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New Technique for Measuring Fine Sediment in Streams

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Abstract.—Techniques commonly used to measure fine-sediment accumulation in streambed gravels can be labor and equipment intensive. We evaluated the sediment trapping capabilities of modified Whitlock–Vibert boxes under both laboratory and field conditions and compared the accumulated fine sediment to that contained in adjacent gravels as indicated by McNeil core samples. Our results suggest the boxes can be used as an alternative to core sampling for monitoring intergravel fine sediment levels. Advantages include ease of transport to remote field sites, small sample volumes, and reduced analysis time. Problems encountered were displacement of boxes by flood and ice flows and inundation by large sediment spills.

The effects of fine sediment on stream biota and their habitats include reduction of primary production, damage to respiratory organs, entombment of organisms, increased disease, reduction of rearing and spawning habitats, reduction of intragravel dissolved oxygen and flow, and alteration of water chemistry (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Research has focused on the effects of sediment deposition, and less effort has been directed toward the development of methods for measuring the accumulation of fine sediment in streambeds. Two types of samplers are commonly used for characterizing substrate composition—the McNeil core sampler and the freeze-core sampler (Platts et al. 1983; Reiser et al. 1985). The major deficiency of the McNeil sampler is that the sampler is difficult to insert to the specified depth if the substrate is coarse or compacted. The major disadvantage of the freeze-core technique is that the large, bulky equipment limits sampling to readily accessible areas. Also, freeze-core probes can be difficult to drive through large substrates, and the weight of samples can make handling difficult. Shortcomings of core sampling and freeze-core techniques have resulted in efforts to develop sediment "trapping" devices (Meehan and Swanston 1977; Mahoney and Erman 1984).

The objective of this study was to test the hypothesis of Reiser and White (1981) that a correlation exists between the percentage of fine sediments trapped by Whitlock–Vibert boxes and that contained in McNeil core samples. We conducted experiments in an artificial flume at different flows and in channel sections with different gradients to test the hypothesis.

Methods

Whitlock–Vibert (W–V) boxes typically are used to incubate fish eggs in stream gravels. They are made of polypropylene and measure 14 × 6.4 × 8.9 cm deep. The sides, top, and bottom of the boxes are perforated with rectangular slots to allow water circulation. Openings in the top and the largest slots on the sides are 3.5 mm × 13 mm. We removed the inner panel from the W–V boxes to increase the effectiveness of the boxes as sediment traps. The boxes were filled with clean gravel 12–

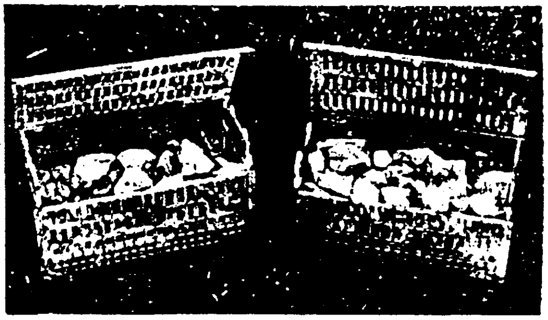

FIGURE 1.—Whitlock-Vibert boxes modified for sediment trapping.

25 mm in diameter (Figure 1), and a strip of duct tape was placed on the bottom of each box to prevent the loss of trapped fine sediment through the bottom.

Initial testing of the sediment-trapping capabilities of the modified W–V boxes was conducted in an experimental flume (Hydraulics Laboratory, University of Wyoming). The concrete flume was 21.3 × 0.9 × 0.9 m deep and filled to a depth of 0.46 m with bed material (including fines) similar in composition to that used by salmonids for spawning in southeast Wyoming (Reiser and Wesche 1977). The substrate was formed into three riffle–pool sequences. Discharge through the channel was controlled by a series of five water-recirculation pumps.

Three experiments were conducted during 1984 and 1985, each following the same general procedure. Modified W–V boxes were buried in the sediments of each riffle and pool. Pumps were activated, and flow was varied throughout the experiment (maximum, 0.14 m^3/s). Suspended sediment samples and bedload samples were taken at the head of each riffle to determine sediment movement. At the conclusion of each experiment, W–V boxes were carefully removed from the substrate, placed in plastic bags, and stored until analysis. At a location immediately adjacent to each W–V box, a McNeil core sample was collected. All samples were dried at 70°C for at least 24 h and gravimetrically analyzed by the dry sieve technique; results are reported as percent of total dry sample weight. Fines of three sizes were measured: <3.35, <1.75, and <0.85 mm diameter.

Among the three experiments, several conditions varied. Experiment 1 lasted 3 d, peak discharge was 0.08 m^3/s, and 44 W–V boxes were planted 7.6 cm deep in the substrate. Experiment 2 ran for 5 d, peak discharge was 0.12 m^3/s, and 46 boxes were planted with their tops flush with the surface of the substrate. Experiment 3 was similar to 2 except 92 boxes were planted and fine sediments (<3.35 mm diameter) were continuously added to the system at the upper end of the flume (1,818 kg over 5 d).

Correlation analysis was used to determine relations between the percentage of fine sediment trapped in the W–V boxes and that present in adjacent McNeil core samples. To test the efficiency of the two methods, we compared the percentage of fine sediment using paired t-tests. For each experiment, separate statistical analyses were conducted for all samples combined, all riffle samples, all pool samples, and all samples taken from midchannel.

Field testing was conducted during 1985 on the North Fork of the Little Snake River. Our purpose was to compare the percentage of fine sediment trapped by the W–V boxes to that contained in McNeil core samples and to evaluate the durability of the boxes over a wide range of field conditions. The North Fork of the Little Snake River is a steep-gradient stream in the upper Colorado River basin of south-central Wyoming. Construction in the watershed contributed large amounts of sediment to the channel during 1984. Modified W–V boxes were planted in four reaches of the stream in 1985. Reach 1, the control section, had a moderate gradient (2.6%); it was located immediately upstream from construction activity. Reaches 2, 3, and 4 were downstream of the construction and subject to sedimentation. Reach 2 had a high gradient (4.5%), reach 3 had a gradient like that of the upstream control (3.0%), and reach 4 had a low gradient (0.4%). Each reach was 12 m long and averaged 6.5 m in width. Discharge varied from 0.1 to 3.1 m^3/s.

Twelve modified W–V boxes were planted and recovered three times in each study reach. At each recovery time, McNeil core samples were taken in each reach. Study periods were: test 1, October 1984–May 1985; test 2, May–July 1985; test 3, July–September 1985. All W–V boxes were planted with the top flush with the streambed surface. Sample handling in the field and laboratory analysis were the same as described for the laboratory experiments. Analysis of variance was used to compare fine-sediment content of the boxes and the cores.

Results

In experiment 1, the mean percentage of fines less than 3.35 mm diameter differed significantly

TABLE 1.—Comparison of mean percent fine sediment (<3.35 mm diameter) in modified Whitlock-Vibert (W–V) boxes and NcNeil core samples in laboratory experiments 1, 2, and 3. Coefficients of variation (100·SD/mean) are in parentheses; r is the coefficient of correlation between percent fines in W–V boxes and McNeil samples. Means not footnoted differed significantly between W–V boxes and McNeil samples ($P \leq 0.05$).

Experiment	Sample	Sample size	% mean fines		r
			W–V boxes	McNeil	
1	All	44	12.2 (41.8)	18.4 (36.7)	0.53[c]
	Riffle	22	14.0 (41.2)	21.8 (25.6)	0.49[c]
	Pool	22	10.4 (35.3)	15.0 (41.2)	0.39
	Midchannel	16	13.2 (46.2)	19.6 (38.4)	0.60[c]
2	All	46	11.4 (77.2)[a]	13.7 (52.4)[a]	0.54[c]
	Riffle	23	12.8 (84.5)[a]	14.6 (44.1)[a]	0.56[c]
	Pool	23	10.0 (61.4)[a]	12.9 (61.6)[a]	0.59[c]
	Midchannel	14	10.8 (72.8)[a]	12.2 (60.0)[a]	0.69[c]
3	All	92	31.0 (39.5)[b]	37.3 (85.0)[b]	0.39[c]
	Riffle	46	33.5 (34.0)[b]	27.9 (62.0)[b]	0.45[c]
	Pool	46	28.5 (44.5)	46.5 (81.5)	0.52[c]
	Midchannel	28	32.7 (35.5)[a]	39.2 (76.0)[a]	0.20

[a] No significant difference between means at $P \leq 0.05$.
[b] No significant difference between means at $P \leq 0.01$.
[c] r significant at $P \leq 0.05$.

($P \leq 0.05$) between W–V boxes and McNeil samples in all sample groupings (Table 1). Results were similar for 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. Little fine bed material was transported during experiment 1 (4 g/min). The lack of bed movement, combined with the depth at which the boxes were planted, limited the ability of W–V boxes to trap fines. Correlation coefficients were significant among all samples, riffle samples, and midchannel samples, indicating a relation between the percentage of fines trapped by the W–V boxes and that in adjacent McNeil samples.

Results of experiment 2 indicated the modified W–V boxes gave as effective a measure of fine sediment as McNeil core samples. Sediment transport during this experiment was 23 g/min. No significant differences were observed between the mean percentage of fines less than 3.35 mm diameter in the two samplers, and all correlation coefficients were significant. Similar results were obtained when fines less than 1.75 and 0.85 mm diameter were considered.

In experiment 3, when fine sediment was added and sediment transport was 300 g/min, the effectiveness of W–V boxes as a fine-sediment sampler was again shown. No significant differences were found between W–V and McNeil means except for pool samples. The discrepancy in the pool data resulted from the filling of the upper two pools with large amounts of fine material. When McNeil samples were taken in these pools, the length of the sampling tube was not sufficient in many cases to penetrate through the fill layer (up to 15 cm of pure fines above the gravel substrate). Thus, the percent of fine material in the samples was abnormally high in comparison to the W–V boxes, in which coarse material had been placed before the experiment began. In the upper two pools, the mean percentage of fines was significantly different ($P \leq 0.05$) between the W–V boxes and the McNeil samples. In the lowest pool, however, where filling was not as severe, there was no significant difference.

The results of field testing (Table 2) were similar to those found under laboratory conditions. At reaches 1, 2, and 3 (moderate to steep gradient) there were no significant differences ($P \leq 0.05$) between the mean percentage of fine sediment in the W–V boxes and the McNeil samples. This relationship held for all three size categories of sediment.

The results from reach 4, the low-gradient pool, were similar to those from the upper two pool samples of laboratory experiment 3. During spring runoff in early May 1985, large quantities of fine sediment were moved into reach 4. Deposition depth of this sediment ranged up to 30 cm throughout the pool. The significant differences found most likely resulted from this heavy deposition coupled with the size limitations of the slots of the W–V boxes. Despite the reach-4 results, no significant differences were found for the mean percentage of fine sediment less than 0.85

TABLE 2.—Comparison of mean percent fine sediment in modified Whitlock–Vibert (W–V) boxes and McNeil core samples from North Fork Little Snake River study reaches, 1985. Means not footnoted differed significantly between W–V and McNeil samples ($P \leq 0.05$).

Sample	Sample size		Fines < 3.35 mm		Fines < 1.75 mm		Fines < 0.85 mm	
	W–V box	McNeil	W–V box	McNeil	W–V box	McNeil	W–V box	McNeil
Reach 1	35	36	22.8[a]	29.6[a]	16.7[a]	18.1[a]	10.2[a]	10.5[a]
Reach 2	21	26	22.4[a]	22.7[a]	15.6[a]	13.9[a]	9.2	7.5
Reach 3	32	36	25.1[a]	30.4[a]	16.9[a]	19.6[a]	9.4[a]	10.6[a]
Reach 4	31	36	27.1	47.3	21.2	40.0	13.4	21.8
All samples	119	144	24.0	31.9	17.4	21.3	10.0[a]	12.0[a]

[a] No significant difference between means at $P \leq 0.05$.

mm when samples from all reaches were combined.

The durability of the W–V boxes throughout field testing was exceptional. More than 90% of the boxes could be reused at least three times. Most breakage resulting from handling during subfreezing temperatures. A problem encountered was the displacement of planted boxes. Of 144 boxes planted during the 1985 field testing, 25 (17%) were flushed from the stream bottom and lost. Spring ice-out (12 boxes lost) and high streamflows (13 boxes lost) were the main causes of displacement. Sixty percent of the losses occurred in reach 2, the steep-gradient site.

Discussion

Our results suggest that W–V boxes, planted flush with the streambed surface to enable bedload sediment to intrude into the boxes, can be used in place of McNeil samples to monitor fine sediment accumulation. The boxes' small size and low cost make them well suited for field use. In addition, field sampling is easier with W–V boxes than with McNeil or freeze-core methods. For example, based on our data from pool samples in laboratory experiment 2, 164 modified W–V box samples or 161 McNeil core samples would be needed to attain 95% confidence that the sample mean was within 10% of the true mean (Burns 1966). An average McNeil sample weighs 4.75 kg, and an average W–V box sample weighs 1.0 kg. Total weight of the needed McNeil samples would be 765 kg whereas that of W–V box samples would be 164 kg of material.

All of our W–V box samples were analyzed by the dry-sieve process. For many studies, such detail may not be necessary. A quick, yet reliable, measure could be obtained by simply weighing the contents of the W–V boxes before planting and after recovery.

A problem encountered during both the laboratory experiments and the field testing was the inability of the boxes to sample high quantities of deposition above the gravel substrate. An alternative approach would be to measure the depth of sediment deposited over the top of the box. From the surface area of the box top and this depth, the volume of sediment above the gravel substrate could be estimated, although not all of this material may actually be fine sediment less than 3.35 mm diameter.

A second problem encountered during field testing was loss of W–V boxes due to displacement. During our experiments, no method of mechanically anchoring the boxes was attempted. Should sampling be necessary in steep-gradient reaches during times when degradation of the streambed may occur (e.g., during ice-out or spring runoff), boxes should be anchored into the streambed.

Acknowledgments

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