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Development and Testing of a New Technique for Measuring Fine Sediment in Streams

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Abstract. The collection and analysis of bed material samples has been a standard practice for determining the quantity of fine sediments (less than 3.35 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.[1]

The impacts of fine sediment on the aquatic biota and their habitat have been extensively reviewed.[1,2,3] 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 and the freeze-core sampler.[4,5,6,7] 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.[8,9]

The objective of this study was to test the observations of Reiser and White 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.[10] 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.[11]

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.

Initial 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.[12] To simulate natural stream conditions, the substrate was formed into three riffle-pool sequences. Peak discharge through the channel, controlled by a series of five pumps, is approximately 0.14 m^3/sec (5 cfs).

Three separate although similar laboratory 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, 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 3.35 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.

Field testing was conducted during 1985 on the North Fork of the Little Snake River (NFLS). The purpose of this testing was to 1) compare the percent fine sediment trapped by the modified W-V boxes to that contained in McNeil core samples, and 2) evaluate the durability of the boxes over a range of field conditions.

The NFLS is a steep gradient, large bed element stream located in the upper Colorado River basin of south-central Wyoming. As a result of water development related construction activity in the NFLS watershed, large amounts of sediment entered the channel during 1984. Testing of the W-V boxes was carried out in conjunction with an ongoing study to determine mitigative flushing flow recommendations for the impacted stream reaches.

Modified Whitlock-Vibert boxes were tested in four study reaches on the NFLS during 1985. Reach 1 was a moderate gradient (2.6%) control section located immediately upstream from construction activity, while Reaches 2, 3 and 4 were located in the zone of impact from the sediment spill. Reach

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

2 was a high gradient (4.5%) riffle-cascade, Reach 3 was most similar to the upstream control (3.0% slope), and Reach 4 was a low gradient (0.4%) pool. Each reach was approximately 12 meters (40 ft) in length and averaged 6.5 meters (21 ft) in width. Discharge varied from approximately 0.1 to 3.1 m^3/sec (3 to 110 cfs).

Twelve modified W-V boxes were planted and recovered three times in each study reach. At each recovery time a McNeil core sample was taken adjacent to each box. The planting and recovery schedule was as follows:

Test 1 - planted October 1984, recovered May, 1985
Test 2 - planted May 1985, recovered July, 1985
Test 3 - planted July 1985, recovered September 1985.

All boxes were planted with the top flush to the streambed surface. Sample handling in the field and analysis in the laboratory was the same as described above for laboratory experiments.

Results

The results of laboratory 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 3.35 mm diameter. Results were similar for percent fines less than 1.7 mm and 0.85 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.

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 3.35 mm diameter and all correlation coefficients were significant. Similar results were obtained when percent fines less than 1.75 and 0.85 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

Table 1. Comparison of Mean Percent Fine Sediment Less Than 3.35 mm Diameter in Modified W-V Boxes and McNeil Samples for Laboratory Experiments 1, 2 and 3

Sample	Sample Size	Mean % Fines: W-V Boxes	Mean % Fines: McNeil	Coefficient of Variation (%): W-V Boxes	Coefficient of Variation (%): McNeil	Correlation Coefficient (r)
EXPERIMENT 1						
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 $\alpha = 0.05$

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.

The results of field testing, as summarized in Table 2, were similar to those found under laboratory conditions. At Reaches 1, 2 and 3 (moderate to steep gradient) analysis-of-variance indicated no significant differences between percent fine sediment in the W-V boxes and the McNeil samples. This relationship held for all three definitions of percent fine sediment that were tested.

The results from Reach 4, the low gradient pool, were similar to those for the pool samples of laboratory experiment 3 (Table 1). During spring runoff in early May 1985, large quantities of fine sediment were flushed into Reach 4. Deposition depth of this new bed material ranged up to 30 cm (12 inches) throughout the pool, thereby completely embedding the W-V boxes. The significant differences found are most likely the result of this heavy deposition coupled with the size limitations of the prefilled W-V boxes. Despite the Reach 4 results, no significant differences were found for percent fine sediment less than 0.85 mm when samples from all reaches were combined. To further test the sediment trapping capabilities of the boxes in low gradient reaches, additional plantings were made during 1986 in several pools downstream from Reach 4 where deposition was not as severe. Preliminary results indicate no significant differences between W-V boxes and McNeil samples.

The durability of the W-V boxes throughout field testing on the NFLS was exceptionally good. More than 90 percent of the boxes could be reusedat least three times, with most breakage being the result of handling during sub-freezing temperatures. Another problem encountered was the displacement of planted boxes. Of 144 boxes planted during the 1985 field testing, 25 (17%) washed out. The two causes for displacement were early spring ice-out (12 boxes) and high streamflow levels (13 boxes). Sixty percent of all displacement occurred in Reach 2, the steep gradient study site.

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, 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.[13] 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 and testing, 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 both the laboratory experiments and the full testing 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

Table 2. Comparison of mean percent fine sediment in modified W-V boxes and McNeil samples from the North Fork Little Snake River study reaches, 1985.

	Sample Size		Mean % Fines < 3.35 mm		Mean % Fines < 1.75 mm		Mean % Fines < 0.85 mm	
Sample	McNeil	W-V Box	McNeil	W-V Box	McNeil	W-V Box	McNeil	W-V Box
Reach 1	36	35	29.6*	22.8	18.1*	16.7	10.5*	10.2
Reach 2	36	21	22.7*	22.4	13.9*	15.6	7.5*	9.2
Reach 3	36	32	30.4*	25.1	19.6*	16.9	10.6*	9.4
Reach 4	36	31	47.3	27.1	40.0	21.2	21.8	13.4
All Samples	144	119	31.9	24.0	21.3	17.4	12.0*	10.0

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

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.

A second problem encountered during field testing was displacement. During our experiments, no method of mechanically anchoring the boxes was attempted. Should sampling be necessary in steep gradient, large bed element stream sections such as Reach 2 during times when degradation of the stream bed may occur (e.g., ice-out, spring runoff), boxes should be anchored. One possible method for doing this would be to insert several small diameter spikes through the holes in the bottom of the box and then working these down into the streambed. A method such as this would increase stability, but should not influence flow and sedimentation patterns on the streambed surface.

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 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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