

# Uncertainty propagation analysis of bedload transport estimates with consideration of how to appropriately quantify the natural variability of flow and grain size parameters in gravel bed rivers

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## Abstract

There is a strong consensus in the literature that the estimation of bedload transport rates has many sources of uncertainty including but not limited to the spatial and temporal variability of the transport, the natural variability of the flow and grain size parameters, and the uncertainty in the existing transport equations. Bedload transport has impacts on the river morphology and ecology and is also of importance in identifying and managing hazards. This study looks specifically at the natural variability of flow and grain size parameters along a single homogeneous reach and how this variability translates into the uncertainty of a bedload transport estimate. Any field measurement campaign will show a minimum of a one order of magnitude spread in measured bedload transport. How much does the natural variability in topography and grain size contribute to this spread? The study looks at the flow or grain size parameter variability that carries the most weight in the uncertainty in transport estimates and how field programs can be refined to decrease the uncertainty in the estimate by having a precise understanding of a parameter's natural variability.

The natural variability in topography was explored by looking at the distribution in active width, and cross section average shear stress within a homogeneous reach. First, 5000 cross sections were randomly generated in R, and the average shear stress was calculated using the Ferguson flow resistance equation (Ferguson, 2007). The distribution of the average shear stress was then fitted to a probability distribution function (pdf) that best describes the variability in this parameter. Second, data from previous field studies was collected with surveyed cross sections from 6 homogeneous gravel bed reaches located in France and the USA to fit a pdf to the variability in active width and average shear stress calculated for each reach (Caillat, 2020; Legleiter et al., 2018; Misset et al., 2020; Sprouse, 2016). The natural variability in grain size was explored similarly by fitting pdfs to the variability in  $D_{50}$  and  $D_{84}$  from multiple Wolman count samples within a reach for 5 gravel bed river reaches located in Spain and in France (pers. comm. Daniel Vazquez-Tarrio, Caillat, 2020). The results suggest that the use of a normal or lognormal distribution could be used to approximate the variability in active width, average shear stress, and grain size fractions. The ratio of standard deviation over the mean was found to be similar across the rivers studied and could be used to estimate the shape and size of a normal or lognormal distribution.

Uncertainty propagation analysis can be done a few different ways. In this study, uncertainty propagation was done using a Monte Carlo, the classic method with each input parameter defined by a pdf or fixed value; and with Hyrisk, a package in R that allows for less precise and more flexible definitions of input parameter variability. The variability of the active width, depth,  $D_{50}$ , and  $D_{84}/D_{50}$  must be defined and then the bedload transport is calculated 1000 times using the Recking equation (Recking, 2013) with different values randomly selected each time for the input parameters based on the input variable definition. The uncertainty propagation analysis was performed for the Sévèraisse River; a braided gravel bed river located

in the SE French Alps. In 2018, there was a large field measurement campaign that included several direct bedload measurements collected using an Elwha sampler, topographic surveys, and Wolman counts for grain size (Misset et al., 2020). The variability in active width, depth,  $D_{50}$ , and  $D_{84}/D_{50}$  was quantified and put through both a Monte Carlo analysis and Hyrisk. The onsite bedload measurements were plotted against the results to check the reasonability of the uncertainty propagation results. A pinching method was then applied in the uncertainty propagation to determine which input parameter's variability contributes most to the uncertainty in bedload estimates to identify which parameters are the most important to measure precisely and accurately in the field.

The results provide a framework that can be used to estimate the uncertainty range in transport estimates that is possible, or probable given the natural variability of the river morphology being worked with and the uncertainty in the measured or estimated reach averaged parameters. For risk mitigation planning, dam design, dredging plans, and others, an understanding of the degree of uncertainty is critical to understanding the risk and resilience of the plan or design.

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