

IMPACTS OF HYDROGRAPH SHAPE ON SEDIMENT TRANSPORT IN A GRAVEL-BEDDED STREAM

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Natural and managed rivers throughout the world display a wide range of hydrographs that vary in shape from steep and flashy to gradual and consistent, thus influencing the volume and timing of water available for aquatic ecosystems. Although hydrograph shape is an inherent feature of river systems, relatively few investigations have focused on the influence of flow variability on channel grain sizes and bedload transport, and many uncertainties remain with regard to accurately predicting sediment movement during high-flow events. We explored the effects of hydrograph shape on sediment transport volume and grain size distribution in a wadable gravel-bedded stream in California, USA. We tracked the movement of tracer grains marked with passive integrated transponder radio frequency identification tags and collected bedload samples through small and moderate storm events during 2015, a climatically dry year. Bedload flux during each storm event exhibited patterns of clockwise hysteresis such that bedload transport rates on the rising limb of the hydrograph were higher than transport rates on the falling limb. The grain size distribution of the bedload throughout each event also varied, not only with changes in bed shear stress as expected, but with timing within the event, suggesting other factors such as flow accelerations or sediment availability may be contributing to movement. While the larger storm moved a greater percentage of available tracer grains a larger distance downstream, the grain size distribution of transported tracers did not vary significantly between storms suggesting conditions of equal mobility throughout the study reach. The results from this study contribute towards a larger concurrent project that seeks a mechanistic understanding of the influence of hydrograph shape on temporal variations in bedload transport, grain size distributions, and armor persistence.

1 INTRODUCTION

Natural rivers throughout the world display considerable temporal flow variability and can experience a wide diversity of hydrographs ranging from flashy (e.g. rain-dominated environments) to gradual (snow or spring-dominated systems). Hydrograph shape (quantified by peak magnitude and rate of discharge change) significantly influences the volume, timing, and quality of water available for anthropogenic use and aquatic ecosystems [7,10]. Human modifications of the timing, magnitude, and slopes of hydrographs, often to more flashy with short peak flows and invariant baseflows, have positively influenced economic development but negatively impacted aquatic species [6,8] and channel morphology [2,3]. Uncertainties remain as to how unsteady flows, such as those common to variable hydrographs, impact bedload fluxes and hysteresis [1], grain size distributions [4], and the persistence of armor layers. The lack of a mechanistic and predictive understanding of hydrograph influences may also partially explain why bedload transport equations in gravel-bed rivers are often inaccurate [9].

As part of a larger study that explores the impact of hydrographs on sediment movement through a series of flume, field, and numerical modeling experiments (National Science Foundation projects EAR-1251681, EAR-1251785), we quantified sediment transport rates and changes in grain-size distribution before, during, and after two small to moderate storm events in a wadable gravel-bedded stream in the northern coast range of California, USA. Our goal was to collect naturally occurring bedload transport data for comparison with results from concurrent flume experiments.

2 METHODS

2.1 Study Site

The study site was located on North Fork Caspar Creek (NF Caspar) in the Jackson Experiment Forest managed by the US Forest Service and California Department of Fire and Forestry. NF Caspar Creek is a gravel and cobble-dominated wadable stream with good accessibility and an extensive historical dataset of flow and annual sediment yield (<http://www.fs.fed.us/psw/topics/water/caspar/>). Due to the flashy nature of storm events coming off the Pacific Ocean and the moderately high sediment supply within the watershed, bedload transport is common within the study reach and in years with normal to above average flows. The study reach length was 12 times the average channel width of 4 m and had relatively simple morphology (plane bed and riffle-dominated) with a moderate gradient (1-3%). The site was instrumented with three pressure transducers (Solinst LevelLoggers®) to monitor flow stage and water surface slope. Discharge during events was measured at multiple flow stages using a March McBirney FloMate® (model 2000) to develop a rating curve for the study site. We completed detailed bed topography surveys with a survey-grade total station at the beginning of the study and after each flow season to monitor changes in local deposition and scour.

2.2 Tracer Grains

We installed 390 painted tracer grains throughout the study reach with passive integrated transponder radio frequency identification tags (PIT RFID), which provide each grain with a unique identification number so that even when buried (up to 0.5 m), the grain does not need to be excavated to be identified. We installed tracer grains with the same grain size distribution as the underlying bed material and replaced existing particles on the bed with a tracer of similar size and shape. The minimum and maximum tracer grain sizes were dependent on the lithology and shape that caused shattering while drilling (>32 mm) and the infeasibility of removal for drilling (>180 mm), respectively. Before and after each event, we located tracer grains using an RFID antenna, and surveyed their locations. We disregarded the first movement of each tracer grain because of unnatural starting positions, but assessed all subsequent movements as naturally occurring.

2.3 Bedload Samples

Bedload samples were collected manually throughout each event at the upstream and downstream ends of the reach to quantify transport rates and mobile grain size distributions of the sediment inputs and outputs. Standard Helley-Smith samplers (60 mm aperture) [5] were used to collect cumulative cross-section samples from three bridges installed over the active channel at the upstream, mid-point, and downstream ends of the study reach. All measurements were taken at several (4-5) locations along the cross section and for a minimum of five minutes to ensure representative samples. Bedload samples were dried, sieved, and weighed to determine total volume and grain size distribution.

2.4 Analysis

We compared the measured transport rates and mobile grain sizes throughout each hydrograph at each cross-section location. Bed shear stress was determined throughout each event as the product of water density, gravitational acceleration, hydraulic radius and water surface slope. Bedload flux rates were calculated from the composite bedload samples with an assumed grain density of 2.65 kg/m³. Travel distances of tracer grains were calculated in ArcGIS as linear distances from the starting and ending point of each individual grain, and the percentage of tracer grains moved within each grain size class was determined.

3 RESULTS

Due to extended and ongoing drought conditions in California, only two storms occurred in the study area during Water Year 2015 (October 2014 to September 2015) that were of sufficient magnitude and duration to mobilize bedload. The first storm event on December 11 2014 peaked at $1.85 \text{ m}^3\text{s}^{-1}$ and sustained flows above $1.13 \text{ m}^3\text{s}^{-1}$ (the approximate discharge at which bedload is mobilized) for a duration of 14 hours (Figure 1a). The second storm event on Feb 6 2015 peaked at $2.53 \text{ m}^3\text{s}^{-1}$ and sustained flows above $1.13 \text{ m}^3\text{s}^{-1}$ for a duration of 23.5 hours (Figure 1b). Bedload flux during each storm event exhibited patterns of clockwise hysteresis such that bedload transport rates on the rising limb of the hydrograph were higher than transport rates on the falling limb. The grain size distribution throughout each event also varied not only with changes in bed shear stress as expected but also with timing within the event. The largest grain sizes in transport (as measured by D_{84} of the bedload samples, or the grain size at which 84% of the bedload sample was smaller than) were observed following the peak flow rather than at the peak flow when bed shear stresses were highest.

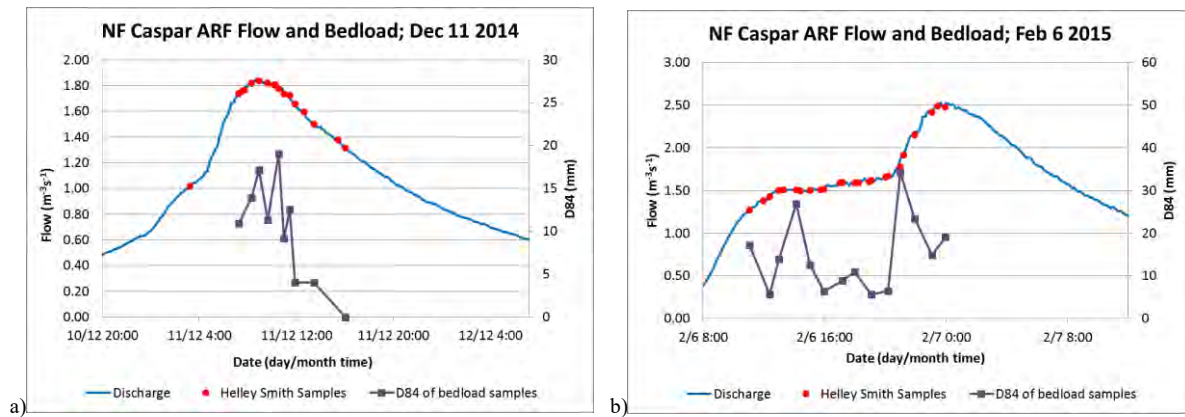


Figure 1. Hydrographs of two storm events during which bedload samples were collected at the downstream end of the study site.

Following each storm, tracer grains were resurveyed throughout the reach. Approximately 10-15% of the tracer grains moved during the December event, traveling an average of 0.5-1.0 m downstream. In general, more tracers moved in the upper locations of the study site where local slopes were slightly steeper (~3% versus ~2%); however, movement was noted throughout the study reach. Following the February storm event, approximately 16-24% of the tracer grains moved throughout the reach and traveled an average distance of 1.5-2.0 m. A total of 12 tracer grains were transported downstream of the study reach and were removed from the stream once their location was documented. While the larger February storm moved a greater percentage of available tracer grains a larger distance downstream than the smaller December storm, the grain size distribution of transported tracer grains did not vary significantly between the two storms. When compared to the bedload samples collected from the Helley-Smith samplers, the size of tracer grains moved was larger in both events than the largest particles manually captured. Although the aperture of the bedload samplers was sufficient to capture particles up to 60 mm, only one sample contained a single 45 mm particle, while the average size of all tracer grains moved in both storms was 64 mm.

4 IMPLICATIONS

The results from this study contribute towards a larger concurrent project that seeks a mechanistic understanding of the influence of hydrograph shape on temporal variations in bedload transport, grain size distributions and armor persistence. Comparison between the field data collected in this study and the flume data collected in the companion study will aid in determining whether transported bed grain sizes can be assumed to be relatively constant over time, which often occurs in bedload transport, landscape evolution and channel incision calculations. This preliminary field data suggests sediment transport rates and mobile grain size distributions vary not only spatially but temporally during storm events. Bedload flux in the study reach varied with changes in bed shear stress as expected but also with timing within the event and location on the hydrograph. These field-based measurements will be compared with results from flume experiments and used to calibrate and test a modified bedload transport equation that accounts for unsteady flow effects, temporal variations in mobile and

bed grain size distributions, and armoring. The goal is to improve predictions of sediment fluxes with regard to flow regimes, and thus better assess how climate change, flow regulation, and different precipitation environments (e.g. snow versus rain dominated) alter channel morphology and bed grain size distributions, which in turn influence infrastructure lifetime and stability, long-term channel incision rates, river restoration success, and aquatic habitat.

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