Sand- and Gravel-Trapping Efficiencies Derived for Four Types of Pressure-Difference Bedload Samplers

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Introduction

Bedload-trapping efficiencies (coefficients) were derived for four types of pressure-difference bedload samplers at the St. Anthony Falls Laboratory, University of Minnesota during the first two phases of flume experiments in January-March, 2006, referred to as "StreamLab06." The bedload-sampler research component was part of a series of community-led, large-scale laboratory experiments performed under the auspices of the National Center for Earth-surface Dynamics (Marr and others, 2010; Singh and others, 2013; Gray and others, 2010, 2019, 2021).

A bedload-trapping coefficient is the ratio of the mass of bedload – sediment transported by rolling, sliding, or skipping in close contact with the riverbed – collected by the deployed sampler, to the mass of bedload that would have passed through the width of the sample section at the same time but in the absence of the sampler (Hubbell, 1964). A trapping coefficient of 1.0 would mean the mass of every particle-size fraction of sediment in the collected sample is in the same proportion as those in transport.

For the 2006 experiments, a Helley-Smith (intake-nozzle width of 76.2 millimeter [mm] and height of 76.2 mm), BLH-84 (76.2 mm × 76.2 mm), Elwha (203 mm × 102 mm) and Toutle River-2 (TR-2; 305 mm × 152 mm) were repeatedly deployed by a hand-held rod with a stabilizing tether line in the main flume. Six combinations of bedload sampler types and bed compositions were tested: The BLH-84, Elwha, and Helley-Smith samplers were deployed on a sand bed (d_{50} = 1.0 mm) during five steady flows ranging from 2.0-3.6 cubic meters per second (m^3/s). The BLH-84, Elwha, and TR-2 samplers were deployed on a gravel bed (d_{50} = 11.2 mm) at four steady flows ranging from 4.0-5.5 m^3/s.

Bedload samples collected manually as part of 37 trials – each associated with a unique combination of a bedload sampler type, steady-flow rate, and bed composition – and associated ancillary data were used to calculate 2,030 instantaneous, at-a-point bedload-transport rates (1,000 as part of 19 sand-bed trials, and 1,030 as part of 27 gravel-bed trials.). Five contiguous weigh drums embedded in a slot spanning the width of the flume independently and continuously weighed captured bedload on approximately 1.1-second intervals. Approximately 3.8-million individual weigh-drum time-series measurements were recorded during the bedload sampler experiments (Groten and Gray, 2021; Gray and others, 2021).

Computational Methods to Compute Trapping Coefficients

Three methods based on Streamlab06 bedload sampler, flume weigh pan, and ancillary data were used to calculate trapping coefficients for each combination of sampler type and bed condition. These methods are listed from the most-to-least computationally intensive and complex, as follows (Gray, 2019; Gray et al., 2019):

Modified Thomas-Lewis Model

The original Thomas and Lewis (1993) model was modified to use with untransformed bedload-transport rate data in addition to cube root-transformed data. Averages of the transport data from three combinations of weigh drums and three drum time “windows” – of relatively short, medium, and long durations – were used to calculate trapping coefficients for the bedload samplers. The original 3-step model:

1. Regressed cube root-transformed sampler-derived bedload-transport rates on time-window averaged cubed transport rates from a single or a combination of weigh drums,
2. Squared the regression residuals from the first step on the variance of the cube root of the interval-mean transport rate for the time window, and regressed on the variance of the trap rate for the day, and
3. Inverted the predicted values from the second regression (from previous, number 2) and used them as weights to re-estimate the first regression.

Coefficients computed in cube root space were back transformed to real space. The retransformation bias for the cube root-transformed sampler data was estimated to be negligible; consequently, neither this computational procedure nor that using untransformed data required adjustment for bias.

Average of Ratios

This method, based on untransformed data, developed average transport rates from data produced by the weigh drums for each of the 2,030 bedload samples. Running-average transport rates were calculated for the drums at intervals equal to the duration of a single at-a-point bedload measurement, which ranged from 15-180 seconds. Ratios (trapping coefficients) were calculated by dividing each single-sample trap rate by the respective interval average from one or a combination of weigh drums. Those ratios were averaged to produce a single trapping coefficient for a trial which, in turn, were combined to derive a single coefficient for each combination of bedload sampler and bed type.

Ratios of Averages

This relatively simple and straight-forward method calculated averages of untransformed bedload-transport rates derived for each of the 37 trials for a given bedload sampler and the nine combinations of weigh drums and time windows.

The coefficients computed by these methods were evaluated for robustness and consistency. Those computed by the Modified Thomas-Lewis Model in real space were considered the most reliable and appear in table 1. They in turn can be compared to trapping coefficients produced by Hubbell and Stevens (1986) and Thomas and Lewis (1993) for the BLH-84, Helley-Smith, and TR-2 samplers.

Results

Trapping coefficients were computed for each sampler and bed composition pairing. Hence, the BLH-84 and Elwha samplers each have two provisional trapping coefficients derived from the sand- and gravel-bed tests. The Helley-Smith sampler (sand bed) and TR-2 sampler (gravel bed) each have a single provisional trapping coefficient. The BLH-84 and Elwha sampler coefficients are produced raw and are generalized based on sand- and gravel-bed data. These provisional trapping coefficients are shown in table 1. Previously computed bedload-trapping coefficients for all but the Elwha sampler can be found in Hubbell and others (1985), Hubbell and Stevens, Jr. (1986) and Thomas and Lewis (1993).

Table 1: Calculated bedload-sampler trapping coefficients by Gray (2019). [mm, millimeter]

Bedload Sampler	Bed Type, median diameters: SAND = 1.0 mm; GRAVEL = 11.2 mm	Nozzle-flare ratio[1]	Provisional calculated coefficients[2]	Provisional suggested generalized coefficients
BLH-84	SAND	1.4	0.83	**0.85**
ELWHA	SAND	1.4	1.67	**1.6**
Helley-Smith	SAND	3.22	3.11	**3.0**
BLH-84	GRAVEL	1.4	0.87	**0.85**
ELWHA	GRAVEL	1.4	1.54	**1.6**
Toutle River-2	GRAVEL	1.4	1.70	**1.7**

[1] The area of the bedload sampler's nozzle outlet area divided by its inlet area.

[2] Coefficients derived from the Modified Thomas-Lewis model in real space.

Conclusions

The four methods used to analyze the StreamLab06 dataset produced provisional trapping coefficients characterized by substantial variability. However, parsing the results revealed fundamental consistencies in the calculated coefficients. These included but were not limited to consistencies with respect to sampler hydraulic efficiencies; coefficients produced for sand- and gravel-bed deployments of the BLH-84 and Elwha samplers; and coefficients produced for the congruent Elwha and TR-2 sampler nozzles. The StreamLab06 bedload-sampler efficiency results infer that use of a 1.0 bedload-trapping coefficient can lead to overestimating bedload transport rates by at least 50 percent in similar flow and bed conditions in which the samplers were tested, except for the BLH-84 which had a mean trapping coefficient of 0.85.

Disclaimer

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