North American Journal of Fisheries Management 24:303–310, 2004

A New Tool for Measuring Sediment Accumulation with Minimal Loss of Fines

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Abstract.—To measure the impact of culvert construction on brook trout *Salvelinus fontinalis* spawning beds, we collaborated with Bio-Innove, Inc., to develop a simple method for measuring the physical characteristics of streambeds and for quantifying the accumulation of fine sediment at spawning depth. We developed a modified version of the Wesche method that greatly limits fine-sediment loss at retrieval and the loss of the sediment collectors themselves. We found all 128 collectors after a 1–3-month period and all but 3 after 1 year in four experimental streams. The collectors are reusable and permit easy transfer of samples to the laboratory without any visible loss of fine sediment. The data collected allowed us to compare, by use of parametric statistics, the upstream and downstream sections from newly built culverts in terms of percent fines of different diameters, distance of sediment accumulation downstream, grading curves, and organic matter content of accumulated fine sediment.

On Québec public lands, nearly 10,000 culverts are built annually in the course of road development for logging or recreational purposes. Culvert construction can increase suspended matter in the water column and subsequent sedimentation (Clarke and Scruton 1997; St-Onge et al. 2001), which is detrimental to spawning sites of fish species like brook trout *Salvelinus fontinalis* (Hausle and Coble 1976; Alexander and Hansen 1983, 1986; Witzel and MacCrimmon 1983; Chapman 1988; Young et al. 1991; Castro and Reckendorf 1995; Argent and Flebbe 1999). Provisions aiming to minimize the impact of road construction and logging operations on forest resources and aquatic environments are included in regulatory intervention standards enacted by the Québec Department of Natural Resources, Wildlife, and Parks (Ministère des Ressources naturelles, de la faune et des parcs [MRNFP]) (Gouvernement du Québec 1996). Several of these regulatory provisions directly concern culvert construction, and one provision prohibits the positioning of these works within 50 m upstream of a known spawning area. The Québec Agency for Wildlife and Parks (Société de la faune et des parcs du Québec, FAPAQ) and the MRN launched a joint study to validate the effectiveness of this 50-m protective distance.

To measure physical characteristics of the streambed and to quantify the accumulation of fine sediment at spawning depth for brook trout, we needed a simple tool. Prévost et al. (2002) reviewed methods for measuring sedimentation of spawning gravel and carried out field trials from 1997 to 1999 with freeze-core samples, infiltration bags, and porous-walled containers similar to the Whitlock–Vibert boxes used as sediment collectors for the Wesche method (Wesche et al. 1989). However, their trials with the first two techniques proved costly and labor intensive and were not practical for large numbers of sampling sites. Their trials with the porous-walled containers proved effective for measuring sediment accumulation on a relative basis, as was determined for the Wesche method in the studies of Garrett and Bennett (1996) and Clarke and Scruton (1997). However, in all cases, the loss of fine particles at retrieval—even when samplers were handled carefully—could not be eliminated to any extent.

Inspired by the Wesche method and the conclusions of Prévost et al. (2002), a new sediment collector was developed to answer Lisle and Eads' (1991) main criticism of the use of porous-walled containers, which is that water flows out at retrieval, bearing infiltrated sediment with it. The new collector was also designed to limit collector loss, another problem emphasized by Lisle and Eads (1991). Our objectives were to describe this new tool and to examine its performance during a study

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Received May 20, 2002; accepted May 9, 2003

TABLE 1.—General characteristics of the study sections in four streams selected to measure sediment accumulation following culvert construction on the Laurentian Shield in Québec during summer 2000.

Study section characteristic	Stream			
	Aux Canards	Bernier	Roza	Saunier
Width (m)	6.0–7.8	5–10	3.5–4.0	3.8–7.0
Length (m)	3–6	5	4–5	3.0–5.2
Depth (cm)				
Before culvert	15–36	7–21	18.0–43.5	18–39
First autumn after culvert	8–25	5–34	15–52	20–38
Distance from culvert (m)				
Upstream	33	25	106	37
Downstream	16, 36, 75	21, 45, 90	65, 111	33, 43, 109, 171
Slope (%)	2.0–2.75	0.5–1.0	0.5–2.0	1.5–4.0
Water velocity (cm/s)	0–44	0–55	9–67	[a]

[a] Values not determined.

of culvert construction impact on potential brook trout spawning areas.

Methods

Four streams were selected for the study: Roza, Bernier, and Saunier in the Laurentides Wildlife Reserve, and Aux Canards in the Buteux-Bas-Saguenay Controlled Exploitation Zone. All streams are located on the Laurentian Shield. Both areas are typified by forest dominance of balsam fir *Abies balsamea* and paper birch *Betula papyrifera*. General characteristics of the study reaches in each stream were typical of potential brook trout spawning grounds. Superficial substrate was a mixture of gravel, cobble, and sand. Streams varied in slope from 0.5% to 4.0% and varied in width from 3.5 to 10.0 m (Table 1). Major habitat quality criteria for brook trout are maintained year-round in these streams: notably, the water flow is permanent, and temperatures generally remain under 18°C even in the peak of summer.

All culverts were built in the summer of 2000.

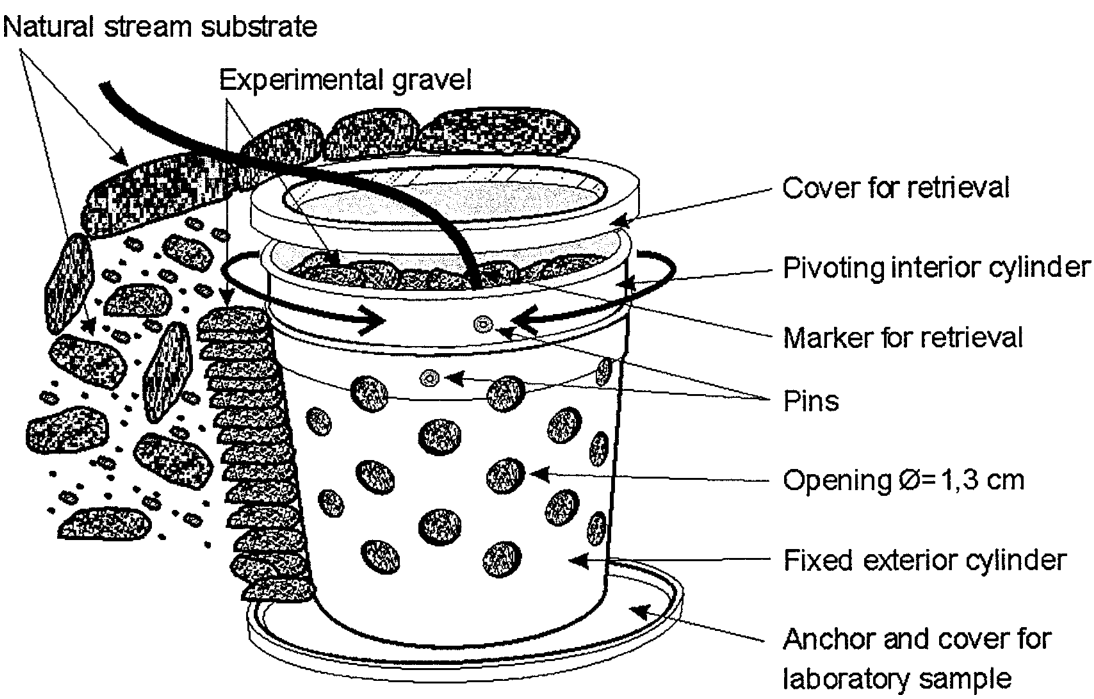

FIGURE 1.—The SÉDIBAC 45 sediment collector and its components (patent pending, Bio-Innove, Inc. 2002). The collector was used to sample sediment accumulation following culvert construction in four Laurentian Shield streams, Québec.

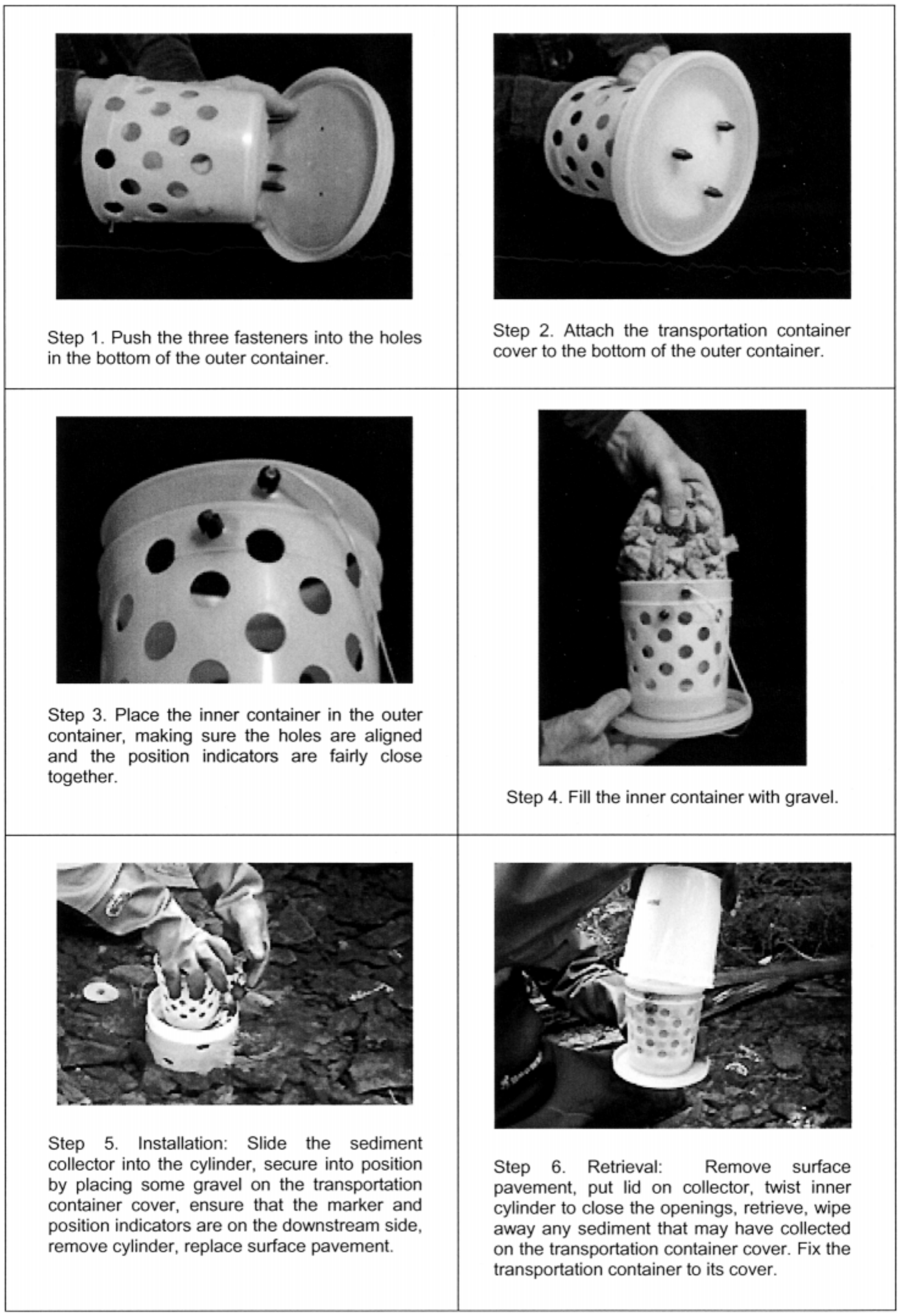

FIGURE 2.—Six steps for the use of the SÉDIBAC 45 sediment collector, from mounting to retrieval.

TABLE 2.—Mean percent fine sediment (±SD) accumulated in the SÉDIBAC 45 for each substrate size-class in the first autumn (2000) following culvert construction on the Laurentian Shield in Québec. Within each sediment size-class and stream, means followed by the same letter are not significantly different (ANOVA followed by the least-significant-difference test, $P = 0.05$).

Stream	Section[a]	Mean percent fines per size-class		
		<5 mm	<2 mm	<0.85 mm
Aux Canards	1	0.30 (0.08) z	0.26 (0.07) z	0.20 (0.04) z
	2	14.76 (4.00) y	14.44 (4.01) y	13.99 (4.01) y
	3	6.98 (3.80) x	6.85 (3.74) x	6.64 (3.66) x
	4	2.59 (1.54) w	2.36 (1.48) w	2.08 (1.35) w
Bernier	1	0.89 (0.14) z	0.51 (0.06) z	0.32 (0.04) z
	2	17.90 (5.36) y	17.72 (5.26) y	17.45 (5.18) y
	3	5.75 (1.42) x	5.49 (1.54) x	5.15 (1.60) x
	4	3.48 (0.56) x	2.90 (0.67) w	2.48 (0.64) w
Roza	1	0.35 (0.06) z	0.30 (0.04) z	0.23 (0.02) z
	3	1.87 (0.76) yx	1.63 (0.58) y	1.37 (0.34) y
	4	1.08 (0.28) zx	0.92 (0.24) zy	0.77 (0.19) zy
Saunier	1	4.74 (2.70) z	4.06 (2.27) z	2.62 (1.09) z
	2	10.07 (3.83) yx	8.67 (3.26) y	6.65 (2.25) y
	3	11.65 (4.22) y	9.24 (3.54) y	6.10 (2.30) y
	4	8.67 (7.22) x	5.01 (2.97) z	2.51 (0.92) z
	5	5.34 (4.43) z	4.42 (3.67) z	2.59 (1.38) z

[a] Section 1 was over 10 m upstream of the culvert and served as the control; sections 2–5 were approximately 20, 50, 100, and 200 m downstream of the culvert.

The four experimental reaches were selected based on the presence of potential brook trout spawning habitat at least 50 m upstream and at least 100 m downstream of the culvert installation point. Four study sections were established in each stream. Section 1, located at least 10 m upstream of the proposed culvert, was regarded as a control, whereas sections 2–4 were located approximately 20, 50, and 100 m downstream of the culvert construction site. In the Saunier stream, an additional section (number 5) was located about 200 m downstream, whereas in the Roza stream, section 2 was not studied because of the bedrock substrate and fast flow it presented. Precise distance from each section to the culvert was measured after construction. We selected study sections with similar flow and substrate conditions. In addition, in selecting our study areas, we stipulated that the stream reach located between the control section and the downstream-most section could not be influenced by any tributaries.

The sediment collector used to assess fine-sediment intrusion in the streambed was the SÉDIBAC 45 (patent pending, Bio-Innove, Inc. 2002) (Figure 1). This collector consisted of two 1-L, cylindrical, plastic containers with perforated walls attached to a lid that anchored and covered the sample after retrieval. The collector was placed in the streambed with the perforations (diameter = 1.3 cm) aligned to permit maximal water flow. At the time of retrieval, the inner container was covered and then rotated using the pins at the top

TABLE 3.—Regression analysis between the quantity of fine sediment (diameter < 5 mm) accumulated in the SÉDIBAC 45 in the first autumn (2000) following culvert construction on the Laurentian Shield in Québec and the distance downstream of the culvert; PFS = percent fine sediment.

Stream	Model	R^2	F	P	df	Simulated distance[a] (m)
Aux Canards	$\text{Log}_e\text{PFS} = 9.0772 - [1.2865 \times \log_e (\text{distance})]$	0.7098	53.80	<0.0001	1	382
Bernier	$\text{Log}_e\text{PFS} = 9.34167 - [1.2304 \times \log_e (\text{distance})]$	0.8519	125.53	<0.0001	1	249
Roza	$\text{Log}_e\text{PFS} = 7.4180 - [1.0003 \times \log_e (\text{distance})]$	0.4866	13.27	0.0027	1	332
Saunier	$\text{Log}_e\text{PFS} = 7.0693 - [0.5588 \times \log_e (\text{distance})]$	0.2638	10.75	0.0026	1	206

[a] Simulated distance is the distance downstream from the culvert at which levels of accumulated fine sediment should return to average upstream (control) levels, according to the regression model.

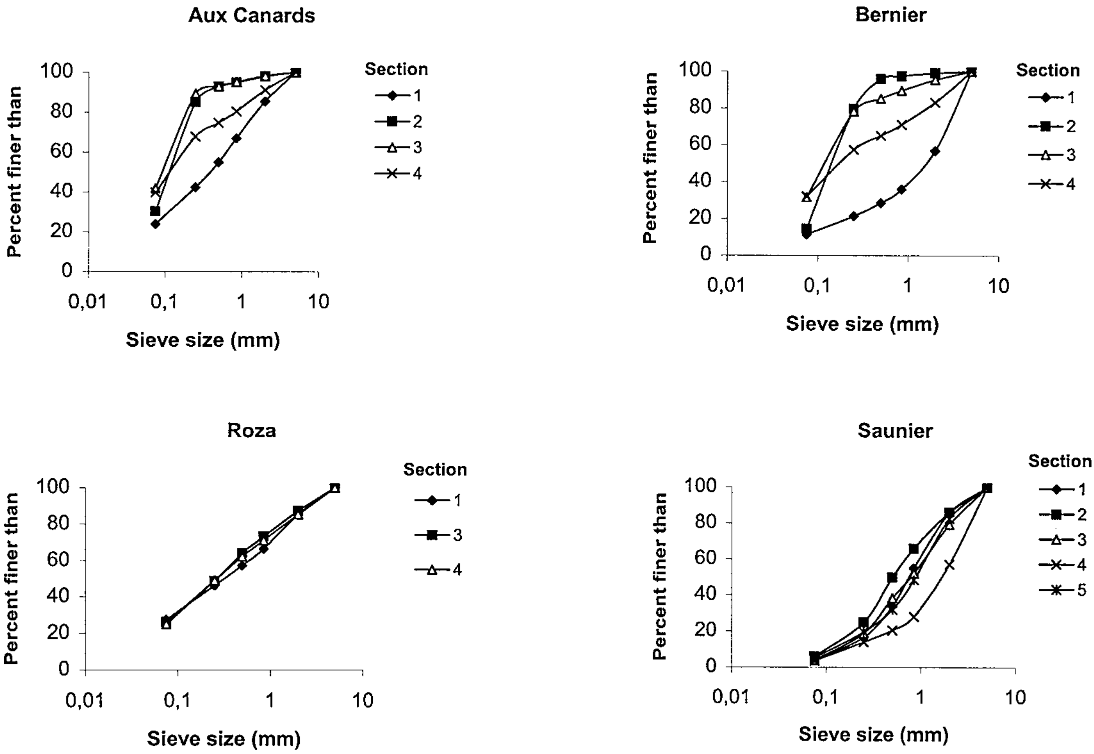

FIGURE 3.—Grading curves of fine sediment (diameter < 5 mm) accumulated in the SÉDIBAC 45 in the first autumn (2000) following culvert construction, for each study section of the Aux Canards, Bernier, Roza, and Saunier streams on the Laurentian Shield, Québec.

to close the side openings before extracting the collector from the streambed. Once removed, the collector was placed in a larger container adapted to the anchor, numbered, and sent to the laboratory for analysis.

Eight collectors per section were installed in the days preceding culvert construction, between June and August 2000 (Figure 2). The collectors were filled with clean gravel 1.5–3.0 cm in diameter. To install the collectors, large surface substrate was first removed and then a plastic cylinder (diameter = 16.7 cm) was inserted into the streambed and emptied to create a hole slightly deeper than the collector (15 cm). The collector was then inserted into the cylinder, the area around it was filled with clean gravel, and the pipe was removed. The top of the collector, which remained uncovered to permit infiltration of fine sediment, was set slightly below the natural surface of the streambed to reconstitute the natural configuration of the substrate. To help with retrieval, a marker made of yellow plastic thread was attached to the collector and floated freely in the water column (Figure 1). Also, a long, twisted, galvanized-steel nail with a yellow plastic disk was hammered into the streambed about 30 cm downstream from each collector.

The collectors were retrieved and replaced in September of 2000 and 2001 (Figure 2). The samples were dried (60°C for 2–7 d until total water evaporation) and then put through a set of standard nested sieves (5.0, 2.0, 0.850, 0.500, 0.250, and 0.075 mm). Each fraction was then recovered and weighed. We selected the sieve mesh sizes based on the size of fine particles reported to hinder egg survival or fry emergence in salmonids (Carline 1980; Lotspeich and Everest 1981; Fraser 1985; Cederholm and Reid 1987; Wesche et al. 1989; Avery 1996; Knapp and Vredenburg 1996; Kondolf 2000). Three classes of fine particles were subsequently analyzed: sediment diameter less than 5.0 mm, less than 2.0 mm, or less than 0.85 mm. Total fine sediments (<5.0 mm) of all eight collectors per section were combined, and three subsamples were chosen from this composite sample to estimate organic matter ratios (g/kg) for each section by use of a combustion method (Carter 1993).

We quantified and compared average percent-

TABLE 4.—Mean ratio (±SD) of organic matter in the fine sediment (diameter < 5 mm) collected in the SÉDIBAC 45 during the first autumn (2000) following culvert construction on the Laurentian Shield in Québec. Within each stream, means followed by the same letter are not significantly different (ANOVA followed by the least-significant-difference test, $P = 0.05$).

Stream	Section	Mean ratio organic matter (g/kg)
Aux Canards	1	141.20 (21.06) z
	2	40.35 (3.46) y
	3	41.49 (4.85) y
	4	83.55 (3.92) x
Bernier	1	352.33 (39.14) z
	2	28.89 (3.01) y
	3	62.12 (8.51) x
	4	123.29 (2.66) w
Roza	1	144.15 (5.96) z
	3	65.62 (1.93) y
	4	109.73 (5.60) x
Saunier	1	60.86 (7.85) z
	2	31.60 (2.74) y
	3	32.80 (4.38) y
	4	56.79 (10.99) z
	5	44.82 (3.82) x

[a] Section 1 was over 10 m upstream of the culvert and served as the control, while sections 2–5 were approximately 20, 50, 100, and 200 m downstream of the culvert.

ages of fine particles per experimental situation. It was possible to compare percent fine particles between sections and streams via analysis of variance (ANOVA) after an angular transformation (SAS Institute 1999). By use of regression analysis, we modeled the distance at which fines accumulated downstream of the culvert and estimated the distance at which accumulation of fines equaled the average observed upstream for the same period (SAS Institute 1999). Grading curves and percent weight of organic matter were used as natural markers of the origin of the fine sediment accumulated downstream. After transformation of organic matter contents, we used ANOVA to compare them (SAS Institute 1999).

Results and Discussion

Each SÉDIBAC 45 collector costs approximately CAN$25. To install 40 collectors on a new site, a team of four people working for about 7–8 h was necessary. This same level of effort permitted the retrieval of 80 collectors or the installation of 60 collectors when replacing them for a second or third time.

During the first autumn following culvert construction, up to 5 cm of sand had accumulated over some collectors, whereas 2–3 cm of gravel had been washed away in others. The markers attached to the collectors and the markers placed on nails in the streambed, as well as additional flags placed on the shore and precise diagrams drawn at the time of installation, permitted easy retrieval of all 128 collectors.

In the second autumn, after 1 year in the streams, 20 of the collectors were covered with sand and gravel. The use of a metal detector to find the markers on the nails enabled us to retrieve all but three of the collectors: two of these were probably buried too deeply, while the third was likely washed away. Wesche et al. (1989) experienced a 17% loss of their modified Whitlock–Vibert boxes in a steep-gradient stream. Clarke and Scruton (1997) experienced a loss of up to 47% with these boxes. In our study, all collectors were in reusable condition after 1 year in the streams.

In the first autumn following construction, sediment intrusion varied significantly among sections for all three fine-particle classes (<5.0 mm: $F = 8.72$, df = 4, 3, $P = 0.0051$; <2.0 mm: $F = 9.05$, df = 4, 3, $P = 0.0046$; <0.85 mm: $F = 9.36$, df = 4, 3, $P = 0.0041$; Table 2). More specifically, fine particles increased significantly immediately downstream from the culvert compared to the upstream section, followed by a gradual reduction as the distance from the culvert increased. Levels of fine-particle intrusion did not return to those observed upstream in either the Bernier or Aux Canards streams (Table 2), where the highest accumulations were noted. In the Saunier and Roza streams, percent fines at sites over 100 m downstream from the culverts were no longer significantly different from the levels observed upstream (Table 2).

Regression models were significant for all streams (Table 3); however, the coefficients of determination were particularly high for the Aux Canards and Bernier streams (Table 3). For all streams, the models predicted a return to upstream levels of fine sediment (diameter < 5.0 mm) at distances between 206 and 382 m (Table 3). These distances are 4–7 times higher than that mentioned in the regulatory intervention standards as a safe distance between spawning beds and culverts.

For each study stream, grading curves described the fraction of substrate with a diameter less than 5.0 mm that was collected in each section (Figure 3). The Bernier and Aux Canards streams were characterized by very similar patterns. In each of these two streams, the curve for the section upstream of the culvert differed from the curves for sections immediately downstream (sections 2 and

3) of the culvert. The curve for section 4 was intermediate, which reflected a return to the conditions present in the upstream control section. In sections 2 and 3 of the Bernier and Aux Canards streams, more than 80% of the fine sediments had a diameter smaller than 0.25 mm, whereas in section 1, only 20% of the fine particles had such a small diameter. This indicates that the fines accumulated downstream were of a different origin than those upstream, probably the sand used for construction. In the Roza and Saunier streams, the grading curves of each section were very similar.

The organic matter ratio measured in the subsamples of particles smaller than 5.0 mm for each stream decreased significantly downstream from the culvert and then increased as the distance from the culvert increased (Table 4). The pattern was similar in all study reaches, but was most pronounced in the Bernier stream and least pronounced in the Saunier stream. These results indicate that fine particles found downstream were partly of a different origin than those found upstream. The fines accumulated downstream were of a more mineral nature, and very probably originated from the sand used for construction. These findings corroborated the information provided by the grading curves for the Aux Canards and Bernier streams, and confirmed the origin of sediments in the Saunier and Roza streams.

Our main objective was to present the SÉDIBAC 45 tool and a short-term application in the study of the effects of culvert construction. The SÉDIBAC 45 permitted the collection of high-quality data and eliminated the problem of sediment loss. The SÉDIBAC 45 also greatly alleviated the loss of collectors, which contain precious information obtained at high cost. This technique is now being used by government agencies, universities, and private consulting firms in several ongoing studies assessing human impacts on aquatic habitats in Québec, from forestry to water level management in reservoirs.

Acknowledgments

We wish to acknowledge the help of the technicians, students, and professionals, in the field or on the scientific committee: Bruno Baillargeon, Jean-François Bernier, Pierre Bérubé, Jacques Boivin, Christian Fradette, Stan Georges, Conrad Groleau, Pierre LaRue, Gilles Mercier, Annie Paquet, and Hughes Sansregret of the FAPAQ, and Denis Auger, Johanne Beaulieu, Véronique Belley, Gisèle Couture, Sylvie Delisle, Gil Lambany, Guy Parent, Danièle Pouliot, and Alain Schreiber from the MRNFP. Financial support was provided by the FAPAQ and the MRNFP.

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