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Effectiveness of Isolated Pipeline Crossing Techniques to Mitigate Sediment Impacts on Brook Trout Streams

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Stream populations of brook trout (*Salvelinus fontinalis*) are sensitive to sediment-caused changes to habitat, i.e., increased embeddedness of bed material. The use of watercourse crossing techniques (dam and pump, and flume methods) that isolate the construction site by diverting flow around the crossing has often been promoted as a means of controlling the amount of sediment released, particularly for those watercourses with sensitive fish species or habitats. However, few case studies have evaluated the effectiveness of isolated crossing construction techniques to mitigate the effects of instream construction activities. We measured suspended sediment concentrations during six isolated pipeline crossings of brook trout streams in Minnesota, Nova Scotia and Ontario. In addition, sediment deposition rates, riffle habitats and fish abundance were monitored upstream and downstream of four of the crossings. Results of our monitoring studies indicate that isolated techniques can be very effective at: (1) minimizing increases to downstream suspended sediment concentrations during instream construction; and, (2) preventing sediment-induced effects on habitat and fish abundance downstream of pipeline water crossings. For sensitive watercourses, isolated crossing techniques are an effective alternative to trenchless crossing techniques (e.g., horizontal directional drilling).

*Key words: s***ediment, pipeline construction, mitigation, trout, streams**

Introduction

The construction of linear facilities such as natural gas pipelines can often require the crossing of watercourses. Construction in and around watercourses can disturb aquatic systems and cause changes to the physical and biological components of aquatic ecosystems. The majority of aquatic effects associated with pipeline construction are attributed to sediment released during instream construction. Sediment load increases during construction have been reported to directly and/or indirectly affect fish through modification of their habitats (e.g., increased embeddedness of substrates or infilling of pools). Generally, these effects are temporary with full recovery to pre-disturbance conditions within 1 to 2 years (Reid and Anderson 1999).

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Isolated crossing methods (e.g., dam and pump or flume crossing methods) have been developed to limit the amount of sediment released during crossing construction. These methods isolate the instream work area with dams and divert water around the work area through either a flume and/or pumps. The approach allows for trench excavation and backfilling to occur under dry conditions thereby reducing the amount of sediment released into the watercourse. However, a lack of suspended sediment monitoring and associated biological effect studies of isolated water crossings has prevented defensible statements regarding their effectiveness (Mutrie and Scott 1982; Reid and Anderson 1999). Given the large distances of new pipeline constructed each year (True 1997, 1998) and that trenchless crossing methods (e.g., horizontal directional drilling) are not always feasible, the documentation of the effectiveness of isolated crossing methods is important to ensure the desired level of environmental protection.

Pipeline construction across six watercourses supporting brook trout (*Salvelinus fontinalis*) populations provided an opportunity to evaluate the effectiveness of isolated crossing methods in limiting the amount of sediment released during instream construction and associated effects on downstream fish and fish habitat. Brook trout streams are excellent study systems to evaluate isolated crossing methods. Brook trout are a widespread and valued sportfish and the vulnerability of brook trout to sediment-induced habitat alteration is well documented (Saunders and Smith 1965; Anderson et al. 1998). In this paper, we evaluate the effectiveness of isolated pipeline crossing techniques by monitoring downstream suspended sediment concentrations, sediment deposition rates, surficial bed material, and fish communities. Effects on resident fish and their habitats at the crossing site due to the clearing of the riparian vegetation and/or the direct physical disturbance of construction were not investigated.

Methods

Two isolated crossing methods were evaluated during this study: the dam and pump, and the flume method. Dam and pump methods were applied to install natural gas pipelines underneath four watercourses in Nova Scotia and Ontario: East and West branches of McDonald Brook, a tributary of Bear Creek and a tributary of Cold Creek. The flume crossing method was applied during pipeline installation across two locations, 250 metres apart along Otter Creek, Minnesota. Watercourses were small with wetted channel widths and flow levels less than nine metres and 0.28 m^3/s, respectively (Table 1). Construction across these watercourses was completed during the summers of 1998 and 1999.

Total suspended sediment concentrations (TSS) were measured upstream and downstream of all six crossings. Sediment deposition rates, habitat condition and fish communities were also monitored upstream and downstream of the four crossings of Otter Creek and McDonald Brook. The methods are described in greater detail in the following text.

Suspended Sediment

To test the effectiveness of isolated crossing methods to limit sediment release during construction, we measured suspended sediment concentrations (mg/L) upstream and downstream of isolated crossings. Grab water samples (0.5 L) were taken at mid-water column from mid-channel locations. Given the small channel widths and observed degree of mixing within a short distance downstream of construction, mid-channel grab water samples characterized downstream suspended sediment concentrations. The first downstream sampling stations were between 13 and 30 m downstream. The locations of all sampling stations are provided in Table 2. The frequency of sampling at each station varied depending on the instream construction activities being conducted. During periods of increased sediment loading, TSS sampling occurred approximately every 30 minutes. Sampling was less frequent during periods of no instream construction. Sampling after the completion of construction continued until downstream turbidity levels returned to background (typically less than 2.5 hours).

For both Otter Creek crossings and the Cold Creek tributary crossing, site-specific TSS-turbidity relationships were developed from field turbidity (NTU) measurements and subsamples of water samples (50 and 35 samples, respectively) representing a range of turbidities that were analyzed for TSS concentration in the laboratory. TSS concentrations were predicted from turbidity measurements taken in the field using site specific TSS-turbidity relationships. Correlation indices (r^2 values: 0.85 to 0.98) from the regression analyses indicate that field NTU measurements provide a good estimate for TSS. For the other three crossings (Bear Creek and MacDonald Brook), TSS concentrations of water samples collected were measured in the laboratory.

As the time intervals between grab water samples were not always equal, time-weighted average TSS concentrations were calculated for each transect and construction activity (except the upstream control)

Table 1. Mean flow characteristics of watercourses crossed by isolated methods

Watercourse	Width (m)	Water depth (m)	Water velocity (m/s)	Discharge (m^3/s)
East Branch McDonald Brook	2.1	0.11	0.02	0.004
West Branch McDonald Brook	1.4	0.08	0.04	0.004
Bear Creek Tributary	1.1	0.10	0.19	0.02
Cold Creek Tributary	3.6	0.31	0.24	0.28
Otter Creek (first crossing)	2.6	0.23	0.24	0.17
Otter Creek (second crossing)	8.5	0.23	0.11	0.24

Table 2. Locations of suspended sediment and habitat alteration monitoring stations for each pipeline water crossing

Watercourse	Monitoring station	Location relative to pipeline crossing
East Branch of McDonald Brook	UPSTREAM	70 m u/s[a]
	D1	20 m d/s[b]
	D2	115 m d/s
West Branch of McDonald Brook	UPSTREAM	20 m u/s
	D1	20 m d/s
	D2	120 m d/s
Cold Creek tributary	UPSTREAM	25 m u/s
	D1	13 m d/s
Bear Creek tributary	UPSTREAM	80 m u/s
	D1	30 m d/s
Otter Creek, Minnesota	UPSTREAM	20 m u/s
	D1	40 m d/s
	D2	295 (45[c]) m d/s
	D3	450 (200[c]) m d/s

[a] u/s; Upstream.

[b] d/s; Downstream.

[c] Location relative to second Otter Creek crossing.

(Anderson et al. 1996). Many of the TSS concentrations were below the laboratory detection limits (<2 mg/L). Where TSS concentrations for specific construction activities were <2 mg/L, a value of 1 mg/L was assigned for the calculation of time-weighted averages.

In addition to water sampling, a time-referenced construction logbook was kept to relate TSS concentrations to specific construction activities. Discharge during construction at each watercourse was measured using a tagline, water velocity meter and a top-setting wading rod and following the methods outlined in Terzi (1981).

Sediment Deposition and Habitat Alteration

The magnitude and extent of downstream sediment deposition and associated habitat alteration were measured at Otter Creek and the East and West branches of McDonald Brook. The locations of upstream and downstream sediment deposition and habitat alteration monitoring sites are provided in Table 2.

Eight modified Whitlock-Vibert boxes filled with washed 25-mm diameter gravel were buried flush with the creek bed before construction to collect sediment deposited during construction (Clark and Scruton

1997). All sediment traps were removed after the completion of construction and sent to a geotechnical laboratory for dry weight and particle size analysis. Habitat alteration due to sediment deposition was evaluated using the pebble count method (Kondolf 1997). The pebble count method provides a measure of the composition of surficial bed material. Pebble counts were conducted at riffle or turbulent run habitats with clean coarse substrates composed of a similar range of particle sizes (e.g., dominated by gravel and cobble versus dominated by sand and gravel). Along both Otter Creek and McDonald Brook, surficial bed material was sampled before and immediately after construction. Surficial bed material was also sampled one month and one year after the completion of the McDonald Brook crossings. Five point measurements of water velocity and depth were taken at each monitoring site.

Differences between upstream and downstream sediment deposition rates were tested using ANOVA and Tukey HSD tests (Zar 1984). Post-construction changes to surficial bed conditions were assessed through the calculation of D_{16}, D_{50}, D_{84} (sediment particle diameter at which 16, 50 and 84% of the sample is finer) and the percentage of particles less than 4 mm in diameter from pebble count data.

Fish Community

Changes to fish communities as a result of instream construction were evaluated through pre- and post-construction electrofishing surveys upstream and downstream of the Otter Creek and both McDonald Brook crossings. The sampling reach was isolated with upstream and downstream blocknets (mesh size: 5 mm) and three electrofishing passes were made with a backpack electrofisher. All fish netted were measured for forklength (mm), identified to species, and released.

Along Otter Creek, 50 metre long reaches were sampled beginning 20 metres upstream, 100 metres downstream and 270 metres downstream of the first crossing. The last reach began 20 metres downstream of the second crossing. Reaches sampled along the East and West branches of McDonald Brook were 30 metres long. Along the East Branch, reaches were sampled beginning 70 metres upstream, 20 metres downstream and 115 metres downstream of the crossing. Along the West Branch, reaches were sampled beginning 20 metres upstream, 20 metres downstream and 70 metres downstream of the crossing. At each crossing, fish sampling occurred immediately before and after construction. Reaches along McDonald Brook were also sampled one month and one year after construction. During electrofishing surveys of the East and West branches of McDonald Brook one year after construction, the locations where juvenile brook trout (<60 mm FL) were captured were marked. Water velocity, depth and bed material were measured at each of these locations to document habitat associations.

Three-pass depletion estimates of fish abundance within each reach were calculated using methods described in Zippen (1957). The similarity of pre- and post-construction fish assemblages at each transect along

Otter Creek was evaluated by calculating the relative abundance of individual species and a Proportional Similarity Index (PSI) (Schoener 1968). PSI values greater than 0.7 have been interpreted to indicate similar fish assemblages (Paller 1997). Due to the low number of species, PSI values were not calculated for McDonald Brook.

Results

Instream Construction

The flume method was used to install a 942-mm (36-inch) diameter gas pipeline underneath two locations approximately 250 metres apart along Otter Creek, Minnesota. The first crossing was isolated with sandbag dams and plastic sheeting. On the second Otter Creek crossing, concrete jersey barriers were used to construct the upstream dam. Flow was conveyed through the workspace through a flume. During this period, water was pumped from the isolated workspace to either upland discharge locations or sumps. Construction of the first crossing required 51 hours of instream work over 5 days. The second flumed crossing was completed in 4 days, requiring 23 hours of instream construction.

The dam and pump method was used to install gas pipelines underneath tributaries of Cold and Bear creeks, Ontario, and the East and West branches of McDonald Brook, Nova Scotia. Pipelines were between 508 mm (20 inch) and 942 mm (36 inch) in diameter. Sandbag and plastic isolation dams were used to isolate the crossing areas while bypass pumps diverted flow around the workspace. Upstream and downstream dams were constructed at the Cold and Bear creek tributary crossings. Alternatively, only upstream dams were installed at both McDonald Brook crossings. Pipeline installation underneath the tributaries of Cold and Bear creeks required less than 16 hours of instream activity over 1 or 2 days. The McDonald Brook crossings required between 26 and 41 hours of instream work over 5 or 6 days. Excavation of the pipe trench up steep approach slopes to both branches of McDonald Brook before pipe installation extended the duration of construction.

Suspended Sediment

The first flume crossing of Otter Creek was effective at minimizing sediment release during construction. Until dam and flume removal, TSS concentrations 40 metres downstream of the crossing were equivalent to background. Removal of isolation dams and the flume resulted in increases to downstream TSS concentration of up to 58 mg/L. Once instream activity was complete, downstream TSS concentrations returned to background levels within one hour. The entire crossing increased the mean downstream TSS concentration by less than 4 mg/L above background.

The second flume crossing of Otter Creek was not as effective at limiting sediment release. Over the 23 hours of instream activity, the average TSS concentration 45 metres downstream of the crossing was 80 mg/L above background. During trench excavation, the upland sump reached its capacity and turbid water was then pumped to an upland location. However, the hose and hose clamps leaked and turbid water flowed back into the creek increasing suspended sediment concentrations during trenching, pipe installation and backfilling. The peak TSS concentration was measured during dam and flume removal (1487 mg/L). During periods of peak sediment loading, suspended sediment concentrations 200 and 340 metres downstream of the crossing were between 43 and 81% lower than 45 metres downstream of the crossing. Downstream TSS concentrations did decrease substantially once construction was complete. However, it was not until 10 hours after construction that downstream concentrations returned to background levels.

The four dam and pump water crossings increased mean downstream (<30 metres downstream of the crossing) suspended sediment concentration by less than 20 mg/L above background. Except for short peaks during trench excavation across the East and West branches of McDonald Brook, large increases to downstream suspended sediment concentrations were generally limited to dam and pump installation and removal. Peak suspended sediment concentrations during these construction activities ranged between 61 and 1032 mg/L.

Sediment Deposition and Habitat Alteration

Mean sediment deposition rates ranged from 0.055 kg/m^2/d upstream of the Otter Creek crossings to 0.16 kg/m^2/d immediately downstream of the second crossing. Compared to the other monitoring sites, a significantly greater amount of sediment was deposited 45 metres downstream of the second crossing (ANOVA: $p < 0.001$; Tukey HSD: $p < 0.05$). Sediment deposition rates at other locations downstream were not significantly greater than upstream. However, there was a greater percentage of silt and clay (<0.062-mm diameter) in downstream sediment traps compared to upstream traps (44.5–64.7% versus 29.9%).

The surficial bed material at monitoring stations along Otter Creek was characterized as gravel and cobble with little sand, silt or clay. Before construction, percent surficial fines (<4 mm) ranged from 0 to 21% along Otter Creek monitoring stations. Mean water velocities ranged between 0.27 and 0.39 m/s with mean depths between 0.13 and 0.16 m. Increased deposition of sediment 45 metres downstream of the second crossing coincided with a small increase in the percentage of fine sediment (<4 mm) from 0 to 8%. For three days after construction, a thin veneer of clay or silt (<1 mm in depth) was visible up to 340 metres downstream of the second crossing. The amount of surficial fine sediment decreased by 2 to 9% at the other monitoring sites.

Mean sediment deposition rates ranged from 0.024 kg/m^2/d upstream of the East Branch crossing to 0.11 kg/m^2/d, 41 metres downstream. A significantly greater amount of silt and clay was deposited immediately downstream of the East Branch crossing than upstream and farther downstream (ANOVA: $p < 0.001$; Tukey HSD: $p < 0.001$). The amount of silt and clay deposited at the first downstream area

(41 metres downstream) was 2.4 and 3.1 times greater than 126 m downstream or upstream, respectively. However, there were no statistical differences in the total amount of sediment or sand fraction (0.062–2.0 mm diameter) collected in traps. There were also no statistical differences between sediment deposition rates along the West Branch of McDonald Brook. Sediment deposition rates ranged between 0.024 and 0.041 $kg/m^2/d$. Most of the sediment collected in sediment traps downstream of both crossings was sand. Less than 26% of the deposited sediment was silt or clay.

The surficial bed material along both the East and West branches was characterized as cobble and boulder with little sand, silts and clay (Table 4). Mean water velocities at monitoring sites ranged between 0.06 and 0.14 m/s with mean depths between 0.05 and 0.11 m. The percentage of fine sediment (<4 mm diameter) in the surficial bed material remained low for the duration of the study.

Fish Community

Otter Creek

Eleven fish species were collected from Otter Creek. The most frequently captured species were brook trout, creek chub (*Semotilus atromaculatus*) and blacknose dace (*Rhinichthys atratulus*). The greatest density of brook trout was found immediately downstream of the second crossing. Other species included brook stickleback (*Culaea inconstans*), central mudminnow (*Umbra limi*), Johnny darter (*Etheostoma nigrum*), longnose dace (*Rhinichthys cataractae*), redbelly dace (*Phoxinus eos*), mottled sculpin (*Cottus bairdi*), common shiner (*Luxilus cornutus*), and white sucker (*Catostomus commersoni*).

Before construction, fish abundance estimates along Otter Creek ranged from 5.7 to 6.4 fish per metre. The greatest abundance of fish was immediately downstream of the second Otter Creek crossing. During the first crossing, schools of unidentified small-bodied fish were observed to congregate and feed at the downstream outlet of the flume. However, after construction 100 metres downstream, the number of fish decreased from 5.7 to 4.2 fish per metre of stream. Alternatively, there was little change in fish abundance immediately downstream of the second crossing. After construction, the estimated number of fish upstream increased from 6.1 to 9.7 fish per metre. Post-construction fish assemblages along Otter Creek were similar to those sampled before construction. PSI values calculated ranged between 0.77 and 0.81. Changes in the relative abundance of individual species were less than 18%.

East and West branches of McDonald Brook

Four fish species were collected from McDonald Brook: brook trout, Atlantic salmon (*Salmo salar*), lake chub (*Couesius plumbeus*) and white sucker. Along the East Branch, lake chub and white sucker constituted only 3% of all fish collected. Brook trout was the only species collected from the West Branch.

After the installation of the East and West Branch pipeline crossings, only 66 and 70% of the pre-construction number of fish were recaptured immediately downstream (20–50 metres downstream), respectively (Fig. 1). However, 95% confidence intervals suggest that differences downstream of the West Branch crossing were not statistically significant. No comparable reductions were observed either upstream or at the second downstream sampling reach. The reduction measured downstream of the West Branch crossing was primarily due to fewer juvenile brook trout. One month after construction, the number of fish captured at downstream reaches of each branch was 27 and 42% of its pre-construction abundance. Downstream of the East Branch crossing, reductions in the abundance of both juvenile brook trout and Atlantic salmon parr (<130 mm FL) occurred. Fish abundance upstream of both crossings was unchanged. One year after construction, the number of fish captured at the first downstream sampling reaches was either equivalent or substantially higher than pre-construction estimates (Fig. 1). Along the West Branch, most of the increase was due to higher numbers of juvenile trout being collected.

Discussion

Compared to open-cut pipeline crossings of other similar-sized watercourses, increases to mean downstream TSS concentrations during dam and pump or flume crossings were at least seven times lower (Table 3, Reid and Anderson 1999). Except for the second flume crossing of Otter Creek, mean TSS concentrations averaged only 3 to 20 mg/L above background levels. Alternatively, mean TSS concentrations measured downstream of open-cut crossings were between 600 and 1300 mg/L above background. Peak TSS concentrations measured downstream of isolated crossings were also lower than open-cut crossings and were generally restricted to the installation and removal of isolation and diversion structures. While mean TSS concentrations were lower during the six isolated crossings, the average duration of instream construction was up to seven times that of open-cut crossings (Table 3; Reid and Anderson 1999).

Several construction-related factors can limit the effectiveness of isolated crossing methods to reduce sediment entrainment during instream construction (CPWCC 1999, this study). These include: (1) leakage around or underneath the isolation dams; (2) dam failures; (3) flume failures; (4) insufficient sump storage volume; (5) insufficient pump capacity; and, (6) inadequate maintenance of sediment control measures. During the latter half of the second Otter Creek crossing, insufficient sump storage volume and poor containment of turbid water pumped from the isolated workspace, resulted in high downstream TSS concentrations. The absence of isolation dams downstream of the McDonald Brook crossings allowed ditch water to periodically flow downstream during trench excavation. Concrete jersey barriers and sandbags were effectively used to de-water and isolate the crossing area during the second Otter Creek crossing. However, these materials are not well suited for crossings of watercourses with higher flows and easily eroded bed material (Reid et al. In press).

Table 3. Comparison of duration of instream work, and TSS concentrations measured within 50 m downstream of isolated and open-cut pipeline crossings of small watercourses (<8 m wide)

Watercourse	Crossing method	Duration (h)	Background TSS (mg/L)	Mean TSS (mg/L)	Peak TSS (mg/L)	Reference
Hodgson Creek, N.W.T.	Open-cut	18	1	609	3524	McKinnon and Hnytka 1988
Coxes Creek, Pa.	Open-cut	12	24	781	2411	S. Reid, unpublished data
Judicial Ditch 1A, Minn.	Open-cut	8	26	1337	4258	S. Reid, unpublished data
South Branch Rush River, Minn.	Open-cut	7	47	1103	2870	S. Reid, unpublished data
Otter Creek, Minn.	Open-cut	11	41	1274	2055	S. Reid, unpublished data
Bear Creek tributary, Ont.	Dam and pump	15	3	23	61	This study
Cold Creek tributary, Ont.	Dam and pump	9	4	8	1032	This study
Otter Creek 1, Minn.	Flumed	51	4	8	58	This study
Otter Creek 2, Minn.	Flumed	23	4	86	1487	This study
East Branch McDonald Brook, N.S.	Dam and pump	41	< 2	16	237	This study
West Branch McDonald Brook, N.S.	Dam and pump	26	4	12	250	This study

Table 4. Pre- and post-construction assessments of surficial bed material along the East and West branches of McDonald Brook

		East Branch				West Branch			
Date	Transect	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	% Fines (<4 mm)	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	% Fines (<4 mm)
July 1999[a]	Upstream	60	118	>256	1	28	76	>256	1
	D1	38	124	>256	0	37	94	>256	0
	D2	34	101	>256	1	42	125	>256	0
July 1999[b]	Upstream	26	108	228	4	36	88	204	2
	D1	35	152	>256	3	29	68	>256	1
	D2	25	80	223	2	41	93	>256	1
August 1999[b]	Upstream	50	115	>256	1	42	125	>256	1
	D1	58	134	>256	1	50	112	>256	0
	D2	43	144	>256	2	51	131	>256	0
August 2000[b]	Upstream	14	72	>256	3	26	84	230	0
	D1	32	100	>256	0	68	121	256	1
	D2	25	91	>256	2	25	104	256	1

[a] Pre-construction.

[b] Post-construction.

Large inputs of sediment have resulted in the infilling of pools, smothering of riffle-run habitat and large reductions in fish abundance in brook trout streams (Saunders and Smith 1965; Waters 1982). Shortly after an open-cut pipeline water crossing of a small brook trout stream north of Algonquin Park, Ontario, the numbers of brook trout within 200 metres downstream of the crossing decreased by up to 100% (Anderson et al. 1998). The observed reduction likely resulted from exposure to high TSS concentrations (approaching 3000 mg/L) during construction, and the

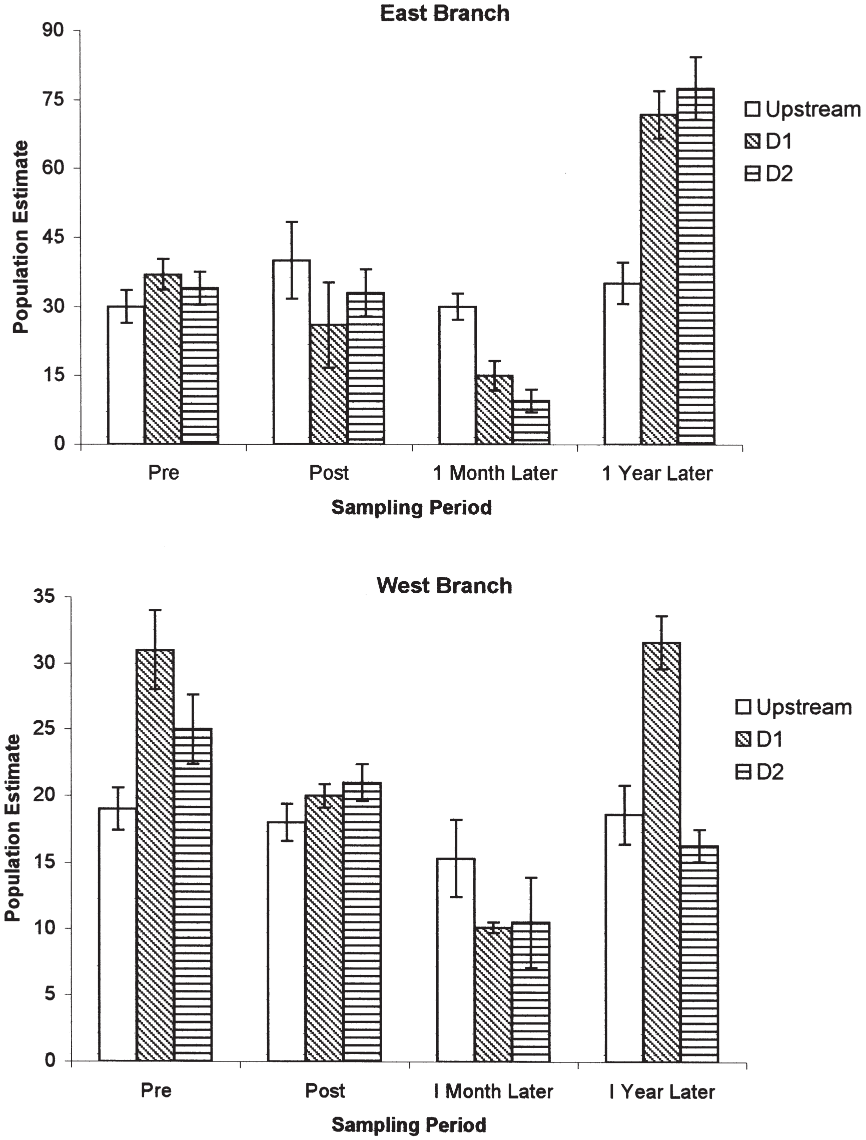

Fig. 1. Pre- and post-construction fish abundance estimates ((95% CI) for 30-m reaches along the East and West branches of McDonald Brook.

alteration of habitat conditions by deposited sand. Recovery of downstream habitats, and benthic invertebrate and fish communities to preconstruction levels was measured within a year after construction (Anderson et al. 1998).

Increased sediment deposition was measured immediately downstream of the second Otter Creek and the East Branch of McDonald Brook crossings. However, pebble count data indicated that surficial bed material downstream of all the crossings was generally unaffected by pipeline water crossing construction. The thin veneer of fine sediment deposited downstream of the second Otter Creek crossing was temporary (<3 days) as it was quickly resuspended by creek flows.

Despite a lack of prolonged exposure to high suspended sediment concentrations or sediment deposition-caused habitat alteration, post-construction reductions in fish abundance were measured downstream of the first Otter Creek and both McDonald Brook crossings. The large post-construction increase in upstream fish numbers suggests that the decrease in fish abundance immediately downstream of the first Otter Creek crossing may be better explained by natural variation in capture success. Reductions in fish abundance downstream of the McDonald Brook crossings measured immediately after construction may have resulted from short-term reductions in water level during construction. When bypass hoses were moved, or pumps temporarily turned off, water levels dropped up to 10 cm along the first 40 to 50 metres downstream of the crossings. The decrease in available habitat or activities in the vicinity may have motivated fish immediately downstream of crossing to move farther downstream.

Considering the lack of sediment-related habitat alteration, it is unlikely that the decrease in brook trout abundance downstream of the McDonald Brook crossings, one month after construction, can be attributed to construction-related activities. Instead, it is more likely that low trout abundance resulted from higher flows in August 1999. Flow levels measured nearby in the watershed were three times greater on August 24, 1999, than on July 20, 1999 (0.422 m^3/s versus 0.142 m^3/s, Middle River Pictou, Water Survey of Canada data). Increased flows reduced the availability of preferred juvenile brook trout habitat and potentially affected electrofishing efficiency.

Juvenile brook trout prefer habitat areas with slow water velocities (0–0.15 m/s), shallow water depths (0.1–0.15 m) and coarse substrates (Griffith 1972; Richardson et al. 1992). Mean water depths and velocities (n = 88) utilized by juvenile brook trout captured in McDonald Brook (August 2000) were 0.16 m and 0.05 m/s, respectively. At the time of construction, water velocities and depths downstream of the crossings ranged between 0.06 and 0.13 m/s, and 0.05 and 0.11 m, respectively. Alternatively, the small pool or glide habitats (where most juvenile brook trout were captured) that were abundant downstream of the crossings during construction in July were replaced by fast-moving turbulent run/riffle habitat in August. Greater numbers of downstream fish one year after construction coincided with flow levels and habitat conditions equivalent to that measured before construction (August 13, 2000: East Branch: 0.004 m^3/s; West Branch: 0.006 m^3/s). No water velocity or depth data is available for August 1999.

No post-construction reductions in brook trout abundance were measured upstream of the crossings. Upstream of both crossings, the channel gradient was shallower than downstream (<0.018 versus 0.03 m/m). Subsequently, the higher flow volume one month after construction increased the volume of suitable juvenile brook trout habitat.

Reduced electrofishing efficiency during higher flows in August 1999 may be an alternate explanation or contributing factor to the decrease in fish capture one month after construction. As water levels increase, increased water velocities, decreased visibility and greater fish dispersion have been previously linked to lower capture success during electrofishing surveys (Reynolds 1996). It is not known why so many juvenile brook trout were captured along the West Branch in August 2000. Natural year-to-year variation in the number of spawning trout and/or the survival of incubating eggs and fry could be factors. However, since no long-term data is available or was collected during this study, these hypotheses cannot be addressed.

Conventional water-crossing methods requiring trench excavation in the active stream flow can release substantial quantities of sediment into the water column as a result of instream construction. Regulatory agencies have responded to sediment pollution concerns by legislating stringent environmental regulations (e.g., instream timing restrictions that avoid spawning periods) and by simplifying permitting approval for crossing methods that minimize instream construction. There is a definite bias towards crossing applications proposing horizontal directional drilling (HDD) or other trenchless technologies. Although HDD installations do not usually generate major sediment discharges and avoid disturbance of riparian vegetation, the potential for environmental damage due to unexpected releases of drilling muds still exists. Recent evaluations of the frequency of mud releases during HDD installations suggest that their occurrence is relatively common (Reid and Anderson 1998). Secondly, construction-related factors such as pipe diameter, wall thickness and radius of curvature, valley geometry, and subsurface geology can prevent the application of this technique at certain crossing locations.

The results of this study indicate that the dam and pump, and flumed crossing methods were highly effective at limiting sediment release during pipeline construction across brook trout streams and therefore, associated risks to fish and fish habitat. These methods should be considered as alternatives to trenchless crossing methods, especially when the risk of unexpected mud releases or construction failure is high. Secondly, four of the six isolated crossings were multiple crossings of watercourses. The low level of sediment release also indicates that application of these crossing methods can reduce the potential for cumulative effects to result from multiple sediment loading events during pipeline construction across watersheds.

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