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A NEW TECHNIQUE FOR MEASURING FINE SEDIMENT ACCUMULATION IN GRAVEL BED STREAMS

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The collection and analysis of bed material samples has been a standard practice for determining the quantity of fine sediments (less than 3.4 mm diameter) in stream gravels. However, the sampling techniques currently in use can be labor and equipment intensive. Also, inaccuracy in quantification of the finer fractions can occur dependent upon bed material composition. This paper reports on a study which has evaluated the utility of a sediment trapping device for measuring fine sediment in the intergravel environment.

Introduction

Inorganic sediment is a major water pollutant in the Western United States. In streams and rivers, sediment enters the system through erosion processes dependent upon climate, geology, exposure, gradient, soil type, vegetation cover and human activity (Iwamoto et al. 1978).

The impacts of fine sediment on the aquatic biota and their habitat have been reviewed by Cordone and Kelley (1961), Gibbons and Salo (1973), and Iwamoto et al. (1978). Within streams, these impacts can include: 1) reduction of primary production; 2) damage to respiratory organs; 3) entombment of organisms; 4) increased disease; 5) reduction of rearing and spawning habitat; 6) reduction of intragravel dissolved oxygen and flow; and 7) alteration of water chemistry.

While much research has focused on describing the impacts of sediment deposition on stream systems, a lesser effort has been directed toward the development of methods for efficiently and accurately measuring the accumulation of fine material in streambeds. Today, two types of samplers are commonly used for characterizing substrate composition: the McNeil core sampler developed by McNeil

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(1964) and the freeze-core sampling techniques developed by Ryan (1970) and subsequently improved by Platts and Penton (1980). Reiser et al. (1985) summarized the application of these techniques and noted the disadvantages of each. In regard to the sampling of accumulated fine sediments, the major deficiencies of the McNeil sampler are: 1) the possible loss of fine material which becomes suspended during the coring; and, 2) the inability to insert the sampler to the specified depth if sediment particles are too large or compacted. The major disadvantage of the freeze-core technique is the equipment-intensive nature of the sampler which can limit sampling only to readily accessible areas. Also, freeze core probes can be difficult to drive into large substrate particles and the weight of samples obtained can make handling and analysis difficult. The characterization of samples collected from both techniques can be equally time consuming. Shortcomings of the McNeil and freeze-core techniques have resulted in increased interest in the use of sediment "trapping" devices (Meehan and Swanston 1977, Mahoney and Erman 1984).

The objective of this study was to test the observations of Reiser and White (1981) who noted during salmonid egg survival studies a correlation between the percentage of fine sediments trapped by Whitlock-Vibert boxes and that contained in McNeil core samples. Should this relationship be validated, a new, efficient and effective sediment trapping technique would be available to monitor fine sediment accumulation in stream systems. This paper presents the results of our testing and discusses potential applications.

Methods

Whitlock-Vibert (W-V) boxes are made of polypropylene and measure 14 cm (5.5 in) long by 8.9 cm (3.5 in) deep by 6.4 cm (2.5 in) wide. The sides, top and bottom of the boxes are perforated with various sized and shaped rectangular slots to allow water circulation (Figure 1). Openings in the top and the largest slots on the sides measure 3.5 mm (0.14 in) by 13 mm (0.51 in). Originally, the boxes were developed as planting chambers for fish eggs (Whitlock 1978).

For the purposes of our study, W-V boxes were modified to increase their effectiveness as sediment traps. The inner panel was removed and boxes were filled with clean gravel 12 to 25 mm (0.5 to 1.0 in) in diameter, as shown in Figure 1. Also, a strip of duct tape was placed on the bottom of each box to prevent the washing out of trapped fine sediment.

Testing of the sediment trapping capabilities of the modified W-V boxes was conducted in the experimental flume located in the Hydraulics Laboratory of the University of Wyoming's College of Engineering. The concrete flume is 0.91 m (3.0 ft) wide, 0.91 m (3.0 ft) deep and 21.3 m (70 ft) long. The flume was filled to a depth of 0.46 m (1.5 ft.) with bed material similar in composition to the material used by salmonids for spawning in southeast Wyoming (Reiser and Wesche 1977). To simulate natural stream conditions, the substrate was formed into three riffle-pool sequences. Peak discharge through the channel,

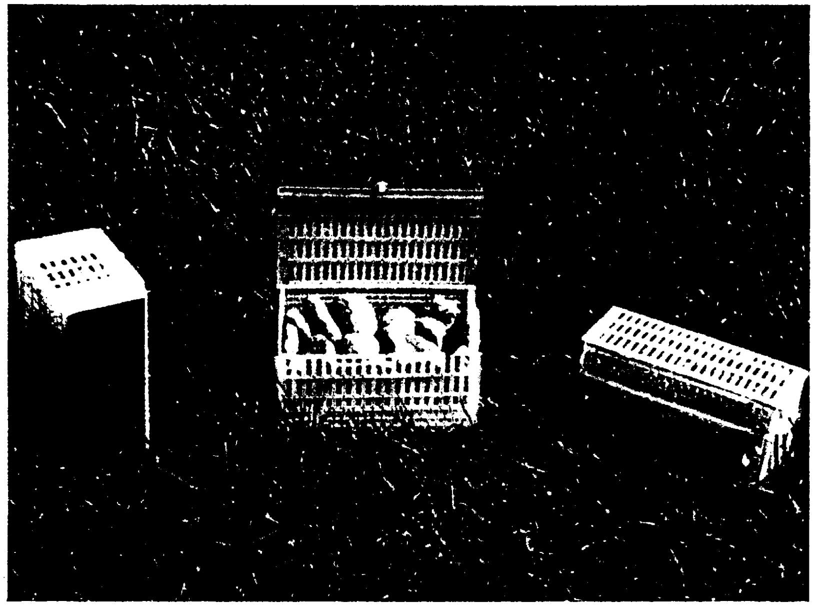

Figure 1. Whitlock-Vibert Boxes as Modified for Sediment Trapping.

controlled by a series of five pumps, is approximately 0.14 m^3/sec (5 cfs).

Three separate although similar experiments were conducted during 1984 and 1985 with each following the same general procedure:

1. Modified W-V boxes were planted in each riffle and pool throughout the flume;
2. Pumps were activated and flow was varied diurnally throughout the experiment;
3. Suspended sediment samples, collected with a USDH-48 sampler, and bedload samples, collected with a Helley-Smith sampler, were periodically taken at the head of each riffle to determine sediment movement;
4. At the conclusion of each experiment, boxes were carefully removed from the substrate, placed in plastic bags, labelled with time and location information, and transported to the University of Wyoming Sediment Laboratory for analysis;
5. At a location immediately adjacent to each W-V box, a McNeil core sample was collected, placed in a plastic bucket, labelled, and transported to the Sediment Laboratory for analysis;

6. Following oven drying at 70°C (160°F) for at least 24 hours, each W-V box and McNeil sample was gravimetrically analyzed by the dry sieve technique following the methods described by Reiser and Wesche (1977), with results reported as percent of total dry sample weight.

Each experiment differed somewhat in terms of duration, flow regime, number of boxes planted, planting depth of boxes, and the amount of fine material added to the system. Experiment #1 lasted three days, had a peak discharge of 0.08 m^3/sec (2.7 cfs), and utilized 44 W-V boxes planted 7.6 cm (3 in) deep in the substrate. Experiment #2 ran for five days, had peak discharges of 0.12 m^3/sec (4.2 cfs), and included 46 boxes planted with their tops flush with the surface of the substrate. Experiment #3 was similar to #2 with the exceptions that 92 boxes were planted and 1818 kg (4000 lbs) of fine sediment were added to the system at the upper end of the flume. All material added was less than 3.4 mm (0.13 in.) in diameter.

Correlation analysis was used to determine the relationship between percent fine sediment trapped in the modified W-V boxes and that present in the adjacent McNeil core samples. Analysis-of-variance was used to compare mean percent fines between the boxes and the cores. For each experiment, separate statistical analyses were conducted for all samples combined, all riffle samples, all pool samples, and all samples taken from the middle of the experimental channel. To compare estimated sample sizes between W-V boxes and McNeil samples needed to achieve given levels of accuracy, the equation given by Burns (1966) was applied.

Results

The results of Experiment #1 comparing the percent fine sediment trapped by the modified W-V boxes and that contained in the McNeil core samples are presented in Table 1. Significant differences existed for all sample types tested for percent fines less than 3.4 mm diameter. Results were similar for percent fines less than 1.7 mm diameter. In all cases, the quantity of fines trapped by the modified W-V boxes was less than that contained in the McNeil samples. Operational problems with the flume's pumping system may have contributed to this result. Pump failure reduced both the magnitude of peak discharges and the duration of the experiment. As a result, little fine bed material was transported through the system. Bedload sample data substantiate this. Peak transport during Experiment #1 was 4 grams per minute, compared with 23 and 300 grams per minute for Experiments #2 and #3, respectively. The lack of bed material movement combined with the depth at which the boxes were planted could have significantly limited their ability to trap fines. Correlation coefficients were statistically significant when considering all samples, riffle samples, and mid-channel samples. These results indicate that linear relationships did exist between the percent fines trapped by the boxes and the amount of fines contained in adjacent McNeil samples.

Table 1. Comparison of Mean Percent Fine Sediment Less Than 3.4 mm Diameter in Modified W-V Boxes and McNeil Samples for Experiment 1,2 and 3.

EXPERIMENT 1

Sample	Sample Size	Mean % Fines W-V Boxes	Mean % Fines McNeil	Coefficient of Variation (%) W-V Boxes	Coefficient of Variation (%) McNeil	Correlation Coefficient (r)
All	44	12.2	18.4	41.8	36.7	0.53**
Riffle	22	14.0	21.8	41.2	25.6	0.49**
Pool	22	10.4	15.0	35.3	41.2	0.39
Mid-Channel	16	13.2	19.6	46.2	38.4	0.60**
EXPERIMENT 2						
All	46*	11.4	13.7	77.2	52.4	0.54**
Riffle	23*	12.8	14.6	84.5	44.1	0.56**
Pool	23*	10.0	12.9	61.4	61.6	0.59**
Mid-Channel	14*	10.8	12.2	72.8	60.0	0.69**
EXPERIMENT 3						
All	92*	31.0	37.3	39.5	85.0	0.39**
Riffle	46*	33.5	27.9	34.0	62.0	0.45**
Pool	46	28.5	46.5	44.5	81.5	0.52**
Mid-Channel	28*	32.7	39.2	35.5	76.0	0.20

* No significant difference between means at $\alpha = 0.05$
** r significant at $\alpha = 0.05$

Experiment #2 indicated the modified W-V boxes to be as effective an indicator of fine sediment dynamics as McNeil core samples. No significant differences were observed between mean percent fines less than 3.4 mm diameter and all correlation coefficients were significant. Similar results were obtained when percent fines less than 1.7 mm diameter were considered.

Experiment #3 further verified the findings from Experiment #2. With the exception of the pool sample, no significant differences were found between means. We feel the discrepancy found in the pool data resulted from the filling (in excess of 15 cm or 0.5 ft) which occurred in the upper two pools due to the addition of large amounts of fine material to the system. When McNeil samples were taken in these pools following Experiment #3, the length of the sampling tube was not sufficient in all cases to penetrate through the fill layer. Thus, the percent of fine material in the samples was abnormally high in comparison to the modified W-V boxes, which had coarse material placed in them prior to the initiation of the experiment. Analysis-of-variance results substantiate this hypothesis. For the upper two pools, significant differences were found between the mean percent fines in the boxes and the McNeil samples. In the lowest pool, however, where filling was not as severe, no differences were found between means.

Discussion

Our results suggest that modified W-V boxes, planted flush with the bed surface, can be used in place of McNeil samples to monitor fine sediment accumulation within stream bed material. Their small size and low cost ($1.30 each at present) make them well suited for use in field projects. In addition, sample handling is easier than with McNeil or freeze core methods. For example, using the data provided in Table 1 for Experiment 2 pool samples and the equation given by Burns (1966), 164 modified W-V box samples and 161 McNeil core samples would be needed to be 95 percent confident that the sample mean was within 10 percent of the true mean. Based upon our laboratory analysis, an average McNeil sample weighs 4.75 kg (10.4 lbs) and an average W-V box sample weighs 1.0 kg (2.2 lbs). In practical terms, then, 765 kg (1683 lbs) of substrate collected by McNeil sampling would have to be carried out from a remote site and analyzed in comparison with 164 kg (361 lbs) of W-V box material.

For the purposes of our experiments, all modified W-V boxes recovered have been analyzed in the laboratory by the dry-sieve process. For many types of studies, such detail may not be necessary. A quick, yet reliable, analysis method would be to weigh the contents of the box before planting and again after recovery. This difference divided by the weight after and multiplied by 100 would estimate the percent fine sediment.

One problem identified during our experiments was the inability of the boxes to sample extremely high quantities of deposition. Several alternatives exist to compensate for this problem. First, boxes could be recovered and replanted more frequently. If this is not possible, a second alternative would be to measure the depth of material deposited over the top of the box. Knowing the surface area of the box top and this depth, the volume of excess deposition can be calculated. Multiplying this volume by the weight per unit volume of the deposited material, the weight of the excess can be calculated. This weight can then be added to the "weight after" for the calculation of percent fine sediment.

Because of their size, cost, transportability and potential ease of analysis, we feel the modified W-V boxes readily lend themselves to time sequence collection of fine sediment data above, within and below impacted stream reaches. Boxes could be used to monitor change in intergravel fines resulting from such activities as road construction, water development and logging. For such studies, plantings could be made upstream and downstream from potential impacted areas prior to the initiation of construction and removed at various time intervals to allow comparisons of sediment content. A second use of the boxes could be for instream flow studies to determine the flushing flows needed to maintain gravel quality.

Conclusion

We feel the modified Whitlock-Vibert boxes, when planted flush to the streambed surface, can function as effective and efficient sediment traps for monitoring the accumulation of fine sediment (less than 3.4 mm diameter) on and in streambed gravels. The information obtained through application of this technique should be useful in assessing stream quality conditions for studies concerned with fish spawning and rearing habitat, sediment transport and flushing flow prescriptions, and more generalized channel morphology investigations. Overall, the technique should be of use for both management and research investigations.

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