SPATIAL AND TEMPORAL CHARACTERIZATION OF SUSPENDED SEDIMENTS AND SUBSTRATE COMPOSITION IN CATAMARAN BROOK, NEW BRUNSWICK.

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Spatial and temporal characterization of suspended sediments and substrate composition in Catamaran Brook, New Brunswick[1]

by

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ABSTRACT

St-Hilaire, A., D. Caissie, R.A. Cunjak, and G. Bourgeois. 1997. Spatial and temporal characterization of suspended sediments and substrate composition in Catamaran Brook, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2165: 31p.

Substrate composition and suspended sediment concentrations are important variables for the evaluation of salmonid habitat quality. Grain size distribution of sediments and suspended solids concentrations from Catamaran Brook in central New Brunswick (Miramichi) were analyzed to delineate their spatio-temporal variability. Two techniques were used to determine the grain size distribution at various sites in three study reaches. The McNeil sampler was used to scoop the top layer of the substrate at sixteen sites. The percentage of fines, defined as sediments having a grain size less than 4 mm, varied between 20 and 35% of the total dry sample weights. These percentages lead to estimates of alevin emergence success of 67% to 100 % using the Freddle Index.

There were no obvious temporal variations in the percentage of fine sediments during the sampling period (1995-1996). Sites located immediately downstream of the only stream crossing had a greater percentage of fine sediments. Whitlock-Vibert (W-V) box samples from various habitat types in 3 study reaches showed greater accumulation of fine sand and very fine sand in low-energy habitat types (flats and pools) than in riffles and runs. Coefficient of variation (CV) of mean weight percentages by habitat type varied between 21% and 70% but were generally higher for W-V boxes than for the McNeil-type sampler for two of three compatible grain sizes .

Suspended sediment concentrations were monitored during rain events. The maximum concentration recorded at Catamaran Brook was 174 $mg \cdot L^{-1}$ on 12 May 1994 during a spring freshet (snowmelt) event. There was generally a lag of two to seven hours between the time of maximum measured concentration of suspended sediments and maximum discharge.

RÉSUMÉ

St-Hilaire, A., D. Caissie, R.A. Cunjak, and G. Bourgeois. 1997. Spatial and temporal characterization of suspended sediments and substrate composition in Catamaran Brook, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 2165: 31p.

La composition du substrat et les concentrations de solides en suspension sont d'importantes variables dans l'évaluation de la qualité de l'habitat pour les salmonidés. La granulométrie et les concentrations de sédiments en suspension du ruisseau Catamaran (N.-B.) furent analysées afin de déterminer leur variabilité saptio-temporelle. Deux techniques ont été utilisées afin de connaître la granulométrie sur différents sites dans trois biefs d'études du cours d'eau. Un échantillonneur de type McNeil a été utilisé pour prélever la couche supérieur du substrat à 16 sites. Le pourcentage de sédiments fins (< 4 mm) a varié entre 20 et 35% du poids total échantillonné. Ces pourcentages ont permis de calculer, à l'aide des indices de Freddle, des pourcentages théoriques d'émergence des alevins variant entre 67% et 100%.

Aucune variation temporelle significative dans le pourcentage des sédiments fins n'a été observée durant la période d'échantillonnage. Les sites localisés près de la seule route traversant le ruisseau ont eu un pourcentage plus élevé de sédiments fins.

Des boîtes "Whitlock-Vibert" ont été placées dans différents types d'habitats pour les 3 biefs étudiés pour des périodes de 6 mois. Ces boîtes ont accumulé plus de sables très fins et de sables fins dans les habitats ayant une pente plus faible (plats et fosses) que dans les radiers et les rapides. Une comparaison des coefficients de variation des deux techniques a démontré que, bien qu'il y ait une grande variabilité, les coefficients de variation (CV) calculés pour 2 des 3 types de granulométries étaient supérieurs pour les boîtes Whitlock-Vibert que pour l'échantillonneur de type McNeil.

Les solides en suspension ont été mesurés à intervalles réguliers durant les pluies importantes. La concentration maximale de solides en suspension mesurée à Catamaran (174 $mg \cdot L^{-1}$) était associée à une crue printanière causée par la fonde de la neige. Il y avait un décalage entre le temps où l'on mesure la concentration maximale de sédiments en suspension et le débit maximum.

1.0 INTRODUCTION

Quantifying fish habitat availability and suitability in rivers requires data for a number of abiotic variables including river morphology, flow regime, water quality and information on the river substrate. A number of management tools such as the Instream Flow Incremental Methodology (IFIM, Bovee 1982) rely on field measurements of these variables.

Spatio-temporal variations of substrate composition become important when trying to quantify fish habitat for different species and life stages. In streams, sedimentation and erosion depend on two dynamic processes: suspended sediment transport and bedload transport. Both processes are often associated with high discharge events (Everest et al. 1987). Anthropogenic activities which change the flow regime and sediment loading affect the spawning, nursery and winter habitat of salmonids (Nelson et al. 1987).

Various fish species display different substrate preferences. American Eel (*Anguilla anguilla*) densities, for instance, have been found to be negatively correlated with substrate size (Ibbotson et al. 1994). For salmonids, substrate preferences may vary between life stages (Heggenes 1991), and even between day and night (Hubert et al. 1994). Young Atlantic salmon (*Salmo salar*) tend to avoid areas with fine substratum (i.e. < 16 mm); young-of-the-year salmon were found to prefer grain sizes between 16 and 64 mm, while older parr preferred coarser substrate (Heggenes 1990). Fine sediments in streams affect egg-to-fry survival by reducing intra-gravel flow and dissolved oxygen, or by physically precluding emergence (Cunjak 1995).

Sediment in the water column is important when assessing habitat quality. High suspended sediment concentrations were found to have adverse physiological effects such as increases in coughing frequency and elevated blood sugar levels in coho salmon (*Oncorhynchus kisutch*) from the Fraser River (Servizi and Martens 1992). High suspended sediment concentrations also affect fish habitat indirectly, by scattering and decreasing subsurface light, thereby decreasing primary production (Lloyd et al. 1987) and affecting food chain dynamics. Suspended sediments are known to have negative effects on macroinvertebrates, especially on filter feeders (Campbell and Doeg 1989; O'Hop and Wallace 1993) (Table 1).

In Atlantic Canada, timber harvesting remains a major activity which can cause soil disturbances in many drainage basins, often leading to increased erosion (Cunjak 1995). Certain logging practices lead to relatively higher fine sediment input to streams and higher suspended sediment concentrations in the water column as well as changes in the substrate composition through deposition (Webster et al. 1988). Logging roads are considered to be a non-point source of fine sediment input in streams. The amount of sediment input depends on many factors such as the design of the road, bank slope, and amount of logging truck traffic (Krause 1982; Everest et al. 1987). More generally, sediment loading is dependent on many factors such as the geomorphology, hydrology, stream gradient, and channel morphology (Cunjak 1995).

The Catamaran Brook (N.B.) Habitat Research Project is a long term (15 year) study of forestry impact to a small stream basin. The study emphasizes spatio-temporal variability in its data collection (Cunjak et al. 1990). Substrate composition and suspended sediment data have been gathered from various sites in the brook.

The objective of this report is to detail the spatial and temporal variability of both suspended sediment and streambed composition in Catamaran Brook during the pre-logging phase (1990-1995). In order to achieve this goal, two substrate sampling techniques were used for streambed composition and suspended sediments were monitored between 1990 and 1995. The present report provides a summary of our findings.

2.0 MATERIALS AND METHODS

Grain size distribution of streambed material was investigated using two different techniques. The first method, which uses a McNeil sampler, allows for spot measurements of the substrate composition whereas the aim of the Whitlock-Vibert boxes is to quantify the deposition of fine sediments.

2.1 McNeil sampler

Table 2 and Figure 1 summarize the sampling dates and sites. Sites were selected to represent various hydraulic conditions in 3 study reaches (Lower, Gorge and Middle). More extensive sampling was performed at site L3 (a flat in the Lower reach; Fig. 1) where geomorphic conditions were such that hypothesized substrate changes from forestry would be most likely in this area (Driscoll 1995). At site L3, samples were taken along transects, located 5 m apart. Five samples were taken along each transect on 3 occasions (Table 2).

Substrate were collected in the study reaches (Fig. 1), in areas where spawning of Atlantic salmon is known to occur, with a McNeil sampler (McNeil 1964; Wesche et al. 1989). The sampler consisted of a 205 cm high tapered steel cylinder with a 15 cm diameter. At the bottom of the cylinder, three sieves were mounted, separated from one another by 10 cm. The mesh size of the top sieve was 1 cm x 2 cm, the second was a 1 mm x 1 mm mesh, and the last one was an 80 micron mesh, allowing for the retention of all fine sediments collected. At each sampling site, 2 scoops were taken in the top 20 cm of the streambed and all sediments were bagged. Each sample covered an area of approximately 0.5 m^2.

Samples were dried and a sieve analysis was performed to establish the grain size distribution. Grain sizes were divided in 6 categories: cobble (>64 mm), coarse gravel (32-64 mm), gravel (4-32 mm), fine gravel (2-4 mm), sand (0.5-2 mm), and fine sand (< 0.5 mm).

Two types of sampling procedure were carried out. The first consisted of collecting 15 samples within a localized stream section in the Lower reach to determine the variability in time and space (left, centre, and right bank). The second series was carried out throughout the basin to assess the spatial and temporal variability between different study reaches.

In addition to the analysis performed on the grain sizes already described, fine gravel, sand, and fine sand were combined and defined as fine sediments (i.e. < 4 mm) for the purpose of this report. The percentage of fines used in the analysis (Pfines) was defined as the percentage of fines from a sub-matrix of dominant material (< 32 mm). This additional category was chosen because of the grater variability in the fines categories due to the presence of coarser material when considering the whole substrate matrix (D. Caissie, Unpubl. data). This new category (Pfines) could show changes where others would not due to higher variability.

The Freddle Index (f_i) was developed by Lotspeich and Everest (1981) to quantify the porosity of the streambed. It is the ratio of the geometric mean of the particle sizes to a sorting index. The sorting index determines the distribution of grain sizes about the median. The Freddle index is calculated using equation 1 and was used by Bourgeois et al. (1996) to estimate the theoretical survival of salmonid fry from hatching to emergence in Catamaran Brook using equation 2.

$$f_i = d_g / S_o \qquad (1)$$

where:

d_g = Geometric mean of particle size

$S_o = (d_{75}/d_{25})^{0.5}$: Sorting index

$$\% \text{ survival} = 96.34 \log (f_i) + 1.33 \qquad (2)$$

Equation 2 shows that for a Freddle Index greater than 10.57, survival will be 100%.

2.2 Whitlock-Vibert (W-V) boxes.

Wesche et al. (1989) introduced a new technique for measuring fine sediment deposition in streams. They used Whitlock-Vibert boxes which were initially intended to be used to incubate fish eggs in stream gravel. The 13.5 x 6.0 x 8.7 cm polypropylene boxes were perforated with rectangular slots to allow water circulation. Larger slots, on the top and sides of the box were 3.5 x 13 mm. Smaller 2 mm x 2 mm holes covered the face of the box. A strip of duct tape was placed on the bottom of the boxes to prevent sediment loss (Wesche et al. 1989). Clean gravel 20-50 mm in diameter was placed inside the box prior to placing it in the brook such that the top of the box was flush with the streambed.

The boxes were placed in the stream for 6 month periods starting in June and November of each year. Replicate boxes were placed in each habitat type (pool, riffle, run, flat) in three study reaches (Middle, Gorge, Lower) (Figure 1). Once retrieved, samples were dried and a sieve analysis was performed. Grain sizes were categorized as fine gravel (2-4 mm), sand (0.5 - 2 mm), and fine sand (< 0.5 mm).

2.3 Suspended sediments

Suspended sediments were sampled at 2-3 hour intervals in Catamaran Brook in association with selected rain events since 1990 (Table 3) from 3 sites located in different study reaches: the Lower, Gorge, and Middle (Figure 1).

A weighted depth-integrated sampler, consisting of a 480 mL bottle, which properly weighed, was lowered through the water column to approximately 9 cm above the bottom and raised. The vertical haul was completed within 30 to 50 seconds in order to obtain between a 350 to 440 mL volume. The sample was then fixed with copper sulphate. Concentrations ($mg \cdot L^{-1}$) of suspended sediments were measured by Environment Canada (Moncton, N.B.). Each sample was filtered using a 45 μm mesh, and then dried and weighted.

2.4 Statistical analysis

One-way analyses of variance (ANOVA) were performed on the sediment data to investigate spatial and temporal differences. For McNeil sample data at site L3, mean percentages of total weight of each grain size class were averaged in accordance to their location with respect to the True Left Bank (TLB; left bank when looking downstream), Centre, and True Right Bank (TRB; right when looking downstream). Variance of mean percentages of each sediment size were analyzed by survey dates (temporal) and by bank (spatial) at site L3. For all other sites, McNeil samples were pooled together to compare variance between sites, study reaches, and surveys. Both nonparametric and parametric ANOVA's were used. Only the results of the nonparametric tests are shown as both methods provided the same results. Duncan's Multiple Range (D.M.R.) test was used to differentiate amongst means which were significantly different and verify which of the variables explained most of the variance. Whitlock-Vibert box data were analyzed using the same statistical methods for means by habitat type, study reach and date of placement.

3. RESULTS

3.1 McNeil samples

3.1.1 Site L3

For all 4 surveys performed at site L3, gravel had the highest percentage of the total dry weight (between 37.6 and 43.1%; Table 4). Also, sand (10-12%) accounted for a greater percentage of total dry weight than fine gravel (7-8%). Fine sand constituted the least abundant grain size category at approximately 2% of the total dry weight. Fine sediments (Fgrav + sand + Fsand) at site L3 represented typically 20% of the total dry weight. There were no significant temporal differences in the means percentages of grain sizes between surveys, except for cobble ($P \ll 0.01$). The D.M.R. test performed on the means by survey showed that most of the variance for cobble is explained by the relatively low percentage of cobble in June 1996 (13.4%). The shift in grain size distribution in June 1996 was from cobble to gravel and coarse gravel.

Deposition of fines was not homogenous across the section width at site L3. Fines were found to accumulate more near the True Left Bank (TLB) and Centre (near mid-stream) than near the True Right Bank ($P < 0.05$). There were no significant spatial differences in the mean percentages of coarser material (cobble, coarse gravel and gravel), but very significant differences ($P < 0.002$) for fine gravel and sand.

3.1.2 Inter-reach comparisons

Samples were also taken in 3 study reaches (Lower, Gorge, Middle) during 3 surveys (Table 2). There were significant ($P < 0.05$) differences among sites in percentage composition for all grain sizes (Table 5). Coarse gravel and/or gravel were the dominant grain sizes at most sites. Cobbles represented between 21% and 31.2% of the total sample weight, except at site G2, the gorge site located immediately downstream of a tributary inflow, which was characterized by a greater percentage of sand and less cobble (5.33%). The percentage of fines varied between 11.2% (site G3) and 22.9% (site G2). Site G3, located upstream of any tributaries in the Gorge study reach, had the highest percentage of coarse material of all sites and the least percentage of fines. This contrasts with site G2 which had the lowest percentage of coarse material and the highest percentage of fines. D.M.R. tests performed on means by site showed that site G2 had significantly less cobble but significantly more small particle sizes (gravel, fine gravel, sand, and fine sand), thereby explaining most of the variance. The same test showed that site M1, the Middle reach site below the bridge crossing, also had significantly more sand and fine sand than the other sites.

When the data were pooled by reach (Table 5), the only significant difference found was for the percentage of sand ($P < 0.05$) which was greatest in the Gorge reach (9.0%) and Middle reach (8.0%) and significantly ($P < 0.01$) less in the Lower reach (5.6%). This difference in the percentage of sand was also reflected in the total percentages of fines (Fines, Table 5), which showed the same pattern by reach ($P < 0.05$). Elimination of the larger substrate (i.e. Pfines) showed an increase in the significance level ($P < 0.02$; Table 5) was realized at the reach level. No significant difference was observed by year for all study reaches, which is consistent with the results observed at site L3 in the lower reach.

Calculated Freddle indices (f_i) for all samples (except site L3) taken in October 1994, June 1995, and October 1995 are reproduced in Table 6. Calculated f_i varied between 4.9 (site G2B) and 30.4 (site L1B) which equates to emergence varying between 68% and 100% ($f_i > 10.57$). All the sites in the Lower and Middle reaches had f_i higher than 10.57, which is predicted to 100% emergence. The only sites with significantly lower f_i were sites G2 and G3, located downstream of tributaries in the Gorge reach. Table 5 shows that these sites were characterized by lower geometric mean grain size. Sites G2 and G3 had lower f_i than all other sites in all 3 surveys.

3.2 Whitlock-Vibert box samples

Sand was the dominant sediment type in all W-V samples. Percentages of the total sample weight classified as sand varied between 40% and 52% (Table 7). Fine gravel and fine sand showed significant ($P < 0.05$) differences between habitat types. Fine sand was more abundant in flats and pools (where water velocity was less) than in riffles and runs. The percentage of coarser material found in the W-V boxes (fine gravel) was significantly higher in riffles (37.65%) and runs (28.67%) than in pools and flats (18.11% and 18.15% respectively; $P < 0.05$).

The analysis of variance and subsequent D.M.R. tests by reach showed that the Middle reach had significantly ($P < 0.05$) less fine sand (20.4%) and more fine gravel (34.3%), than the other study reaches (Table 7). The Upper reach was found to have significantly less fine gravel (14.0%) compared with the other reaches. No significant differences ($P > 0.05$) in the percentage composition of particle sizes was found between Gorge and Lower reach samples.

Temporal (seasonal) variability was also investigated (Table 7). There was no clear temporal pattern in the changes in granulometry except that the percentage of fine gravel was lower in each summer of a previous winter. The lowest percentage of fine gravel and the highest percentage of fine sand was found in the summer of 1994 (Table 7), the year of lowest summer discharge (Bourgeois et al. 1996).

3.3 Comparison of variability between the McNeil and W-V box sampling techniques

Table 8 compares the coefficients of variation (CV) of mean weight percentages by habitat type for 3 grain sizes for both sampling methods. CV for fine gravel proportions were consistently higher for W-V boxes while CV's for sand proportions were higher in the case of McNeil samples. Fine sand showed higher CV's in runs for W-V boxes (70% for W-V boxes and 57% for McNeil sampler; Table 8). It was observed that no technique consistently showed lower coefficient of variation which could have helped in the selection of a technique for quantifying fine sediments

3.4 Suspended sediments

Maximum suspended sediment concentrations were compared with maximum event discharge, maximum discharge at the time of maximum concentration, and cumulative rainfall during each rain event and at the time of maximum concentration (Table 9). The highest concentration of suspended sediments (174 $mg{\cdot}L^{-1}$) in Catamaran Brook was recorded on 12 May 1994 (Figure 2) when 56 mm of rain fell over a 37 hour period, with a maximum hourly discharge of 21.5 $m^3{\cdot}s^{-1}$ (or cms) in the Lower reach (river km 0). During the same event, a peak of 43 $mg{\cdot}L^{-1}$ of suspended sediments were measured at the Middle reach site (river km 8). Maximum concentrations were reached during the rising limb of the hydrograph (hourly discharge of 13.2 $m^3{\cdot}s^{-1}$ (or cms) in the Lower reach and 10.0 $m^3{\cdot}s^{-1}$ in the Middle reach), 15 hours after the onset of precipitation in the Middle reach and 4 hours later in the Lower reach.

More intense storms, such as the one on 19 August 91, resulted in weaker concentrations of suspended solids (37 $mg{\cdot}L^{-1}$), even though nearly 77 mm of rain fell in 14 hours (Table 9). In general, where rain lasted less than 20 hours, maximum suspended sediment concentrations were reached after the event; for longer events, maximum concentrations were measured between 6 (10-11 August 1990; maximum measured 21 hours after the start) and 16 hours (1-2 November 1994; maximum measured 22 hours after the start) before the end of events (Table 9).

The Gorge site appeared to be the site with highest concentration of suspended sediments. On 1 November 95, suspended sediment concentrations reached 32 $mg \cdot L^{-1}$ at the Gorge site compared with a measured maximum at the Middle and Lower sites of < 23 $mg \cdot L^{-1}$ (Figure 3). On 18 September 95, the maximum suspended sediment concentration measured at the Gorge site was 12 $mg \cdot L^{-1}$; in the other two reaches, measured concentrations remained below 9 $mg \cdot l^{-1}$. Figures 2 and 3 also show that there is a lag time between the time of maximum measured concentration and maximum hourly discharge. Concentrations of suspended sediments peaked on the rising limb of the hydrograph (2 to 7 hours before maximum discharge) for all sites during the events of 12-14 may 94 and 1-2 November 94.

The relation between cumulative precipitation and maximum suspended solid concentrations was investigated by calculating linear regressions between the two variables at the Lower reach site. When the sample taken in the spring of 1994 (a snow-melt event) was included, the relation was weak ($r^2 = 0.2$; $P < 0.3$). Figure 4 shows the regression between cumulative precipitation and maximum suspended sediment concentrations from Table 9, except the snow-melt event of 12 May 94 ($r^2 = 0.9$; $P < 0.0005$). Regressions were also calculated between maximum suspended sediment concentrations and maximum stream discharge, as well as all measured concentrations with hourly stream discharge. In both cases, the relationships were weak ($r^2 < 0.3$; $P < 0.3$).

4.0 DISCUSSION AND CONCLUSION

The percentage of fines in the stream substrate matrix is an important abiotic variable affecting the habitat quality of aquatic biota. In Catamaran Brook, the percentage of fines (<4 mm) typically ranged between 11 and 23%. Marty et al. (1986) found that similar percentages of fine sediments (defined as <10 mm in their study) resulted in Atlantic salmon alevin survival of 70% - 94%.

Spatial variations in sediment concentrations between study reaches in Catamaran Brook showed that the highest percentage of fine sediments for McNeil-type samples were found at sites G2 immediately downstream of inflow streams affected by a logging road and M1, located downstream of the only road crossing of Catamaran Brook. The percentage of fines was, on average, 5 to 10% higher at these two sites than the other sampling locations. This higher percentage of fines resulted in generally low Freddle indices (4.9 < fi < 18.6, Table 6) especially at site G2. In 1995, theoretical survival of alevins to emergence declined from 94.6% to 67.8% in June and 77.6% for the October sample (site G2B). These theoretical survival values can be compared with those of Marty et al. (1986) who found a mean survival rate of 74.5% for a percentage of material less than 10 mm varying between 19% and 66%. Their experiment showed that alevin survival depends primarily on the percentage of fine sediments and dissolved oxygen content in the interstitial spaces in the substrate. Stream crossings have long been recognized as sources of fine sediments. Data from the Coweeta Basin (North Carolina), showed that the majority of fine sediment collected at an experimental weir originated from 8 bridges located upstream of the site (Swift 1987).

The logging plan for the Catamaran Brook basin requires only one additional stream crossing, on the main tributary, but culvert replacement, road construction and increased traffic are expected near existing first-order tributary crossings in the Gorge reach. These are the areas where increased deposition of fine sediments may have a significant impact. Although salmon parr are rare in the tributaries, brook trout (*Salvelinus fontinalis*) and cyprinids such as slimy sculpin (*Cottus cognatus)* are common and may be negatively affected by any increase in fines entering the stream.

At the study reach level, our data gathered with the McNeil sampler showed a higher percentage of fines among the dominant substrate (Pfines) in the Gorge and Middle reaches than in the Lower reach. Sand was the grain size which best explained this significant differences in the percentages. Although the Gorge reach is the study reach with the higher gradient and higher velocities, which should reduce deposition, its close proximity to the important sources of sediment input (i.e. tributary crossings and main bridge crossing) may explain the high percentage of fines. High suspended sediment concentrations were also present in the Gorge reach.

Whitlock-Vibert box data also indicated that, on average, the Gorge and Lower reaches had a greater percentage of fine sand and less coarse particles (gravel) compared with the Middle reach which showed significantly less fine material than the three other reaches. The percentage of fine sand was similar in all study reaches, except for the Middle reach which showed significantly less fines.

The results from W-V boxes are difficult to compare with the McNeil sampler data. In the former case, the grain size distribution is limited to material finer than gravel, while in the latter, the entire substrate matrix is analyzed. An analysis of the coefficients of variation of mean weight percentages for three grain sizes showed similar results in Catamaran Brook with those found by Wesche et al. (1989) for Wyoming streams. In both cases, the CV of mean weight percentages by habitat type typically varied between 20 and 70%. Everest et al. (1987) mentioned similar variability for grain sizes in streams in Oregon and British Columbia. Our results showed that the McNeil sample data yielded CV's which were lower or equivalent to those calculated for W-V boxes for 2 of 3 grain sizes. Given these results, it was not possible to select a particular sampling method based on lower coefficient of variations. It should be noted that W-V boxes offer the advantage of providing a method of sampling with limited disturbance of the site.

Temporal variations in the substrate composition at site L3 (Lower reach) were analyzed to verify whether the grain size distribution was modified by the construction of logging roads in the late summer and autumn of 1995 in the upper basin. There were no significant differences in the percentage of fines from the whole substrate matrix (Fines), nor in the percentage of fines from the sub-matrix of dominant material (Pfines). The significant decrease in the percentage of cobble and increase in the percentage of gravel in 1996 for site

L3 were more likely caused by extensive site-specific ice scouring and bedload movement during the mid-winter thaw of 1995/96 than by the impact of road construction 5 km upstream. The input of fine sediments can be associated with important hydrological events such as the spring snowmelt or large rainfall (Everest et al. 1987). The latter were scarce between the time of road construction and the time of sampling. Further sampling will be required to quantify spatial variations between habitat-types. W-V data showed no clear pattern in the temporal variations of grain size distribution except for very fine sand which appeared to be more abundant in the summer samples than in winter samples.

There was a clear temporal pattern of suspended sediment concentrations during rainfall events. The strong relationship between maximum concentrations and cumulative precipitation applied only during non-snowmelt events. Maximum concentration of suspended sediments always preceded peak hourly discharge by two to seven hours. This is in accordance with measurements from west coast streams which showed that greater concentrations of suspended sediments occur during the rising limbs of hydrographs (increasing discharge) than during receding flows (Feller and Kimmins 1979; Everest et al. 1987). This lag effect was also noticed for a number of solutes in a river in Devon, Great Britain (Walling and Foster 1975). It is associated with the initial flushing, rather than dilution processes caused by the rising flow. The sampling technique based on regular sampling through a rain event may need to be revised. That is, it may be preferable to sample more intensively during the rising limb of the hydrograph in order to maximize the probability of measuring peak concentrations.

It is also important to note that the most significant event for suspended sediments was monitored during the spring season. Seasonal patterns in suspended sediments have also been noticed elsewhere and appear to be related to forest canopy and the annual discharge variability (Feller and Kimmins 1979). At Catamaran Brook, the spring snowmelt is one of the most significant seasonal hydrological events. This may explain the highest recorded concentration of suspended solids in May 1994, especially when one considers that the soil is saturated at that time of the year and may be more easily disturbed. Hartman and

Scrivener (1990) found that suspended sediment yield was correlated with the annual number of peak flows above a certain threshold at Carnation Creek , British Columbia.

In Catamaran Brook, the highest measured concentration of suspended sediments was 174 $mg{\cdot}L^{-1}$. Such a rapid increase in suspended sediments may also increase invertebrate drift in the brook (Table 1). This maximum measured value of suspended sediments is less than 60% of the threshold concentration for which coho salmon fingerlings, for instance, lose their ability to capture prey (Everest et al. 1987). Concentrations of suspended sediments at levels similar to the maximum measured value would have to remain constant for a long period (e.g. 24 hours) before sublethal effects such as an increase in coughing frequency of coho salmon is measured (Servizi and Martins 1992). However, Hynes (1973) mentioned that concentrations over 80 $mg{\cdot}L^{-1}$ may be a critical threshold for stream biota, including brook trout which will avoid the highly turbid areas. Behavioral effects of high suspended sediment concentrations include avoidance, as shown by Hale (1988) who confirmed a significant relationship between salmon outmigration, high discharge and high turbidity events during a 3-year study on chinook and sockeye salmon. If high levels of suspended sediments remained present during the period of timber harvest, there could be important behavioral effects on fish, such as the breakdown of social hierarchies and a reduction of the perceived risk of predation (Table 1).

Monitoring of suspended sediment concentrations and substrate variability is continuing in Catamaran Brook. Logging began in August 1996, and will continue for a period of 3 years. Less than 10% of the total drainage basin area will be cut. The hypothesis that temporal variations in the grain size distribution may be linked to road constructions on the drainage basin will be verified with a longer time-series. Spatial variations already showed that the Gorge reach may be the site of greatest interest.

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LIST OF ABBREVIATIONS:

CV:	Coefficient of variation
Fgrav:	Fine gravel
Fsand:	Fine sand
IFIM:	Instream Flow Incremental Methodology
Pfines:	Percentage of fines
D.M.R. test:	Duncan's Multiple Range test
TLB:	True left bank
TRB:	True right bank
W-V:	Whitlock-Vibert

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Table 1. Selected studies showing the variety of effects of suspended sediment concentrations and turbidity on aquatic biota. For some studies, suspended sediment concentrations were taken in mg·L^{-1} or g·L^{-1}, while for others, turbidity was measured in nephelometric turbidity units (NTU).

Author	Concentration of suspended sediments or turbidity	Biota	Effect
Hynes (1973)	80 mg·L^{-1}	Brook trout	Avoidance of turbid areas
Auld and Schubel (1978)	100 mg·L^{-1}	White perch Striped bass	Reduced hatching hatching success
	500 mg·L^{-1}	striped bass Yellow perch	Reduced larval survival
O'Hop and Wallace (1983)	50% increase from background	Stonefly (*Peltoperia maria*)	Increased drift
Berg and Northcote (1985)	60 NTU (maximum)	Coho salmon	Breakdown of hierarchies, territories not defended, gill flaring increased
Everest et al. (1987)	300 mg·L^{-1}	Coho salmon fingerlings	Lose their ability to capture prey
Lloyd et al. (1987)	50 NTU (maximum)	Freshwater phytoplankton	Decrease in primary production
Hale (1988) Servizi and Martens (1991)	4000 mg·L^{-1} (maximum)	Coho salmon	Increased coughing
Servizi and Martens (1992)	666 NTU (maximum)	Coho salmon	Elevated blood sugar level and increased coughing frequencies
Gregory (1993)	23 NTU	Chinook salmon	Reduced perceived risk of predation

Table 2. Site locations and sampling dates for McNeil samples. Site numbers refer to Figure 1.

Date	Location
26 October 1994	L1A, L1B, L1C, L2A, L2B, G1A, G1B, G2A, G2B, G3A, G3B M1A, M1B, M2A, M2B
2 June 1995	L3A, L3B,L3C
14 June 1995	L1A, L1B, L1C, L2A, L2B, G1A, G1B, G2A, G2B, G3A, G3B M1A, M1B, M2A, M2B
8 August 1995	L3A, L3B,L3C
18 October 1995	L3A, L3B,L3C
19 October 1995	L1A, L1B, L1C, L2A, L2B, G1A, G1B, G2A, G2B, G3A, G3B M1A, M1B, M2A, M2B
3 June 1996	L3A, L3B, L3C

Table 3. Time and location of suspended sediment sampling.

Start Date (YY-MM-DD)	End Date (YY-MM-DD)	Study reach
90-09-23	90-09-24	Lower
91-08-10	91-08-12	Lower
91-08-19	91-08-21	Lower
93-06-09	93-06-11	Lower
93-09-10	93-09-11	Lower
94-05-12	94-05-16	Lower Middle
94-07-27	94-07-29	Lower Middle
94-09-05	94-09-07	Lower Middle
94-09-28	94-09-30	Lower Middle
94-11-01	94-11-03	Lower Middle Gorge
95-05-18	95-05-19	Lower Middle Gorge
95-07-26	95-07-28	Lower Middle Gorge
95-09-18	95-09-18	Lower Middle Gorge
95-11-07	95-11-10	Lower Middle Gorge

Table 4. Mean percentages of total dry weight for McNeil sampler data from site L3. Chi-squared values (χ^2) and significance levels (P) for nonparametric analysis of variance (ANOVA) by survey (June 1995, August 1995, October 1995 and June 1996) and by bank (Left or TLB, center or C, and right or TRB bank) are given for all four surveys.

		N	Cobble	Coarse gravel	Gravel	Fine gravel	Sand	Fine sand	Fines[1]	Pfines[2]
By Surv	06/95	15	26.53	14.04	42.00	7.52	10.19	2.19	19.90	33.50
	08/95	15	23.84	12.61	39.43	7.94	11.18	2.41	21.53	33.93
	10/95	15	26.33	13.93	37.62	7.28	12.09	2.52	21.88	36.77
	06/96	15	13.38	15.14	43.07	7.89	11.36	2.09	21.35	33.00
NPAR	χ^2		24.09	2.86	6.67	3.19	3.42	3.23	3.50	4.67
	P		0.0001	0.41	0.083	0.37	0.33	0.36	0.32	0.22
By Bank	C	13	22.81	14.39	37.85	7.38	13.34	2.14	22.87	37.59
	TLB	25	20.18	13.31	42.29	8.35	11.61	2.53	22.50	34.80
	TRB	22	25.01	14.36	40.12	7.03	9.48	2.13	18.65	31.79
NPAR	χ^2		4.26	1.19	3.12	14.06	14.19	2.83	12.15	12.52
	P		0.12	0.55	0.21	0.001	0.001	0.24	0.002	0.002

[1] Fines = Fine gravel + sand + Fine sand
[2] Pfines = Fines / (fines + Gravel)

Table 5. Mean percentages of total weight for McNeil sampler data from sites L1, L2,G1, G2, G3, M1, M2. Chi-squared values (χ^2) and significance levels (P) for nonparametric analysis of variance (ANOVA) by site (for all 3 surveys) by reach (Lower, Middle and Gorge) and by year (October surveys only) are given.

		N	Cobble	Coarse gravel	Gravel	Fine gravel	Sand	Fine sand	Fines[1]	Pfines[2]
By Site	L1	9	21.78	33.79	38.73	4.85	5.51	1.11	11.41	23
	L2	6	26.33	35.78	33.31	5.51	5.73	1.04	12.30	27
	G1	6	27.67	25.79	32.99	5.19	6.79	0.96	12.94	28
	G2	6	5.33*	27.16	46.5*	38.2*	12.3*	2.3*	22.90	32
	G3	6	31.17	38.62	27.80	4.49	4.49	0.88	11.21	26
	M1	6	27.17	22.52	36.97	6.19	10.5	1.86	18.57	34
	M2	6	22.17	38.64	33.07	4.85	7.54	0.84	13.23	28
NPAR		χ^2	15.03	14.82	20.60	11.98	22.32	24.14	21.93	23.03
		P	0.02	0.02	0.001	0.06	0.01	0.001	0.04	0.03
By Reach	L	15	17.36	34.59	36.56	5.11	5.59*	1.05	11.76	24
	M	18	18.50	30.52	35.77	5.98	7.98	1.41	15.36	29
	G	12	18.71	30.58	34.97	5.51	9.04	1.35	15.90	31
NPAR		χ^2	0.50	1.29	0.46	0.84	8.54	1.87	5.92	11.27
		P	0.78	0.53	0.80	0.66	0.01	0.39	0.05	0.02
By Year	94		15	15.43	32.40	38.10	5.21	7.60	1.20	0.2827
	95		15	24.12	29.5	33.3	5.45	6.73	1.15	0.2728
		χ^2	0.80	0.39	2.68	0.00	0.65	1.21	0.36	0.07
		P	0.37	0.58	0.10	0.98	0.42	0.27	0.55	0.79

* Shown to explain most of the variance by D.M.R. test

[1] Fines = Fine gravel + sand + Fine sand

[2] Pfines = Fines / (fines + Gravel)

TABLE 6. Characteristics of substrate samples (McNeil type)at Catamaran Brook: Percentage exceeding 0.85 and 9.5 mm, d75 and d25 are the sieve diameter for 75% and 25% of the total sample weight respectively. The sorting coefficient (So), geometric mean of the diameter of substrate samples (dg), Freddle index (f_i) and % emergence of alevins are calculated using equations 1 and 2. October 1994 and June 1995 data reproduced from Bourgeois et al. (1996).

Site	0.85 (%)	9.5 (%)	d75 (mm)	d25 (mm)	So	dg (mm)	f_i (mm)	Emergence (%)
October 1994								
L1A	3.1	21.5	55.3	12.3	1.12	35.6	16.8	100
L1B	2.5	18.0	48.6	13.3	1.91	32.1	16.8	100
L1C	3.3	26.1	44.7	8.9	2.24	28.1	12.5	100
L2A	2.8	22.4	64.1	11.6	2.35	41.5	17.7	100
L2B	2.3	19.4	65.3	13.9	2.16	41.2	19.0	100
G1A	3.6	23.6	47.3	10.5	2.12	30.0	14.1	100
G1B	3.5	29.0	63.4	7.6	2.88	35.5	12.3	100
G2A	4.3	20.8	47.3	12.2	1.97	30.9	15.7	100
G2B	3.2	33.9	37.0	5.2	2.67	24.8	9.3	94.6
G3A	3.2	26.1	55.0	8.9	2.49	37.0	14.9	100
G3B	1.6	12.6	60.5	21.9	1.66	43.1	25.9	100
M1A	5.8	31.8	38.3	5.9	2.55	26.4	10.4	99.3
M1B	5.1	29.5	55.8	6.8	2.86	35.1	12.3	100
M2A	2.0	14.8	58.9	19.2	1.75	40.3	23.0	100
M2B	4.0	23.4	51.0	11.3	2.12	33.0	15.5	100
June 1995								
L1A	2.8	25.7	48.9	9.1	2.32	30.5	13.2	100
L1B	1.6	16.4	51.4	16.6	1.76	34.7	19.7	100
L1C	2.8	21.4	61.1	10.6	2.40	35.5	14.8	100
L2A	3.0	25.7	56.6	9.1	2.49	34.6	13.9	100
L2B	3.5	26.4	53.4	8.8	2.46	33.6	13.6	100
G1A	3.1	19.6	54.1	14.2	1.95	35.7	18.3	100
G1B	4.0	27.4	49.6	8.1	2.47	31.1	12.6	100
G2A	6.9	32.9	37.5	5.5	2.61	24.8	9.5	95.5
G2B	8.1	49.4	27.1	2.4	3.36	16.6	4.9	67.8
G3A	4.1	26.7	59.6	8.5	2.65	36.7	13.9	100
G3B	2.1	14.9	65.9	22.1	1.73	44.6	25.8	100
M1A	6.3	27.1	50.9	7.8	2.55	31.1	12.2	100
M1B	5.2	28.9	54.7	7.2	2.76	32.5	11.8	100
M2A	2.8	18.9	59.6	14.9	2.0	39.2	19.6	100
M2B	1.8	13.5	62.4	24.7	1.59	44.9	28.2	100
October 1995								
L1A	2.2	22.5	68.5	11.5	5.96	40.7	16.7	100
L1B	1.0	11.4	68.5	28.4	2.41	47.1	30.4	100
L1C	4.3	25.2	52.5	9.4	5.58	32.5	13.7	100
L2A	2.3	21.8	51.3	11.7	4.39	32.8	15.7	100
L2B	1.4	14.3	54.0	23.2	2.33	42.2	18.1	100
G1A	1.4	18.6	100.	16.2	6.17	58.7	23.6	100
G1B	1.3	14.5	100.	21.6	4.63	62.33	28.9	100
G2A	6.1	30.3	36.3	6.7	5.42	24.7	10.6	100
G2B	7.2	42.4	29.1	3.4	8.56	18.3	6.2	77.7
G3A	1.7	15.6	57.4	19.9	2.88	40.2	23.7	100
G3B	1.2	10.9	72.7	28.8	2.52	50.0	9.32	94.7
M1A	4.0	22.7	86.4	11.6	7.45	50.8	18.61	100
M1B	5.1	28.6	59.7	7.3	8.18	34.3	12.0	100
M2A	4.2	27.3	45.5	7.8	5.83	29.6	12.27	100
M2B	2.8	26.3	47.8	8.7	5.49	29.78	12.71	100

Table 7. Mean percentages of total sediment weight for Whitlock-Vibert Boxes data. Chi-squared values (χ^2) and significance levels (P) for nonparametric analysis of variance by habitat type (flat, pool, riffle, and run), by reach (Lower, Middle, and Gorge) and by date of placement (summer 1992, winter 1992, summer 1993, winter 1993, summer 1994, winter 1994 and summer 1995) are given.

		N	Fine Gravel	Sand	Fine Sand
by Habitat Type	Flat	24	18.15	49.06	38.49
	Pool	50	18.11	43.78	42.19
	Riffle	24	37.65	48.74	20.71
	Run	38	28.67	48.33	25.73
NPAR		χ^2	28.26	7.21	31.71
		P	0.001	0.07	0.0001
By Reach	Lower	29	25.79	46.53	34.64
	Middle	55	34.29	47.39	20.44*
	Gorge	25	23.42	44.66	36.89
	Upper	27	14.04*	49.41	37.86
NPAR		χ^2	22.91	2.14	14.89
		P	0.0001	0.54	0.002
By Season	summer92	19	18.98	46.91	34.10
	Winter 92/93	13	32.69	40.18	29.48
	summer93	22	30.68	45.15	24.18
	winter 93/94	7	25.30	52.91	24.10
	Summer94	20	17.10*	48.75	44.85*
	winter 94/95	18	35.25*	44.68	29.39*
	summer95	35	20.37	49.77	36.40
NPAR		χ^2	19.29	9.92	13.43
		P	0.004	0.12	0.037

*Shown to explain most of the variance by D.M.R. tests

Table 8. Coefficient of variation of mean weight percentages for 3 grain sizes by habitat type for 2 substrate sampling techniques (W-V Boxes and McNeil-type sampler).

		Whitlock-Vibert box		McNeil sampler	
		N	CV(%)	N	CV(%)
Flat		24		60	
	Fine Gravel		62.64		22.30
	Sand		22.85		27.10
	Fine Sand		36.07		39.90
Run		38		30	
	Fine Gravel		48.98		39.35
	Sand		21.06		57.11
	Fine Sand		70.29		56.80

Table 9. **Maximum suspended sediment concentrations during rain events at Catamaran Brook. The first discharge, cummulative rain and duration reported are from the begining of the rain event to the time of maximum concentration. The maximum discharge, cumulative rain and duration are for the total period of each event.**

		At maximum concentration of suspended sediments				Total event		
Event Start (YYMMDD) End (YYMMDD)	Reach	Conc. ($mg \cdot L^{-1}$)	Disch. (cms)	Cum. Rain (mm)	Duration. (Hours)	Disch. (cms)	Cum. Rain (mm)	Duration (Hours)
90-09-23 90-09-24	Lower	18	1.1	36.83	1+	2.79	36.83	12
90-08-10 90-08-11	Lower	25	1.2	66.29	21	3.34	73.12	27
91-08-19 91-08-20	Lower	37	3.9	76.95	2+	11.7	76.95	14
93-06-10 93-06-11	Lower	6	2.4	19.6	11	4.1	20.31	12
93-09-10 93-09-11	Lower	3	0.8	17.3	6+	0.98	17.3	11
94-05-12 94-05-14	Lower	174	13.2	49.8	25	21.5	56.13	37
	Middle	43	10.0	46.0	21	15.0		
94-11-1 94-11-2	Lower	22	1.0	29.0	22	1.89	41.65	38
	Middle	14	0.68	27.5	19	0.99		
	Gorge	32	0.39	25.9	16	1.29		
95-5-18 95-5-19	Low	4	4.7	14.22	23	4.74	14.22	19
	Middle	2	1.95	13.32	20	2.49		
	Gorge	2	2.99	12.7	16	3.31		
95-9-18	Low	8	0.11	26.17	15	0.30	26.42	15
	Middle	2	0.10	26.42	16	0.16		
	Gorge	12	0.10	26.17	14	0.21		

Conc. = concentration of suspended sediments ($mg \cdot L^{-1}$), Disch. = discharge in cms ($m^3 \cdot s^{-1}$) and Cum. Rain = cumulative rain in mm.
+ refers to the number of hours after the end of the rain event

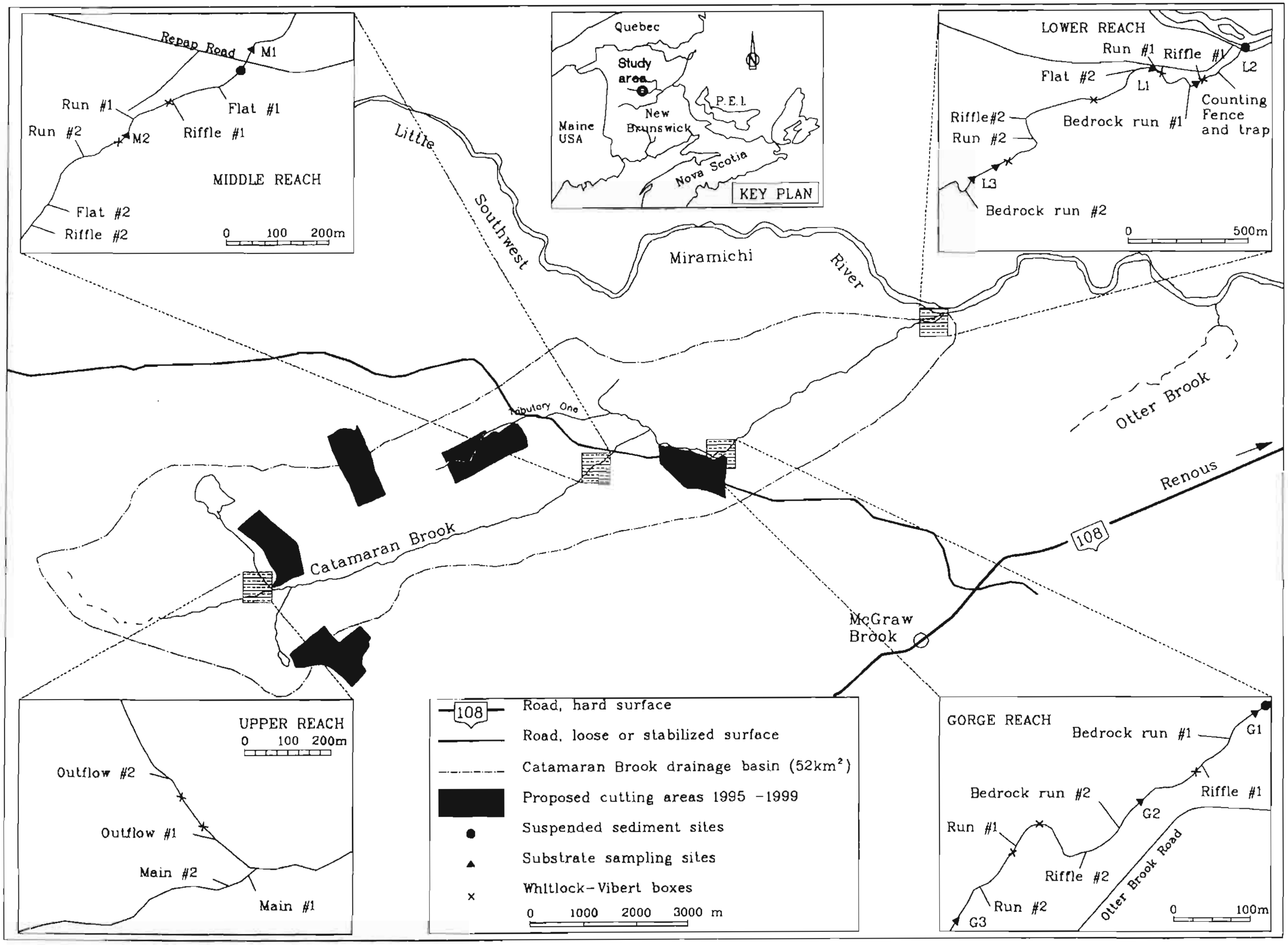
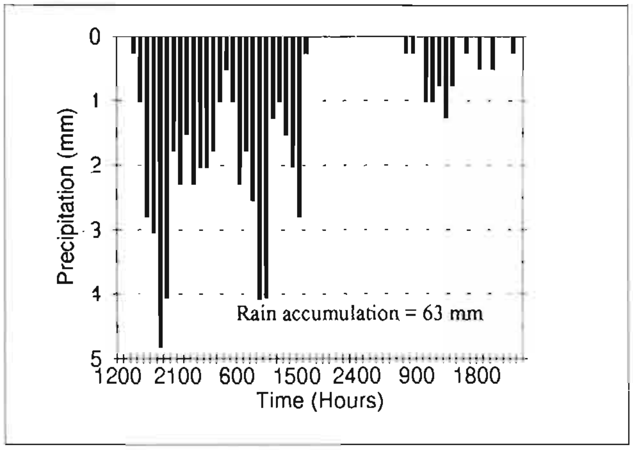
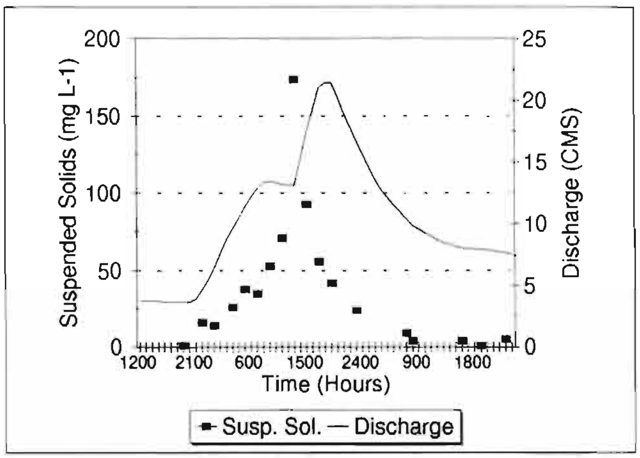


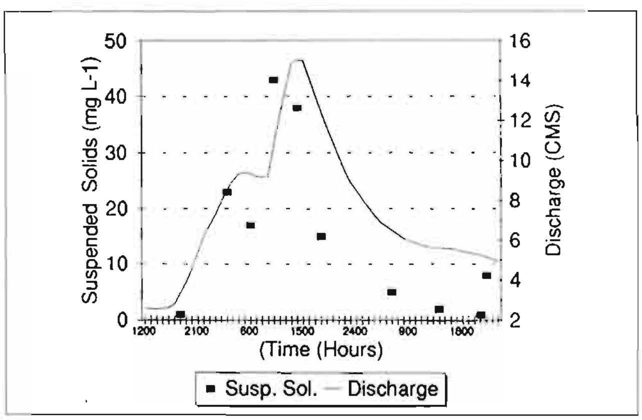
Figure 1. Map of Catamaran Brook drainage area showing the location of Whitlock-Vibert boxes, suspended sediment and substrate sampling sites.



Precipitation

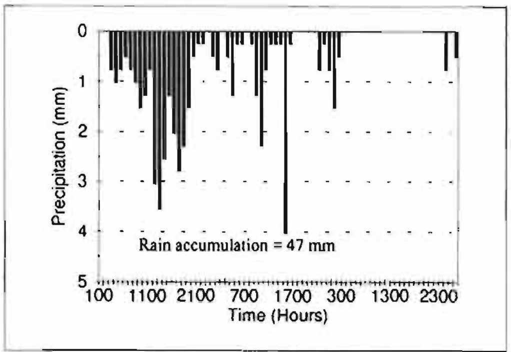


Lower reach

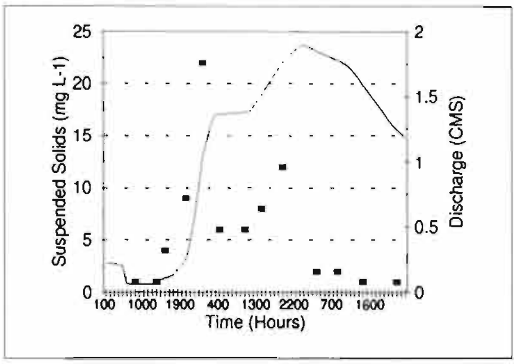


Middle reach

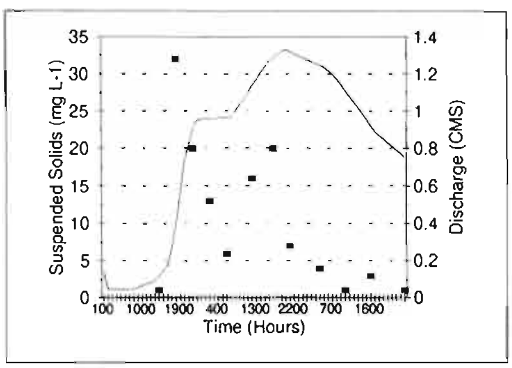
Figure 2. Time series of suspended sediment concentrations with discharge and precipitation (12 May 94).



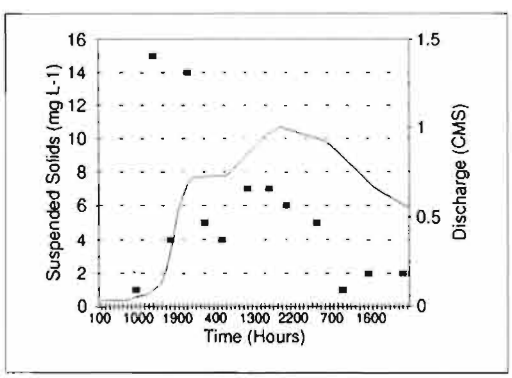
Precipitation



Lower Reach



Gorge Reach



middle Reach

Figure 3. Time series of suspended sediment concentrations with discharge and precipitation (1-2 Nov. 94)

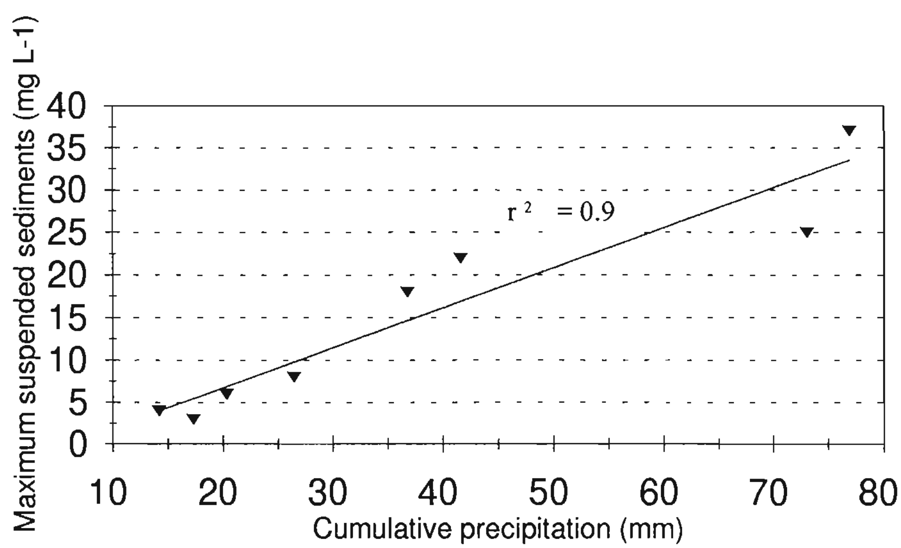


Figure 4. Maximum suspended sediments-cumulative rainfall relationship at Catamaran Brook (1990-1994). Note that the May 1994 snowmelt event was excluded (see text).