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Increased bag size improves Helley-Smith bed load sampler for use in streams with high sand and organic matter transport

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ABSTRACT Flume measurements showed that the sampling efficiency of the Helley-Smith bed load sampler rapidly decreased as sands clogged the 0.2 mm mesh of a standard bag (surface area = 1950 cm^2). Sampled transport rates were consistently low in relation to ambient rates of sediment transport. For sampling intervals of 4 and 14 min, sampling efficiencies averaged 20 and 14%, respectively. Because the change in efficiency was nonlinear with time, transport rates computed from samples collected over a variety of sampling times should not be compared directly. A three-fold increase in bag surface area prevented the rapid decline in sampling efficiencies, and calculated transport rates were within a few percentage points of ambient rates. Instream measurements further indicated that organic matter decreases the sampling efficiency of the standard bag, another problem minimized by use of a larger bag.

Amélioration de l'appareil à prélever les échantillons Helley-Smith par augmentation de la taille du sac, pour une utilisation en cours d'eau ayant un charriage important de sable et de mâtières organiques

RESUME Des mesures en canal ont montré que l'efficacité de l'appareil à prélever les échantillons Helley-Smith diminue rapidement à mesure que le tamis (maille de 0.2 mm; surface = 1950 cm^2) du sac standard est obstrué par les sables. Des vitesses de transports solides prises au hasard se révèlent faibles de façon significative par rapport à la vitesse d'ensemble des sédiments. Pour des intervalles d'échantillonnage de 4 et 14 min, l'efficacité d'échantillonnage a été en moyenne de 20% et 14% respectivement. Comme la variation d'efficacité n'est pas linéaire avec le temps, on ne peut comparer les vitesses de transports solides calculées à partir d'échantillons prélevés avec différents temps de mesure. Le triplement de la surface du sac évite la diminution rapide de l'efficacité d'échantillonnage et les vitesses de transports solides alors calculées se situent à quelques pourcents près des vitesses d'ensemble. D'autres mesures dans le courant-même indiquent que la présence de matière organique diminue l'efficacité d'échantillonnage des sacs standards, autre problème minimisé par l'emploi d'un sac de taille supérieure.

INTRODUCTION

Despite various devices that have been proposed for measuring bed load (American Society of Civil Engineers, 1969; Graf, 1971; Hubbell, 1964), none has been universally accepted. The scarcity of published transport rates and particle sizes of bed load sediments in mountain streams, as indicated by Leopold & Emmett (1976), may largely reflect this lack of adequate techniques and devices for obtaining accurate measurements over diverse flow conditions, sediment transport rates, bed load particle sizes, and channel morphology. A Committee on Erosion and Sedimentation (1977) has recommended additional research to develop a bed load sampler that will operate properly over a range of hydraulic characteristics and sizes of bed material. The need for such a sampler in mountain streams has become increasingly important as land management agencies and organizations attempt to assess the effectiveness of control techniques designed to reduce nonpoint sources of sediment and instream sedimentation problems.

In 1971, Helley & Smith reported on the development and calibration of a pressure-difference bed load sampler. Testing their sampler in a tow tank at velocities of 0.6 to 1.8 m s^{-1}, they found that velocities within the orifice were increased 12 to 25% regardless of whether sample bags were empty, one-third full, or two-thirds full of sediment. Mesh size of the sample bag was 0.2 mm. Using a recirculating flume for further tests and a splitter to measure actual transport rates of sand-size material with a median particle diameter (D_{50}) of 1.15 mm, they showed that the pressure-difference sampler consistently over-registered.

Additional hydraulic testing by Druffel *et al.* (1976) indicated that flows entering the Helley-Smith sampler do accelerate and result in a hydraulic efficiency of approximately 1.5. However, Druffel *et al.* (1976) noted that in their flume system, the 0.2 mm mesh sample bag was quickly plugged by organic matter. They further concluded that sediment whose diameter is close to the 0.2 mm mesh size can plug the sample bag and cause an unpredictable decrease in hydraulic efficiency and, hence, sampling efficiency.

Field calibration of the Helley-Smith bed load sampler with a slotted bed load sampler installed in the bed of the East Fork River of Wyoming has been reported by Emmett (1976). Results indicated that for particles between 0.5 and 16 mm the Helley-Smith sampler measured essentially the same transport rates as the slotted sampler. However, sampling efficiency was not determined for either sampler.

Field measurements by Johnson *et al.* (1977) indicated that the Helley-Smith sampler may actually under-register transport rates in mountain streams. The unpredictable drop in sampling efficiency as a result of sand-sized particles or organic matter plugging the sampler's catch bag represents a major problem in obtaining accurate field measurements of bed load transport. Many mountain streams have median particle sizes of sediments in bed load transport of 1 mm or less. In addition, streams draining forested basins typically carry large amounts of organic matter during the high flows that are also responsible for bed load transport. Thus, if the mesh size of the sample bag is small enough to trap sand-sized particles, the opportunity for plugging (by either sediments or organics) is greatly increased. Alternatively, if the mesh size of the bag is increased, major portions of the sediments in transport may not be measured. The problem of under-registration of the Helley-Smith sampler has been noted by the author during both flume and stream measurements of bed load transport. This paper further quantifies the effects of fine sand and organics upon sampling efficiency and illustrates how an increase in size of the catch bag may minimize under-registration by the sampler.

EQUIPMENT AND PROCEDURES

For this study, a hand-held Helley-Smith sampler with an orifice 7.6 x 7.6 cm and either a standard bag with a surface area of 1950 cm^2 or a larger bag with 6000 cm^2, as patterned after Johnson *et al.* (1977), was used. Mesh openings were 0.2 mm for both "standard" and "large" bags. Both sizes were used in a flume study at Kalama Springs, a Weyerhaeuser Company field laboratory about 80 km east of Longview, Washington. Only the standard bag was used for field sampling at Flynn Creek, which drains a 2 km^2 forested basin in the Oregon Coast Range.

During the summers of 1977 and 1978, the sampling efficiency of the Helley-Smith sampler was tested under controlled conditions of discharge and sediment transport at Kalama Springs. Sand-sized sediments (with median particle sizes of approximately 0.5 mm) were metered into the upstream end of a flume 7.6 m long, 0.71 m wide, and 0.30 m deep. The amount of metered sediments was used to calculate ambient transport rates, expressed in grams per second per metre width of channel ($g\ s^{-1}\ m^{-1}$). Transport rates measured with the Helley-Smith sampler are also expressed in the same units. Horizontal velocity profiles showed velocities were uniform across the flume. Observations further indicated that sands in transport appeared to move downstream evenly, with the amount in transport not varying across the width of the flume. Gravel-sized materials with a median particle size (D_{50}) of 15 mm covered the bottom of the flume at the downstream end where samples were collected. The gravels were not entrained by the flow and remained stable during each test run. At the downstream end of the flume, transport rates were measured with the Helley-Smith sampler over time intervals of 0.5 to 14 min.

During the winter of 1977-1978, bed load was sampled at Flynn Creek in a modified portion of the channel that was rectangular in cross section, with a 2.54 m wide flat bottom and vertical side walls. Resting the Helley-Smith sampler on the bottom of the fish trap during sampling provided an excellent contact and ensured that lowering or raising the sampler did not scoop additional bed material. Two or three replications were collected at each of three time intervals: 0.25, 0.50, and 1 min. Replicate samples for each time interval were composited for determining an average rate of sediment transport. A variety of stream discharges were sampled. Ashing the samples at 310°C for 24 h removed organic material, and regression analysis was used to correlate sample times and weights.

RESULTS AND DISCUSSION

During the 1977 tests at Kalama Springs with 0.5 mm (D_{50}) sands and a standard bag, samples collected over intervals of 4, 9, and 14 min and a range of discharge and sediment transport rates indicated that sampling efficiency was less than 20% (Table 1).

Table 1 Efficiency of the Helley-Smith bed load sampler in 18 flume tests at Kalama Springs, 1977

Water		Sample		Sediment transport ($\mathrm{g\ s^{-1}\ m^{-1}}$)*			Sampler efficiency %**
Discharge ($\mathrm{l\ s^{-1}}$)	Velocity ($\mathrm{m\ s^{-1}}$)	Number	Interval (min)	Ambient rate†	Sample rate§	SD¶	
45.3	0.75	5	9	40	7	3.0	16
49.8	0.92	3	14	58	5	1.5	9
51.0	1.03	3	14	47	3	0.2	8
44.2	0.82	5	4	237	25	3.5	11
53.8	0.94	5	4	302	25	2.0	9
48.7	1.20	5	4	202	38	5.7	19
78.7	0.84	2	14	47	7	0.5	15
73.1	1.09	3	14	62	7	1.2	10
70.2	1.14	3	14	58	7	1.3	10
73.1	0.81	5	4	278	32	5.3	11
73.6	1.06	5	4	278	40	2.7	14
72.2	1.15	5	4	303	43	5.3	14
90.1	0.88	3	14	50	5	1.2	11
90.6	1.10	3	14	85	10	1.5	11
96.3	1.24	3	14	73	5	2.8	7
91.8	0.94	5	4	255	25	1.8	10
92.3	1.05	5	4	278	52	4.8	19
92.6	1.24	5	4	278	42	6.8	15

* $\mathrm{g\ s^{-1}\ m^{-1}}$ = grams per second per metre width of channel.
† Based on known volumes of sediment metered into the flume.
§ Measured with Helley-Smith sampler (standard bag, 0.2 mm mesh).
¶ SD = standard deviation of sample rate.
** Sampling efficiency is the ratio of W_0, the weight of bed load collected by the sampler, expressed as a per cent of W_t, the weight of bed load that would have passed through the area occupied by the opening in the sampler nozzle had the sampler not been there.

For example, rates measured over 4 min intervals with the Helley-Smith sampler averaged 13.6% for ambient transport rates of 245 $\mathrm{g\ s^{-1}\ m^{-1}}$. Efficiency for the 14 min samples averaged only 10.1% when ambient transport rates averaged 60 $\mathrm{g\ s^{-1}\ m^{-1}}$. Because nearly all sands in transport were moving within 6 cm of the bed (Beschta & Jackson, 1979), the 7.6 cm high orifice of the Helley-Smith sampler should have trapped most of the moving sediments. Thus, the exceedingly low sampling efficiencies in Table 1 do not reflect sediment flow over the top of the orifice. Observations indicated that fine sediments had almost completely plugged the fine mesh of the bag.

Because of the low efficiencies for sampling intervals of 4, 9, and 14 min, an additional run with sample intervals of 0.5, 1, 2, 4, and 8 min was conducted in order to determine the influence of sample time on the efficiency of the Helley-Smith sampler. Discharge was 92 l s^{-1}, velocity was 1.06 m s^{-1}, and the ambient transport rate of sand was 262 g s^{-1} m^{-1}. If the efficiency of the sampler remained constant, sample weight would increase linearly with sample time. However, the curvilinear response (Fig. 1, solid line) indicates a rapid drop in efficiency (Fig. 1, broken line). Within 60 s, sampler efficiency dropped to less than 20% and continued to decrease asymptotically with time. Thus, for conditions of constant sediment transport, the amount of sediment trapped becomes a function of the sampling time. Because the change in efficiency is nonlinear, transport rates from samples collected over different sample times cannot be compared.

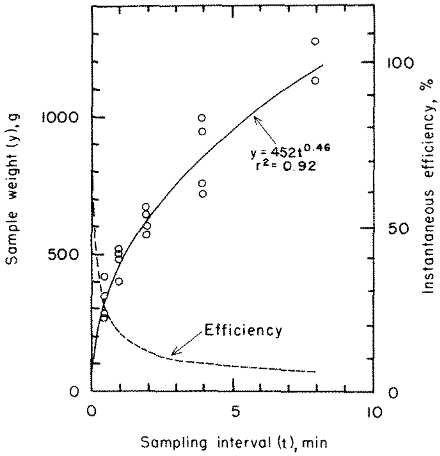

Fig. 1 Average sample weight (solid line) at different sampling intervals for a Helley-Smith bed load sampler with a standard bag. Sampler efficiency (broken line) is expressed as a percentage.

The ambient transport rate of 262 g s^{-1} m^{-1} in the flume test may be higher than typically measured rates in streams and rivers. Several years of sampling the East Fork River in west-central Wyoming (Leopold & Emmett, 1976, 1977; Emmett, 1979) have shown most transport rates to be less than 308 g s^{-1} m^{-1}. In Idaho, Johnson *et al.* (1977) measured average transport rates of 17 g s^{-1} m^{-1} with a standard bag of 0.2 mm mesh. Increasing either mesh size, bag size, or both, increased the amount of sediment trapped by the sampler. Using a large bag of 0.2 mm mesh, they measured an average of 72 g s^{-1} m^{-1} over a range of flow conditions. During the 1977-1978 winter at Flynn Creek in western Oregon, 42 g s^{-1} m^{-1} was the highest transport rate measured with a standard-sized 0.2 mm bag.

Although ambient transport rates at the Kalama Springs flume were generally higher than the above values, a rapid reduction in catch efficiency for sand-sized particles should occur even at lower transport rates (Table 1). In the Wyoming, Idaho, and

Oregon studies, median particle sizes averaged approximately 1, 0.5, and 0.6 mm, respectively, indicating that a significant component of the bed load transport in many natural streams may be the size of fine to coarse sands. Unpublished data by the author for Huntington Creek in central Utah also indicated the D_{50} of bed load sediments to be less than 1 mm. However, Emmett (1976) has shown that during periods of high flow in the Snake and Clearwater rivers in Idaho, gravel-sized particles may predominate.

During the winter of 1977-1978 at Flynn Creek, bed load transport rates ranged from nearly 0 to almost 43 g s^{-1} m^{-1} as discharges ranged from 0.9 to 1.9 m^3 s^{-1}. Transport rates typically, but not always, increased with an increase in flow. An analysis of variance indicated a highly significant difference (99% confidence level) according to length of sampling interval (0.25, 0.5, and 1.0 min), further illustrating that transport rates for different sample times cannot be compared when a standard-sized, 0.2 mm bag is used. Although measured sediment transport rates generally decreased as sample time increased from 0.25 to 1 min (Fig. 2), this effect was confounded by organic matter trapped by the sampler. As the percentage of organic matter increased, the transport rate tended to decrease at a given flow condition. Thus, both the amount of sand-sized inorganic particles and the amount of organic matter are variables that inversely affect the efficiency of the Helley-Smith sampler. Organic materials were not part of the bed load in any flume test at Kalama Springs.

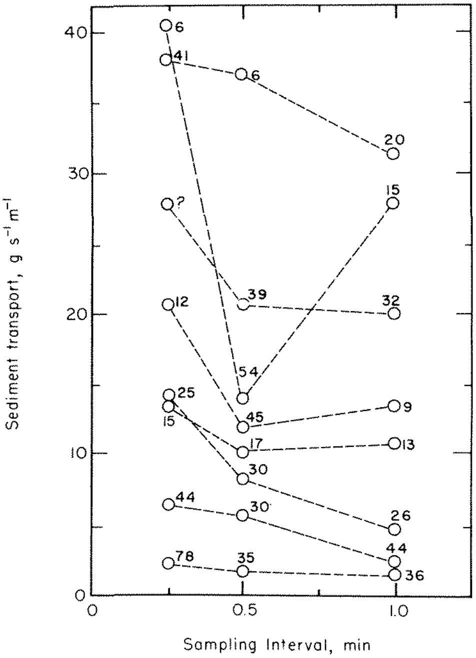

Fig. 2 Transport rates of bed load sediments sampled at different time intervals with a Helley-Smith bed load sampler and a standard bag. The number at each point represents the percentage of organic matter.

During the summer of 1978, additional flume tests were conducted at Kalama Springs with various sands ($0.2 \text{ mm} \leqslant D_{50} \leqslant 0.5 \text{ mm}$) to assess how bag size (1950 and 6000 cm^2) and sample time (0.5, 1, 2, 4, and 8 min) affect the efficiency of the Helley-Smith sampler. In conjunction with other studies, the flume had been narrowed to 0.36 m and roughness elements about 1.5 cm high had been installed along its bottom. Again sand particles were metered into the upstream end of the flume; however, because the roughness elements trapped sands along the flume bottom, transport rates at the downstream end of the flume were initially low in each test. As sand filled the spaces between the elements, transport rates increased and approached steady state. Consequently, the first replication of samples consistently showed lower transport rates and was excluded from analysis.

Observations of sediment storage and transport in the flume indicated that the transport rate generally reached equilibrium with the sediment input rates during the second replication of each test. Regression equations were fitted through data points *for the second replication according to the form* $y = at^b$, where y = sample weight (g), t = sampling time (min), and a and b are coefficients fitted by regression.

Averaging regression coefficients for the various sands resulted in relationships which illustrate the effect of bag size on sample weights (Fig. 3). The average ambient transport rate of 17.7 g s^{-1} m^{-1} closely corresponds to the measured transport rate of 17.8 g s^{-1} m^{-1} for 1 min samples with the large bag. The reason for "b" being slightly greater than 1 (Fig. 3) is not known but may reflect experimental error. In contrast to results with the large bag, 1 min samples with the standard bag were only 76% efficient. Increasing the sample times drastically reduced the overall efficiency of the standard bag (illustrated by b = 0.56, Fig. 3) as it plugged with fine sands.

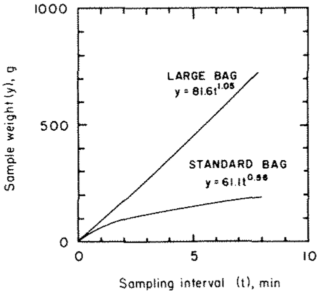

Fig. 3 Average weight of bed load sediments collected at different sampling intervals with a standard bag (1950 cm^2) and a large bag (6000 cm^2). Both bags are of 0.2 mm mesh.

The efficiency with the standard bag again dropped off rapidly as sampling time increased, so much so that the instantaneous efficiency dropped to approximately 50% within 0.5 min. Thus, although the efficiency drops off more slowly at lower transport rates (18 g s^{-1} m^{-1} *vs.* 262 g s^{-1} m^{-1}), it nevertheless does decrease, indicating that sample times must be short (<15 s) whenever the standard bag is used. However the relative errors due to "scooping" of bed material in gravel-bedded streams may become excessively large with short sampling intervals.

Subsequent field observations have confirmed that the large bag does not easily plug. Being more flexible, eddies within the flow create a washing action which tends to move sediment particles and organics toward the downstream end of the bag. This movement does not occur with the standard bag. Because the bag aligning rod is easily extended, the use of a larger bag with a hand-held version of the Helley-Smith sampler is not a major problem. However, the cable-supported version of the Helley-Smith sampler would have to be redesigned when a large bag is used so that the bag would not rub the sampler frame and tail assembly.

CONCLUSIONS

As sample times increase, the standard-sized (1950 cm^2) bag of 0.2 mm mesh quickly clogs with sand-sized sediments and causes an unpredictable reduction in the sampling efficiency of the Helley-Smith bed load sampler. Similarly, particulate organic matter can also clog the standard bag. With the standard bag, samples collected at high sediment transport rates or at high levels of organic matter will grossly underestimate actual rates of bed load transport. A 3-fold increase in bag surface area appears to reduce the effect of fine inorganics and organics clogging the bag so that the sampling efficiency of the Helley-Smith bed load sampler was approximately 100% over sampling intervals up to 8 min long. Although the Helley-Smith sampler was not designed for bed load sampling in mountain streams with relatively high proportions of fine sands and organics, the adaption of a larger bag allows the sampler to be effectively used under these conditions. Because the median size of inorganic bed load particles being transported in many streams is less than 1 mm, such a capability is particularly important.

Until the hydraulics and efficiency of the Helley-Smith bed load sampler can be characterized further, those making field measurements of bed load transport should use a large bag, as suggested by Johnson *et al.* (1977). Although the sampling efficiency appeared to remain constant over intervals up to 8 min, shorter sampling intervals are recommended, particularly in those streams where sand-sized particles or organics comprise a major component of the bed load.

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