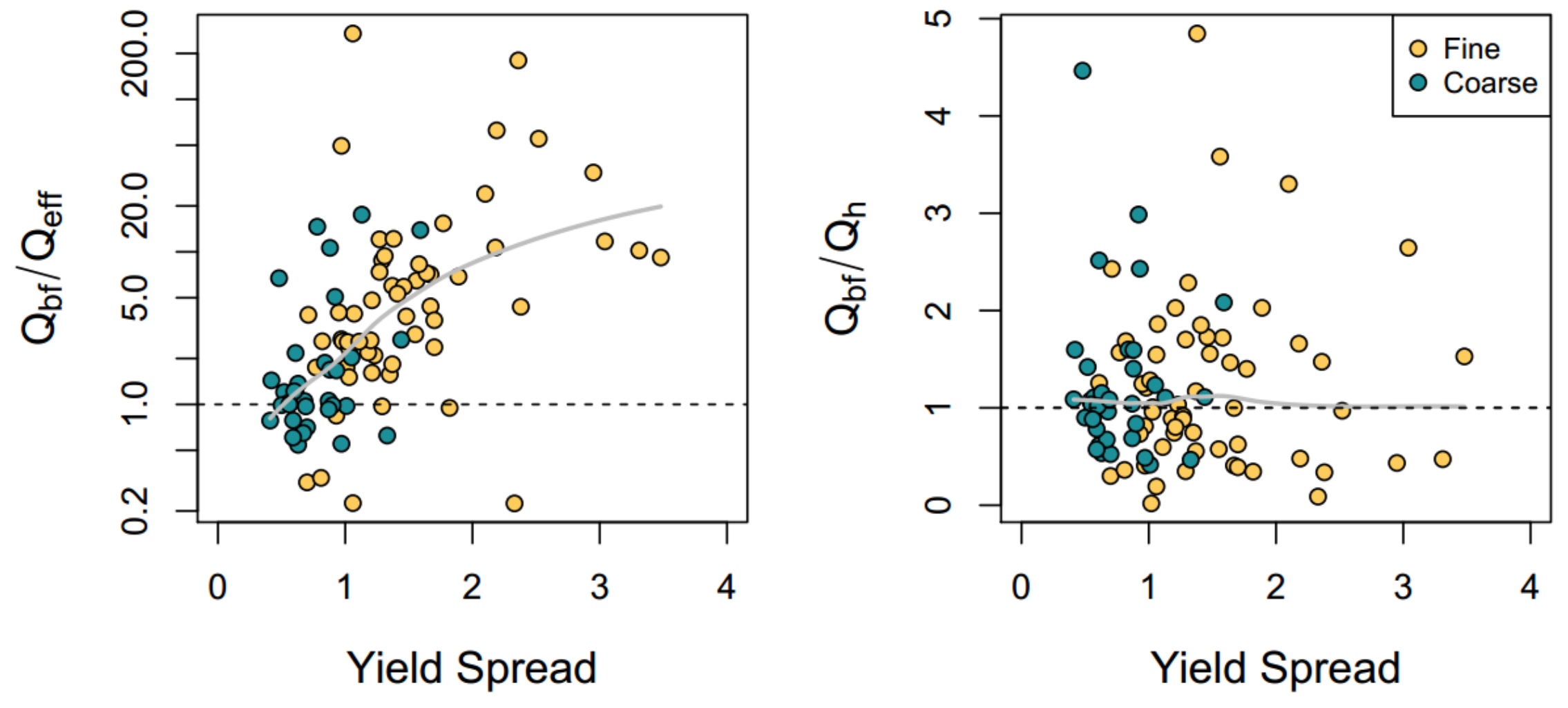


Figure 7. As *Yield Spread* increases the ratio of bankfull to effective to discharge (Q_{bf}/Q_{eff}) increases to values much larger than unity. No trend is observed between the ratio of bankfull and the half-yield discharge (Q_{bf}/Q_h). Grey lines represent smoothed LOESS lines.

Here I take the morphological bankfull discharge, Q_{bf}, as the dominant discharge and compare other sediment yield-base dominant discharge metrics with it (i.e., Q_{eff} and Q_h). I find that as *Yield Spread* increases, Q_{eff} become much smaller relative to Q_{bf} and that the value of Q_h relative to Q_{bf} does not vary.

The dominant discharge concept applies where *Yield Spread* is relatively small, i.e., where $Q_{bf} \sim Q_{eff}$.

Note that Q_h best predicts Q_{bf} in fine bed rivers compared to Q_{eff} as well as hydrologic predictors (e.g., the 1.5 year return interval flood) (Sholtes and Bledsoe, 2016).

5 Theoretical Relations

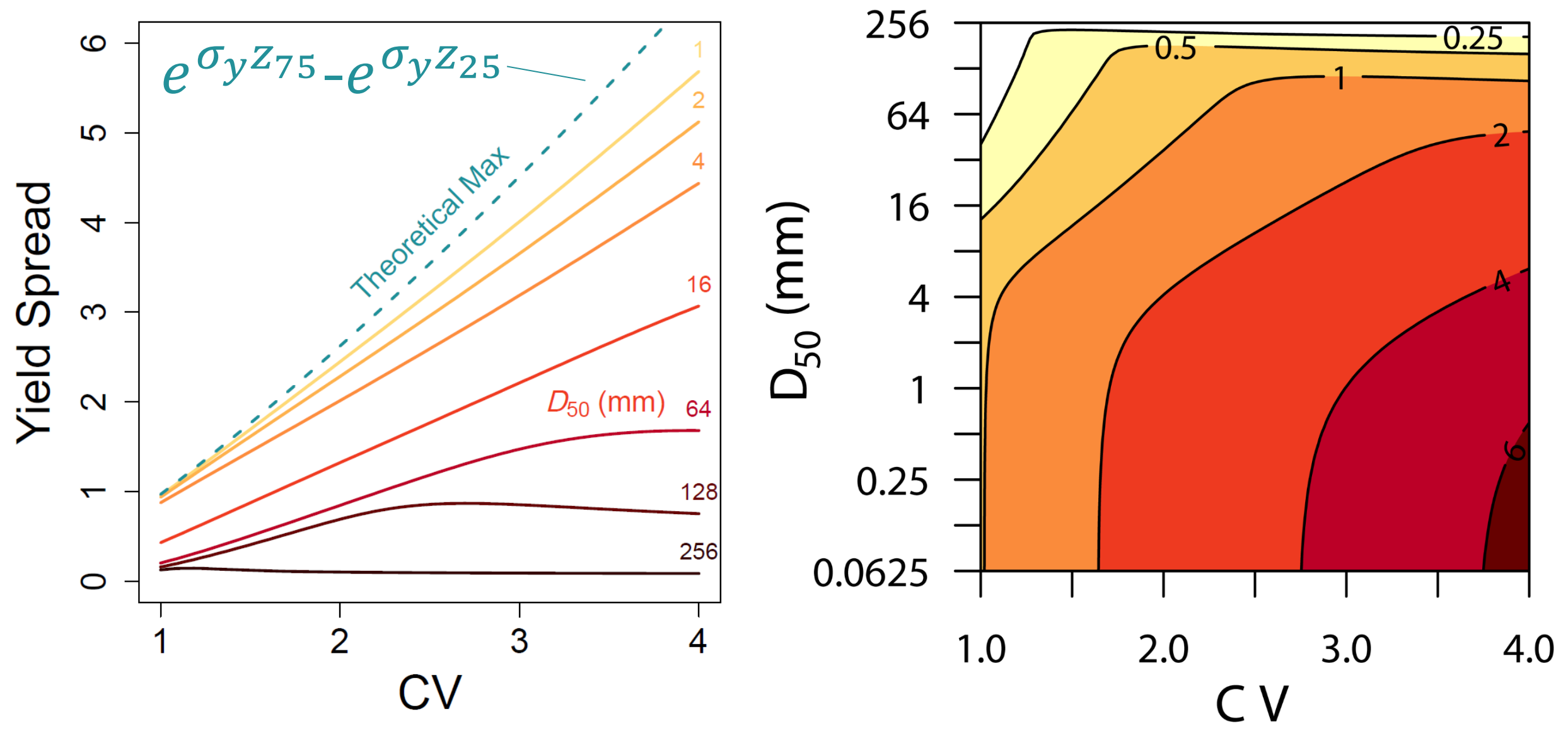


Figure 8. Yield Spread plotted as a function of D50 and CV based on a theoretical channel with mean discharge = 10 m³/s, bankfull discharge = 100 m³/s, a log-normal flow frequency distribution, and the discharge-depth relationship represented as a power law function. Parker (1979) is used to model transport rate as a function of depth and grain size.

Yield Spread monotonically increases with increasing CV and decreasing *D*50 for sand up to medium gravel (16 mm). It then tails off for larger grain sizes and even begins to decrease for CV > 2.5. The theoretical maximum value plotted in blue (left) is based on a log-normal flow distribution and a power-law sediment rating curve of the form, $Q_s = aQ^b$, where σ_y is the standard deviation of the lognormal distribution as determined by method of moments.

6 Take Home Points

1. Sediment *Yield Spread* quantifies the relative width of the range of flows responsible for the middle 50% of cumulative sediment yield in a river.
2. As a river's bed material decreases in size, a wider range of flows are responsible for transporting sediment (*Yield Spread* increases).
3. *Yield Spread* increases with flow regime variability (CV), especially in fine bed rivers.
4. The ratio of Q_{bf} to Q_{eff} increases with increasing *Yield Spread*, but is approximately unity for Q_{bf}/Q_h regardless of *Yield Spread*.
5. The dominant discharge concept applies to streams with coarser bed material load and lower flow variability. Whereas river with greater flow variability and finer bed fine gravel and sand) material load transport sediment across all flow.
6. Streams with fine beds are more sensitive to changes in flow and sediment regimes brought on by environmental change.

7 References

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